THE INTERACTIVE NATURE OF SPELLING AND SOUND

Evidence from children with reading difficulties

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December 2000

Contents

Abstract

This study investigated the interactive nature of spelling and sound in normal-reading children and dyslexic children. Sound-to-spelling inconsistent and consistent words, such as *hond,* in which the /t/ sound can be spelled either as a *d* or as a *t*, were presented to dyslexic children with an average age of 10 years, reading-matched normal-reading children with an average age of 8 years, and age-matched normal-reading children. Hypotheses were derived from two models, the dual-route model and the phonological coherence model concerning the effect of word consistency on the word perception of the children. The participants performed three tasks, a lexical-decision task, a rhyme task, and a letter search task. The results showed similarities and differences between the groups. The results were best predicted by the phonological coherence model and it was concluded that a model of word perception should be an interactive model.

Acknowledgements

After working for a year on my thesis, I can finally thank the people that have been supporting me over this period of time. First I would like to thank my two supervisors, Wietske Vonk and Anna Bosman. You both taught me how to set up, conduct and report everything. I enjoyed watching the two of you discussing the results of the experiments. It made me realize that when two people do not always share the same opinion, fruitful results can come out of the discussion. Writing my thesis in English was quite an experience, and I am glad that you were willing to keep correcting me and gave me advice. I am quite sure though that my English also must have made you laugh. Thanks for the good support, the helpful comments and for thinking with me.

I also would like to thank Pim Mak, who helped me with the statistical analyses. He always answered my questions and patiently explained to me (many times) the nature of three-way interactions. Also thank to Joyce Vliegen, who helped and supported me during the beginning of my research when we both had to learn the computer program NESU. I had a great time with her trying to get the experiment to run. Vivika, my roommate of the last year with whom I ate many chocolate bars and drank liters of tea, would I like to thank for her support and I wish her the best of luck with her final stage of her study.

Of course, I will not forget my friends Sharmila, Antoinette, Claudia, Ellen, and Patrick. I am glad that I could talk to you all about everyday things, complain about how things were going and that I have such a great time when I am with you. Sharmila, I will see you under the Harbor Bridge of Sydney!

Tenslotte wil ik natuurlijk mijn ouders bedanken. Voor het geduld dat jullie met me hebben gehad. Voor het aanhoren van alle verhalen (goed of slecht) en voor het niet constant vragen van 'hoe gaat het?'. Mama, vooral bedankt voor je relativerings-vermogen, je goede zorg en natuurlijk voor je heerlijke maaltijden wanneer ik weer thuis kwam met vitaminegebrek. Papa, ook bedankt voor alle raad en daad.

Nijmegen, 2000

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Introduction

Models of word perception can roughly be divided in dual-route models and connectionist models. In this chapter we will discuss the main examples of both types of models, namely Coltheart's dual-route model and Van Orden's phonological coherence model. Published experimental results will be used to show the utility of the models in their explanation of robust findings and the explanatory value of dyslexia of both models will also be discussed. We will derive hypotheses from both models concerning the effect of word consistency on word perception in reading-disabled children and normal-reading children. In the next chapters we will describe and discuss the research questions of the study.

Models

Dual-route model

Coltheart's (1978) original dual-route model has two routes that can lead to word activation. The first is the indirect, phonological route (the sub-lexical route) and the second is the direct, visual route (the lexical route).

The indirect route works through so-called grapheme-phoneme rules. From left to right, the letters of a word are transformed into phonemes. After this transformation the separate phonemes are blend together, that leads to the complete sound of the word. This sound-output is the input for the mental lexicon. In the mental lexicon a word has a meaning representation, a spelling representation, and a phonological representation. Phonological activation will lead to the meaning activation of the word. In this route phonology always comes into play.

In the direct route the spelling representation is automatically activated in the mental lexicon, without transforming the word into a phonological code. The spelling representation will activate the meaning of the word directly. The direct route needs only one step to word activation. The indirect and the direct route operate both at the same time.

Coltheart used the term horserace (Paap & Noel, 1991) to define the operation of his dual-route model. The competition of the two routes is compared with two horses trying to win the race to the mental lexicon. One horse will go by the direct route to the mental lexicon,

the other one by the indirect route. The direct route is only available for words with a spelling representation. The speed with which the routes operate depends on word frequency.

What does this mean for particular word types? The fastest way to word access for high-frequency words is the direct route. In the case of high-frequency words, the output of the phonological route will always come later than the output of the direct route, which already has produced an output. As a result no influence of phonology is expected. For low-frequency words the outcome of the direct lexical route is quite slow. Sometimes the indirect route has already produced much faster an output. In that case phonological effects are expected.

An example of a phonological effect is the regularity effect. Regularly spelled words are words that can be pronounced according to the grapheme-phoneme rules. For a irregularly spelled word like *pint* the direct route will produce the correct output, but the indirect route will produce a pronunciation that rhymes on *mint*. The regularly spelled words are read faster than the irregularly spelled words. This is called the regularity effect.

However, Glushko (1979) discovered that the regularity effect is actually a consistency effect. Consistent words are words that consist of letter strings that are always pronounced the same, such as *proud*, *loud* and *shroud*. These words are consistent, regular words. There are however also inconsistent regular words, such as *gave*, *pave* and *save*. These words are regular, but inconsistent because they have a neighbour word *have* that is pronounced differently. Glushko found that inconsistent regular words, such as *gave*, have slower reading times than consistent regular words, such as *proud*. Even though the words are regular, the fact that *gave* has an irregularly spelled neighbour word affects reading time for this word.

Another example of a phonological effect is the pseudohomophone effect. Pseudowords (pronounceable letter strings with a legal orthography, such as *mard*) do not have a spelling, meaning, or sound representation in the mental lexicon. They must be read by means of the indirect route. The word will be transformed into a phonological code and this code will be used directly for speech output. The processing of pseudohomophones is a good example of how pseudowords get transformed into a phonological code. A pseudohomophone, such as *brane,* is a pseudoword which, when pronounced, has the same sound as an existing word. The indirect route will produce a phonological code for *brane* that is exactly the same like the phonological code for the existing word *brain*. This code can activate the orthographic and meaning representation in the mental lexicon of the word *brain*

and as a consequence the reader may think that he or she actually saw the word *brain*. This phonological effect is called the pseudohomophone effect.

Coltheart's dual-route model is an example of a bottom-up word perception model in which activation flows from one stage to the next. From stages at a low level, such as detecting letters in visual input, to stages at a higher level such as retrieving the meaning of the word. During each step operations are performed on the input and the resulting output of the operations is again the input for the next processing step. Coltheart's model claims that word perception is not always mediated by phonology. Phonology only mediates word perception when a spelling pattern has more than one pronunciation. In that case two phonological output representations will compete with each other and it costs time to resolve this competition. This model does not predict an effect on word perception when a pronunciation pattern has more than one spelling, such as */dear/* which could be spelled as *deer* or *dear*. Also sound patterns like */eep/* as in *deep* or *heap* should, according to this model not produce an effect on visual word perception.

Phonological coherence model

A second type of model is a connectionist model, such as the phonological coherence model defined by Stone and Van Orden (1994), Van Orden and Goldinger (1994), and Stone, Vanhoy, and Van Orden (1997). This model is a connectionist network with three node families: letter nodes, phoneme nodes, and semantic nodes.

The model is recurrent: Each node is connected to the other nodes in such a way that not only activation streams forward but also streams back to the nodes (recurrent). Each node of each family is recurrently connected to each node of the two other families. The connections within one family are recurrent as well. Thus, nodes do not only affect the activation of other nodes, but they are in return, influenced by feedback activation from all other nodes.

When a word is presented to the network the letter nodes become activated. The letter nodes send activation forwards to the phoneme nodes and the semantic nodes and these nodes in return send activation forwards to each other but also stream activation back to the letter nodes. When forward activation matches feedback activation stable feedback loops are created and a coherent whole arises. New input can change this coherent whole.

The more often a letter is pronounced by the same phoneme, the stronger the relation between the letter node and the phoneme node will become. When the model receives a particular letter as input, the correct phoneme node gets immediately activated. It is also

possible that a letter cluster always has the same pronunciation. In that case the model also very quickly creates a stable activation pattern across the particular letter nodes and phoneme nodes. In the model activation flows from one node to another and also back to the same nodes: there is feedforward and feedback activation. Note that in bottom-up models, such as Coltheart's dual-route model, there is only feedforward activation.

In the phonological coherence model phonology always plays a role in the identification of all printed words (not only in low-frequency words like the dual-route model states). The basis for this statement is the fact that the relation between phonemes and letters is the strongest relation in an alphabetic writing system, a writing system in which symbols (letters) represent vocals and consonants. Letters stand in most cases for the same phonemes, for example the letter S will almost always be pronounced as /s/. The relation between letters and semantics and between phonemes and semantics is not as strong. People do not know anything about the meaning of a word when they see or hear a word that begins with an S, but they do know something about the pronunciation of it. Because of the strong relation between letters and phonemes, feedback loops among letters and phonemes cohere before the ones among letters and semantics and the ones among phonemes and semantics. Therefore, phonology always plays a role in word identification.

Because the relations between letters and phonemes are recurrent, reading time is not only affected when a word is inconsistent in spelling-to-sound, but also when a word is inconsistent in sound-to-spelling. In order to explain this something has to be said concerning spelling/pronunciation correspondences. One-syllable words can be broken down in onsets and bodies. The onset is the initial sequence of consonants. The vowel and everything that follows, is called the rhyme or body. For example the word *heap* can be broken down in the onset *H* and the spelling body *EAP*.

When a spelling body has only one pronunciation and when that pronunciation has only one spelling (such as the word *probe*), then it is a consistent word. The body OBE is always pronounced the same and the pronunciation /ob/ is always spelled the same way. However when a word has a spelling body that can be pronounced in more than one way this word is inconsistent in spelling-to-sound. When the word has a pronunciation body that can be spelled in more than one way, it is inconsistent in sound-to-spelling. For instance, the spelling body EAP is consistent in spelling-to sound, because EAP has only one pronunciation (/eep/). The spelling body EAP, however, is inconsistent from sound-to-spelling, because the pronunciation body /eep/ can be spelled either as EAP in *heap or* as EEP in *deep*. Consider Figure 1 to see how the model works when it is presented with a sound-to-

spelling inconsistent body, like *EAP*. Figure 1 is a simple version of a network. The spelling body EAP will be presented as shorthand for the consisting nodes.

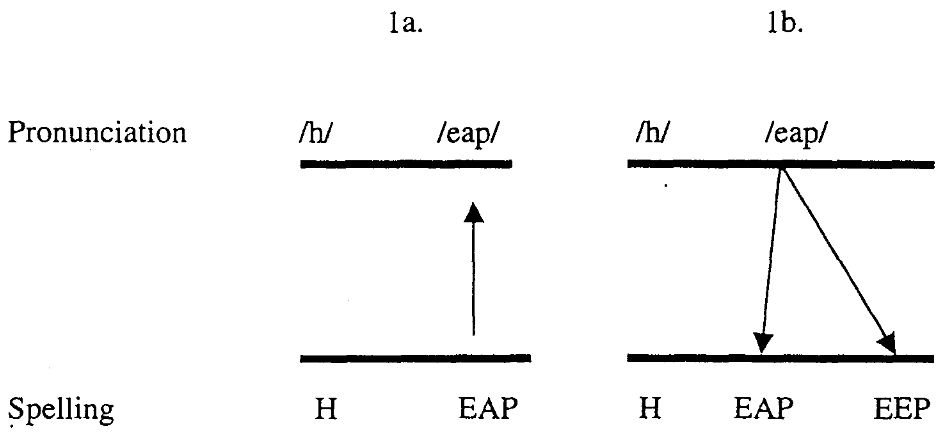

Figure 1. Presentation of the spelling body of the word *Heap* to the phonological coherence model.

The letter nodes will send activation to the correct phoneme body /eap/ (1a) which in turn will activate the correct letter node EAP but also the wrong letter node EEP (1b). To create a stable feedback loop between the correct nodes, the wrong node EEP needs to be inhibited. This node will compete with the node EAP and this competition costs time.

Empirical evidence

The interactive nature of visual word perception has been shown in recent studies with experienced readers (Gibbs & Van Orden, 1998; Stone, Vanhoy, & Van Orden, 1997; Ziegler & Jacobs, 1995; Ziegler, Van Orden, & Jacobs, 1997). Stone et al. (1997) demonstrated this with a simple lexical-decision experiment using four types of words. One set of words was consistent in both their spelling-to-phonology relationships and their phonology-to-spelling relationships. An example is the word *lust*. Its spelling body UST is only pronounced one way in the various words that share this spelling body, and its pronunciation body /ust/ is only spelled one way in the words that share this pronunciation rhyme *(e.g., dust, just, must, rust)*. A second set of words was inconsistent in both directions. For example, the spelling body EAK in *bleak* has multiple pronunciations, as in *break* and *leak*, and the pronunciation body /eak/ has multiple spellings as in *freak* and *creek*. The third and fourth sets of words were consistent in one direction but inconsistent in the other. The example *heap* has a spelling body EAP that is always pronounced the same, but the pronunciation body /eap/ can be spelled

multiple ways, as in *creep* and *leap*. The contrasting example *hull* has a pronunciation body /ull/ that can only be spelled one way, but a spelling body ULL that can be pronounced multiple ways, as in *dull* and *pull*.

Words that are consistent in both directions got faster 'yes'-response times than words that are inconsistent in either direction. Thus, not only is word perception affected by the fact that a certain spelling has more than one pronunciation, word perception is also affected when the pronunciation has more than one spelling. The dual-route model of Coltheart only predicts the effect on word perception when a word is inconsistent from spelling-to-sound.

To be able to explain the consistency effect of spelling-to-sound inconsistent words found in various experiments (Glushko, 1979; Jared, 1997; Seidenberg et al., 1984), Coltheart changed his dual-route model into the dual-route cascade model (DRC, 1994). This DRC model still has two ways to word-access, but a word presented to the model not only activates the correct lexical entry, but also lexical entries of words that are visually similar. The next stage consists of activation of the whole-word pronunciations and since more lexical entries are activated, also more pronunciations become activated. Competition has to take place and this costs time. Thus, reading time is influenced by words that are similarly spelled but have different pronunciations. However, the dual-route cascade model still can not explain why it is also important that a pronunciation has more than one spelling possibility, because the dual-route cascade model is still a bottom-up model.

A finding by Jared (1997) also gave important evidence against a dual-route model, or any model that does not incorporate a feedback principle. She found that spelling-to-sound consistency not only affects the naming of low-frequency words but also of high-frequency words. This finding provides serious problems for Coltheart's model, since he claims that high-frequency words will be accessed directly without transforming the word into a phonological code. So it should not matter for high-frequency words whether the spelling-to-sound relationship is consistent or inconsistent.

Seidenberg and Tanenhaus (1979) also showed the interactive nature of spelling and sound, even in an auditory task. They examined the orthographic effect on auditory word perception in a rhyme-monitoring task. In their experiment, participants were either auditorily or visually presented with a single word in isolation, the cue-word. After the cue-word they heard a list of five words. The task was to detect the word in the list of five words that rhymed with the cue-word. The rhyme word was either orthographically similar to the cue, *pie-tie*, or orthographically dissimilar to the cue, *rye-tie*. Seidenberg and Tanenhaus found that orthographically similar pairs were detected faster than orthographically dissimilar pairs. The

difference in reaction times between the orthographically similar rhyming pairs and the orthographically dissimilar rhyming pairs is called the orthographic effect. It made no difference whether participants heard the cue word or saw the cue word. One might think that when participants were presented with the cue word visually they might be tempted to use this visual information to compare with the target words. In that case it is not so surprising that visually similar rhyme words are discovered faster than visually dissimilar words. However, the orthographic effect was the same for auditory cue words as for visual cue-words. So even when the participants were not 'forced' to compare visual information, they still made use of it.

Zecker (1991) performed a rhyme experiment similar to that of Seidenberg and Tanenhaus (1979) with reading-disabled and normal-achieving children. The children had to judge whether orthographically similar and dissimilar word pairs rhymed or not. Zecker found that all normal-achieving children showed an orthographic facilitation effect and that the older participants showed more facilitation than the younger participants. However, only the oldest children in the reading-disabled group showed an orthographic facilitation effect. They responded faster to orthographically similar pairs than to orthographically dissimilar pairs. The youngest children in the reading-disabled group showed no facilitation effect. Zecker concluded that these young reading-disabled children had no access to orthographic information in the mental lexicon. Reading-disabled children appear to develop an orthographic code at a much slower rate, but eventually they will be able to use such information.

The orthographic facilitation effect can both be explained by the dual-route model and the phonological coherence model. The models explain the effect in terms of priming. Details however differ.

The finding that inconsistency of spelling-to-sound relationship and sound-to-spelling relationship has an effect on visual and auditory word perception underlines the suggestion of Van Orden that spelling and reading are fundamentally related. Spelling and reading are interactive processes in the sense that the relationship between letters and phonemes and between phonemes and letters affects both reading and spelling. The same model can explain both processes.

For now the phonological coherence model proves to be the model that can best account for the results reported in various experiments. Zecker's statement that dyslexic readers are slower in developing an orthographic code, but that they eventually must be able to use orthographic information is interesting. Would dyslexic readers also show a similar

consistency effect just like normal readers and how does the phonological coherence model explain dyslexia?

Dyslexia

People with developmental dyslexia lag behind in technical reading ability compared to age-matched readers. The most widely accepted explanation of the problem of people with dyslexia is the inefficiency to use and process phonological information (Vellutino, 1979; Stanovich, 1988). For instance, dyslexic readers find it difficult to match the correct graphemes with the phonemes and it is hard for them to recognize phonological structures in words. This affects not only the speed of reading (because the grapheme-phoneme matching is slow) but also the building of orthographic structures. These structures can only be formed when a reader is able to apply grapheme-phoneme conversion rules and when a reader is able to discover the underlying structure of words.

A major indication of dyslexia (and of disfunctional phonological processing) is the inability to read pseudowords. Pseudoword reading in dyslexic readers is severely impaired, that is, dyslexic readers are much slower in reading pseudowords than normal readers and they make more errors.

Dual-route model

Over the years, the dual-route model of Coltheart has been the inspiration for defining dyslexia. The assumption in this model is that the direct route is not available to dyslexic readers, since it is only accessible when the reader is experienced.

The indirect route is also problematic, otherwise dyslexic readers would not have problems with pseudoword reading. This is however the only route available and dyslexic readers have to try to transform each grapheme into a phoneme. This process is difficult and slow, and this is the reason why the direct route does not function in dyslexic readers. Normal readers who have phonological decoding skills will eventually be able to directly recognize these words. Words that are successfully decoded and recognized will be stored in the mental lexicon and in the future these words can be accessed directly. So according to the dual-route theory the problem with dyslexic readers is an immediate consequence of their poor decoding skills.

Phonological coherence model

Van Orden and co-workers (Van Orden, Bosman, Goldinger, & Farrar, 1997) presented an alternative explanation for dyslexia. Dyslexic readers have, as said before, various problems with reading pseudowords (Rack, Snowling, & Olson, 1992), due to the problem with processing phonological information. Even when dyslexic readers are able to read words, pseudowords are still extremely difficult for them to read. The inefficiency to read pseudowords is explained by the model assuming that the relations between letter nodes and phoneme nodes are not fully recurrently connected but only partially. Figure 2 gives an example of a recurrent network and a partial recurrent network.

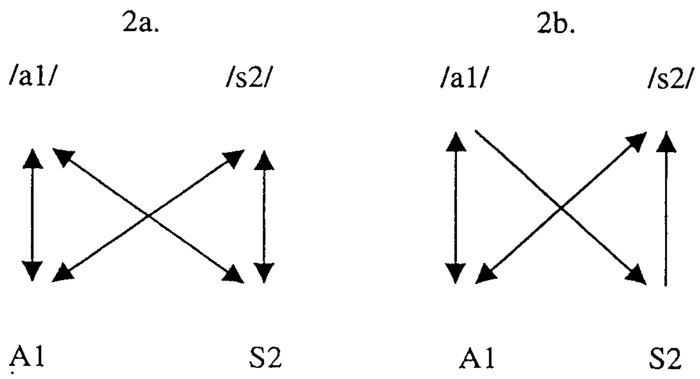

Figure 2. A comparison of a fully recurrent network (2a) and a partially connected network (2b) for the word AS. The indices 1 and 2 represent letter or phoneme positions.

Figure 2b shows that the relation between the letter S and the phoneme /s/ is not recurrent. Activation can only go from the letter S to the phoneme /s/, but this activation cannot directly stream back to the letter S. There is no way a strong stable recurrent connection can be formed between the letter S and the phoneme /s/. The consequence of such a partial recurrent network is that on the fine-grain level, i.e., relations between letters and phonemes, no stable feedback loops can cohere, but on the course-grain level, i.e., the relations between a word and the sound of the word this is still possible.

In the example (Figure 2b), the letter *A* sends activation to the phoneme /a/, which sends in return activation to the letter *S*, which sends activation to the phoneme /s/, and finally the phoneme /s/ streams the activation back to the letter *A*. After several presentations of this word, the model will be able to recognize this particular word. But, because the specific connection between the S and the /s/ will not be developed, the model will not be able to quickly recognize the letter *S* when for instance the word *is* is presented. The partial

connection between the phoneme node /a/ and the letter node S will not have an influence on the word-size feedback loop.

For pseudoword reading, however, strong relations between letters and phonemes are essential, and if these relations are not present it explains why dyslexic readers have so much problems reading pseudowords.

Predictions from dual-route model and phonological coherence model

We have shown how both models explain dyslexia and how they can account for consistency effects in word reading. We will derive hypotheses from both models concerning the effect of word consistency in reading-disabled children and normal-reading children.

Dual-route model

This model does not predict that inconsistency in the sound-to-spelling relationship affects word reading of normal-reading children, who have access to both the direct and indirect route. The dyslexic children do not have access to the direct route. They are restricted to the indirect, phonological route. This route only causes a consistency effect if a word is inconsistent in spelling-to-sound. No consistency effects are expected to show up for sound-to-spelling inconsistent words.

Phonological coherence model

According to the phonological coherence model normal readers will be influenced by the consistency of the relation between spelling and sound and the relation between sound and spelling. When this relation is inconsistent reading times should become longer.

For dyslexic readers two interpretations are possible. The first is that the partial connections between phonemes and letters operate in such a way that interference is not possible, because uni-directional relations simply do not have a chance of activating the wrong alternative spellings and as a consequence of this no influence is expected from the consistency of a word. Thus, according to this hypothesis it does not matter for dyslexic children whether a word is consistent or inconsistent in the sound-to-spelling relationship or spelling-to-sound relationship.

Another interpretation is also possible. As said, the phonological coherence model claims that no stable feedback loops between letters and phonemes will be created, but

eventually word-size feedback loops get formed. It is likely that even though the partial connections will not cause any disturbance, the alternative spellings of a sound still become activated through word-size connections. In Figure 2b the letter S eventually gets activated due to the letter A and phoneme /a/ and a word-size feedback loops coheres. In case the word is *heap*, the letter H may not only activate the letter body EAP, through the phoneme /h/, but also the letter body EEP. If the word-size feedback loops are indeed affected by the factor consistency, then we expect longer reading times for inconsistent words. Perhaps the lack of recurrent relations between letters and phonemes does not mean that no interference can take place.

The goal of this study is to find out whether visual word perception of children with reading problems is of similar interactive nature as the visual word perception of normal-reading children. In this study normal-reading children and reading-disabled children participated. The study was done in the Netherlands with native Dutch speakers. Earlier experiments looking for phonological influence on word perception were done in English, French, and German. English is a language with a phonologically deep writing system and a complicated set of grapheme-phoneme correspondence rules. The English language has many words that are inconsistent in spelling-to-sound relationship and sound-to-spelling relationship. French is highly consistent in spelling-to-sound relationship, but highly inconsistent in sound-to-spelling relationship.

Ziegler, Jacobs, and Stone (1996) performed a statistical analysis of the bi-directional inconsistency of spelling and sound in French and English. 79% of all monosyllabic words in French are sound-to-spelling inconsistent, whereas only 12.4% is spelling-to-sound inconsistent. In English 76% is sound-to-spelling inconsistent and 33% is spelling-to-sound inconsistent. Ziegler et al. (1996) did not perform a statistical analysis on the German mono-syllabic words. Ziegler and Jacobs (1995) say about the German language that the grapheme-phoneme conversion is not difficult.

Dutch is a transparant language with a fairly overall consistent relationship in letter to sound, but with a relatively large number of inconsistent relationships in sound to letter. In Dutch there are few words that are both inconsistent in spelling-to-sound relationship and in sound-to-spelling relationship as in English. Most inconsistencies are in the sound-to-spelling correspondences. This quality of Dutch is well suited for this experiment. The theoretical models predict different outcomes of the sound-to-spelling inconsistencies on word perception. The dual-route model predicts no influence of sound-to-spelling inconsistencies on word perception, the phonological coherence model expects longer reading times for

sound-to-spelling inconsistent words. The participants performed three tasks, a lexical-decision task, a rhyme-detection task, and a letter search task to investigate the interactive nature of spelling and sound in word perception.

EXPERIMENT 1: EFFECTS OF SOUND-TO-SPELLING INCONSISTENCY ON VISUAL WORD PERCEPTION

Stone et al. (1997) performed a lexical-decision experiment with words that were inconsistent in either the spelling-to-sound relationship or the sound-to-spelling relationship. The outcome was that words that were inconsistent in either direction got slower lexical-decision times than words that were consistent in both directions. Thus, when a word is inconsistent in sound-to-spelling, it appears to affect lexical-decision times.

In our experiment we also investigated whether sound-to-spelling consistent words, for example *paal* (pole) are indeed processed faster than sound-to-spelling inconsistent words, for example *paus* (pope). Both high-frequency and low-frequency words were used in this experiment. We especially wanted to find out whether dyslexic children are affected by word consistency.

The participants of our experiment were children with reading problems and normal-reading children. The group of normal-reading children consisted of children with the same age as the dyslexic children and children with the same word-reading score as the dyslexic children. Matching the dyslexic children with normal-reading children on word-reading level will allow us to look for potential differences in phonological reading skills.

If the phonological coherence model is correct, it is indeed expected that reading times for consistent words are faster as compared to inconsistent words. This must definitely be the case for normal-reading children. The model does not give a clear prediction of the performance of the dyslexic children. It is an empirical question whether they are also affected by the factor consistency. The dual-route model does not expect a sound-to-spelling consistency effect for both normal-reading children and reading-disabled children.

The factor frequency will also be taken in account. The phonological coherence model predicts that for high-frequency and low-frequency words a consistency effect will be found, since phonology always mediates word perception in this model. The dual-route model only predicts for low-frequency words a spelling-to-sound consistency effect.

Method

Participants

Sixty-nine children participated in the study, comprising three groups. One group consisted of children with dyslexia, one group consisted of children with the same chronological age as the children with dyslexia and the last group consisted of children with the same reading level as the children with dyslexia. The children with dyslexia were recruited from a school for special education and scored two years or more below their expected reading level (see Rayner & Pollatsek, 1989, for this definition of dyslexia). The remaining 46 children were children without reading problems. They attended a regular primary school.

Two weeks before the experiment was conducted, the reading skills of the children were assessed. The reading level was measured with a standardised reading-decoding test, the *Eén-Minuut-test* (Brus & Voeten, 1972). In this test children have to read as many words as they can in one minute. The number of words read correctly in one minute is the score on this test. Children's reading level for pseudowords was also assessed. The pseudoword-reading level was measured with a standardised pseudoword reading test, the *Klepel* (van den Bos, Spelberg, Scheepstra, & de Vries, 1994). Children have to read as many pseudowords as they can in two minutes. The score on this test is the total number of pseudowords correctly read in two minutes.

Only children who matched the criteria of having the same score on the word-reading test or having the same age in months were included in the experiment. Children were matched on the word-reading test since we are firstly interested in how they read existing words. Not everyone with the same age or same score however was automatically included. Those children whose scores on the *Eén-Minuut-test* and the *Klepel* differed more than 10 points from each other were not selected. We wanted to make sure that the normal-reading children did not have any difficulty with pseudoword reading.

The reading-match children could not be matched with the dyslexic children on both the word-reading and pseudoword-reading test, because the dyslexic readers score significantly lower on the pseudoword-reading test compared to the normal-reading children with the same word-reading score. Table 1 shows the scores on the reading tests and the mean ages of the children in the three groups.

Table 1 indicates that the children in the age-match group were as old as the children with dyslexia (mean age 10 years and 3 months), but the word-reading and pseudoword-

reading levels of the age-match group were significantly higher than that of the children with dyslexia ($F(1, 44) = 163.6$, $p < .001$ for word reading, and $F(1, 44) = 185.8$, $p < .001$ for pseudoword reading). The children in the reading-match group (mean age 7 years and 8 months) were on average 2 years and 7 months younger than the children with dyslexia. Performance on the word-reading test of the children in the reading-match group was not different from that of the children with dyslexia ($F < 1$), but on the pseudoword-reading test they outperformed the dyslexic children ($F(1, 44) = 7.0$, $p < .05$).

Table 1

Mean age in months, mean word-reading level, mean pseudoword-reading level, and sex ratio of the three readers groups (with standard deviations in brackets).

Readers	Age	Word reading	Pseudoword reading	N	Girls/Boys
Dyslexic	123.7 (8.6)	31.2 (9.7)	20.7 (10.8)	23	13 /10
Reading-match	91.8 (5.5)	31.5 (9.3)	29.0 (10.5)	23	9 / 14
Age-match	123.3 (8.8)	69.5 (10.6)	64.7 (11.1)	23	11/12

Materials

The experiment consisted of 120 items, 60 words and 60 pseudowords. The words consisted of 30 high-frequency words and 30 low-frequency words. Half of the words were consistent in their spelling-to-sound relationship and half were inconsistent in the spelling-to-sound relationship. The words were selected from the Woordfrequentielijst (word frequency list) of Staphorsius, Krom, and De Geus (1998). This is a corpus of 202.526 words of child literature. The words and pseudowords consisted of one syllable and contained either 4 or 5 letters. The average length of the words and the pseudowords was 4.3 letters. Appendix A, Table A1 shows the items of Experiment 1.

The inconsistent words in this experiment were words with the following graphemes: *au/ou*, *ij/ei*, *d/t* and *ch/g*. We chose these pairs of graphemes because they are very clear examples of inconsistent phoneme-grapheme relations. The *au/ou* and *ij/ei* are two examples of vowels in Dutch that both can be presented by two different ways of spelling. For example the words *klein* (small) and *vijl* (file) have an identical /ij/ sound, even though this sound is

spelled in two different ways. The words *fout* (wrong) and *blauw* (blue) have an identical /ou/ sound.

The *d/t* and *ch/g* are two pairs of consonants which have a similar sound, but that can be spelled in two ways. The letters *d* and *t* only have a similar sound at the end of a word. Only then both letters are sharp consonants (ANS, 1997, p.30). For example, the words *hond* (dog) and *kat* (cat) have an identical /t/ sound at the end. The *ch* is a sharp consonant and the *g* is a soft consonant, but this difference has no meaning anymore for the pronunciation in Dutch (ANS, 1997, p.30). Both graphemes are identical in sound. So the words *leeg* (empty) and *pech* (bad luck) sound alike at the end of the word[1]. The inconsistent words in all experiments were words with either an *ou/au*, *ei/ij*, *d/t* (at the end of a word), or *ch/g*. The consistent words contained none of the letters *au/ou*, *ij/ei*, *ch/g* or *d/t*. Notice that the words do not have complete bodies that are inconsistent, but only part of the body is inconsistent. The words *leeg* and *pech* are only inconsistent in one phoneme. The phoneme /*ch*/ can be spelled in two ways: the *g* or the *ch*.

As high-frequency words were selected words with a frequency larger than 17. As low-frequency words were selected words with a frequency lower than 14. The average frequency of the high-frequency words was 94.3 (SD = 115.2) with a range from 18 to 422. The average frequency of the low-frequency words was 4.4 (SD = 3.8) with a range from 1-13. The difference in frequency was significant (F(1, 54) = 19.4, p < .0001). Table 2 shows the number of words and average frequency for the four combinations of the factors frequency and consistency

Table 2

Number of words and average frequency (with standard deviations in brackets) for the four conditions: high-frequency consistent words, high-frequency inconsistent words, low-frequency consistent words and low-frequency inconsistent words.

	Number	Frequency			
High-frequency, Consistent	15	112.1 (29.0)		94.1	112.1
High-frequency, Inconsistent	15	122.2 (31.6)		94.5	122.7
Low-frequency, Consistent	15	4.5 (1.2)		4.7	4.5
Low-frequency, Inconsistent	15	3.1 (0.8)		4.2	3.1

[1] The difference between the *au/ou*, the *ij/ei* and the *ch/g* are historically determined. The difference between the *d/t* is a consequence of the rule of analogy. *Paard* (horse) is written with a *d* (although it has the pronunciation like the *t*, the sharp consonant) because the plural form of *paard* is *paarden*, with a *d* in the middle.

There was no difference in frequency between high-frequency consistent words and high-frequency inconsistent words, nor between low-frequency consistent words and low-frequency inconsistent words ($F < 1$). The average frequency of the consistent words was 49.4 ($SD = 90.3$) and 49.3 ($SD = 96.6$) for the inconsistent words.

The pseudowords were derived from the words by changing one or two of the containing letters, but maintaining the number of letters. For example the word *mens* (human) was transformed into *bins*. So two letters were changed. Sometimes only one letter was changed to form a pseudoword. For instance the word *bruin* (brown) was changed into *gruin*. The letters that are inconsistent in their phonology-to-spelling relationship in the words were kept in the pseudowords. In this way, words that are inconsistent in their phonology-to-spelling relationship were changed into pseudowords that are inconsistent in their phonology-to-spelling relationship. Consistent words were changed into consistent pseudowords.

Design

The items were presented in a pseudo-random order. There were never more than two yes-items (words) or no-items (pseudowords) in succession. Care was also taken to present the pseudowords as far from the words they were derived from. The factors frequency and consistency were also taken in consideration. For example, there were never more than two consistent words or two high-frequency words in succession. Appendix B, Tables B1 and B2 show the design of Experiment 1.

Two experimental lists were constructed in order to control for order effects. The only difference was the order of the items. The order of the items in list A was from item 1 to item 120. List B had the order of first items 61 to 120 and then items 1 to 60. In each list each item occurred once. Participants were assigned randomly to one of the two lists.

Procedure

The children were instructed that words they knew and words they did not know would appear on the computer screen. They had to press the yes-button in case they knew the word, and to press the no-button in case they did not know the word[2]. Appendix C, Table C1 shows the instruction of Experiment 1.

[2] The instruction said to press the no-button in case the children saw a word they did not know. The instruction did not say to press the no-button in case they saw a non-existing word. In that case a child might hesitate to press the no-button, because they might think it is an existing word that they just do not know.

The presentation of the stimuli and the registration of latencies and responses were computer-controlled. Participants were seated in front of a computer screen at a distance of approximately 50 cm. Words were typed in Arial size 32.

After the offset of an auditory warning signal there was an interval of 250 ms before a word was presented. Lexical-decision latencies were measured from the onset of the word or pseudoword on the screen until the participant gave a response by pressing either the yes-button or the no-button on the panel. After giving a response the word disappeared from the screen. If the participant for whatever reason did not respond within 10.0 seconds the word automatically disappeared and the next trial started. The inter-trial interval was 1.0 second. Participants were instructed to respond rapidly, but accurately.

Experimental items were preceded by 3 practice items that were similar to the experimental items. After these practice items the children had the possibility to ask questions. The experimental series started with three warming-up trials for which the reaction times were not analysed. Participants were tested individually. An experimental session lasted about 10 minutes. No feedback on task performance was given to the children.

Results

Before lexical-decision times were analysed first seven items with an error percentage of more than 60 percent were removed from the data set. These items were two consistent low-frequency words, two inconsistent low-frequency words, one consistent pseudoword and two inconsistent pseudowords.

For the remaining items the reaction times for the error responses, reaction times faster than 250 ms, time-out responses, and reaction times for the error responses due to panel key failure[3] were removed. After that a subject mean and item mean were assessed for word items and pseudoword items separately. Responses more than three standard deviations above the subject mean and the item mean were removed. So outliers were removed separately for word items and for pseudoword items.

[3] Panel-key failure means that the computer did not register a reading time even though the participant pressed one of the two buttons.

In total 8.7 % of the lexical-decision times of the words were removed from the data set (errors 8.1 %, errors due to panel-key failure 0.05 %, and extremely long responses, more than 3 SD above the subject mean or item mean 0.5 %).

In total 9.0 % of the lexical-decision times of the pseudowords were removed from the data set (errors 8.3 %, errors due to panel-key failure 0.2 %, time-out responses 0.2 %, responses faster than 250 ms 0.05 %, and extremely long response 0.3 %).

For the error-analyses only responses with reaction times faster than 250 ms (0.02%) and panel-key failures (0.1 %) were removed.

Words

Lexical-decision times. A four-way analysis of variance was performed on the average lexical-decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), consistency (consistent words, inconsistent words), frequency (high-frequency words, low-frequency words), and list. The factors group and list were between-subjects factors and the factors consistency and frequency were within-subjects factors. The factor list will not be discussed. Table 3 presents the mean latencies of the participants.

Table 3

Mean reaction times for words (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and consistency (Experiment 1).

	High-frequency words		Low-frequency words	
Readers	Consistent	Inconsistent	Consistent	Inconsistent
Dyslexic	1836 (1159)	1811 (1104)	1954 (1106)	2171 (1298)
Reading-match	1755 (877)	1824 (817)	2018 (1012)	2097 (924)
Age-match	894 (288)	924 (316)	960 (350)	990 (385)
Mean	1490 (952)	1509 (909)	1623 (1005)	1720 (1074)

The effect of consistency was significant. Words with a consistent relationship between spelling and sound got faster yes-responses than words with an inconsistent relationship between spelling and sound, ($F(1, 63) = 8.6$, $p = < .01$). The factors consistency

and group did not interact ($F < 1$). Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In neither case was the interaction between consistency and group significant: the dyslexic group vs. the age-match group ($F < 1$), the dyslexic group vs. the reading-match group ($F < 1$).

The effect of frequency was significant ($F(1, 60) = 71.9$, $p < .01$). High-frequency words got faster yes-response times than low-frequency words. The factors frequency and group interacted ($F(2, 60) = 8.3$, $p < .01$). The age-match group had numerically the smallest frequency effect.

There was a marginal interaction-effect between consistency and frequency ($F(1, 63) = 2.6$, $p = .10$). To find out whether in each group the factors consistency and frequency interacted, three two-way analyses were performed. The dyslexic group showed an interaction between consistency and frequency ($F(1, 21) = 3.1$, $p = .09$). The age-match group and the reading-match group did not ($F < 1$).

An additional analysis was performed to find the locus of the interaction effect in the dyslexic group. Two one-way analyses were performed, one for the low-frequency words and one for the high-frequency words. The effect of consistency was significant for the low-frequency words ($F(1, 21) = 5.3$, $p < .05$), not for the high-frequency words ($F < 1$).

The main effect of group was also significant ($F(1, 63) = 29.4$, $p < .01$). A post-hoc analysis showed that the age-match group had the fastest response-times (Tukey, $p < .05$) and that the difference in response times between the dyslexic group and the reading-match group was not significant.

Errors. A four-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), consistency (consistent words, inconsistent words), frequency (high-frequency words, low-frequency words), and list. The factors group and list were between-subjects factors and the factors consistency and frequency were within-subjects factors. The factor list will not be discussed. Table 4 shows the average percentage errors of the participants.

The effect of consistency was not significant ($F < 1$). The percentage of errors is the same for consistent and inconsistent words. The factors consistency and group did not interact ($F < 1$). The effect of frequency was significant ($F(1, 63) = 152.4$, $p < .01$). Fewer errors are made on high-frequency words than on low-frequency words. The factors group and frequency interacted ($F(1, 63) = 4.5$, $p < .05$). This interaction was caused by the small

frequency effect in the age-match group. The dyslexic group and the reading-match group had a large frequency effect.

The factors frequency and consistency interacted ($F(1, 63) = 3.5$, $p = .07$). Two additional one-way analyses were performed. One for low-frequency words and one for high-frequency words. When the words were high frequent, fewer errors were made on consistent words than on inconsistent words. When the words were low frequent, fewer errors were made on inconsistent words than on consistent words.

Table 4

Mean error percentages of words (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and consistency (Experiment 1).

	High-frequency words		Low-frequency words	
	Consistent	Inconsistent	Consistent	Inconsistent
Readers				
Dyslexic	6.7 (7.5)	9.0 (7.7)	21.2 (6.9)	21.2 (12.2)
Reading-match	4.6 (6.2)	5.8 (7.3)	21.5 (8.5)	18.3 (9.1)
Age-match	3.2 (4.0)	3.5 (4.9)	11.9 (9.6)	10.4 (7.2)
Mean	4.8 (6.1)	6.1 (7.0)	18.2 (9.4)	16.7 (10.6)

Pseudowords

Lexical-decision times. A four-way analysis of variance was performed on the average lexical-decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (word, pseudoword), consistency (consistent words, inconsistent words), and list. The factors group and list were between-subjects factors and the factors word type and consistency were within subject factors. The factor list will not be discussed. Table 5 presents the mean latencies of the participants.

The effect of word type was significant ($F(1, 63) = 148.7$, $p < .01$). Words had faster reaction times than pseudowords. The interaction between the factors word and group was significant ($F(2, 63) = 16.6$, $p < .01$). The age-match group had the smallest (significant) word effect (their reaction times are much faster compared to the two other groups).

The factors word type and consistency interacted ($F(1, 63) = 13.5$, $p < .01$). The effect of consistency was significant in the word condition, ($F(1, 63) = 7.6$, $p < .01$), but not in the

pseudoword condition, (F(1, 63) = 1.3, p > .1). The factors consistency and group did not interact (F(2, 63) = .43, p > .1).

The main effect of group was also significant: (F(2, 63) = 32.7, p < .01). A post-hoc analysis showed that the age-match group had the fastest response-times (Tukey, p < .05) and that the difference in response-times between the dyslexic group and the reading-match group was not significant.

Table 5

Mean reaction times (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on consistency and word type of the stimuli (Experiment 1).

	Consistent		Inconsistent	
	Word	Nonword	Word	Nonword
Readers				
Dyslexic	1887 (1136)	2634 (1460)	1970 (1206)	2544 (1477)
Reading-match	1870 (947)	2596 (1207)	1947 (876)	2619 (1172)
Age-match	924 (320)	1128 (448)	955 (351)	1110 (385)
Mean	1549 (978)	2090 (1313)	1605 (993)	2055 (1293)

Errors. A four-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (word, pseudoword), consistency (consistent words, inconsistent words), and list. The factors group and list were between-subjects factors and the factors word type and consistency were within-subjects factors. The factor list will not be discussed. Table 6 shows the average percentage errors of the participants.

The effect of word type was not significant (F(1, 63) = 2.2, p > .1). The factors word and group however interacted (F(1, 63) = 7.5, p < .01). The dyslexic group showed no word effect (F(1, 21) = 2.1, p > .1) whereas the reading-match group and the age-match group did (respectively (F(1, 21) = 32.0, p < .01), (F(1, 21) = 13.1, p < .01)). This means that a word was more often considered a pseudoword by children from the age-match and reading-match group than by the dyslexic children.

The factor consistency was marginally significant (F(1, 63) = 2.9, p = .09). However, consistency interacted with group and word type. Consistency interacts with group (F(2, 63) = 3.5, p = .06). Further analysis showed that only in the dyslexic group the factor consistency

was significant ($F(1, 21) = 5.7$, $p < .05$). More errors were made by the dyslexic children on inconsistent words than on consistent words.

Consistency also interacted with word type ($F(1, 63) = 3.6$, $p = .06$). This interaction is due to the fact that consistency only has an effect on the pseudowords ($F(1, 21) = 9.1$, $p < .01$). The error percentage was lower for consistent pseudowords than for inconsistent pseudowords. The factor group was also significant ($F(1, 63) = 30.1$, $p < .01$): The dyslexic group made the most errors, followed by the reading-match children. The age-match group made the least errors.

Table 6

Mean error percentages (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on consistency and word type of the stimuli (Experiment 1).

	Consistent		Inconsistent	
Readers	Word	Pseudoword	Word	Pseudoword
Dyslexic	13.9 (5.2)	16.1(11.9)	15.1 (8.3)	21.6 (16.2)
Reading-match	13.0 (5.8)	6.5 (6.5)	12.1 (6.3)	7.7 (6.0)
Age-match	7.5 (5.6)	3.2 (4.0)	7.0 (4.3)	3.2 (2.9)
Mean	11.5 (6.1)	8.6 (9.8)	11.4 (7.2)	10.8 (12.7)

Discussion

This experiment showed that all three groups read words with a consistent relationship between sound and spelling, like *mens* (human) significantly faster than words with an inconsistent relationship between sound and spelling, like *mond* (mouth). So the model of Van Orden et al. correctly predicts that word perception is being slowed down when the sound of a word can be spelled in more than one way. The dual-route model cannot explain this sound-to-spelling consistency effect.

The important question of this experiment was, of course, whether dyslexic children also display a consistency effect. No interaction was found between group and consistency, indicating that all three groups display a consistency effect. But there was a tendency towards significance between group, consistency, and frequency. The dyslexic children showed an

interaction between consistency and frequency, whereas the normal-reading children did not. We will first discuss the effect of the normal-reading children.

The normal-reading children, the age-match group and the reading-match group showed a word frequency effect (Cattell, 1886). High-frequency words were read faster than low-frequency words. These children also showed a consistency effect: Sound-to-spelling consistent words had faster response times than sound-to-spelling inconsistent words. The absence of an interaction-effect indicates that even for high-frequency inconsistent words reaction times are longer, just like Jared (1997) reported. Again, this is important evidence against the dual-route model. The dual-route model only predicts a spelling-to-sound consistency effect for low-frequency words.

The dyslexic children were the only ones with an interaction effect between consistency and frequency. For them it only mattered whether a word is inconsistent in sound-to-spelling relationship when the word was low frequent. Consistency had no impact on high-frequency words. Before discussing this last result we first want to say something on the effect of consistency on low-frequency words with the dyslexic children.

This effect tells us that even though the relations between letters and phonemes may not be recurrent in dyslexic readers somehow disturbance is still possible. An explanation in terms of the phonological coherence model is that even though disturbance from the fine-grain relations is not possible, it is likely that the course-grain size relations (the relations between letter- and phoneme groups and the relation between the spelling and the pronunciation of the complete word) activate the correct and wrong possible spellings.

This still leaves us with the question why consistency did not have an effect on high-frequency words and why this was only the case for the dyslexic children. A possible explanation is that once a word-size relationship has been created for high-frequency words, this resonance is so strong and powerful that no interference can take place anymore. At least not when there are no fine-grain relationships between letters and phonemes that can disturb. These strong and important recurrent connections are only present in normal readers and will cause problems for them in reading inconsistent words, whether they are high frequent or low frequent.

The dyslexic group made the most errors of all groups. Looking at the errors, all children showed an effect of frequency. Low-frequency words were often being judged as non-existing words. This is not surprising, the low-frequency words may not be familiar at all to the children and the instruction said to press the no-button in case the children saw a word

they did not know. It is very likely that low-frequency words were considered to be pseudowords.

No explanation can be found for the fact that all three groups found it more difficult to correctly accept inconsistent high-frequency words compared to consistent high-frequency words, while the pattern was opposite for the low-frequency words. It was easier to say 'yes' to inconsistent low-frequency words than to consistent low-frequency words.

An effect that has been described in the literature many times and that was also found in this experiment is the lexicality effect (Frederiksen & Kroll, 1978): Words have faster response times than pseudowords. All three groups showed this effect. The age-match group, the group of good readers, had the smallest lexicality effect. Probably because these children had fast reaction times, it was more difficult to get a large lexicality effect. The pseudowords were, in comparison to the words, not influenced by the factor consistency when we look at lexical-decision times.

Looking at the errors, though, more mistakes were made when a pseudoword is inconsistent than when it is consistent. So even if the reaction times to consistent and inconsistent pseudowords were alike, the children did react differently to inconsistent pseudowords. These pseudowords must have looked like existing words to the children and this resulted in more mistakes.

Only the normal-reading children made more errors on words than on pseudowords. Probably the orthography of the pseudowords was so strange and so unfamiliar to the children that they immediately detected these items as pseudowords. Correctly accepting existing words appeared to be more difficult. As soon as children did not know a word they simply rejected it by pressing the no-button. The dyslexic group however showed no difference in word type. The cause of this may be that they do not have a good image of words (they do not have good knowledge of orthographic structures), so non-existing words were not immediately discovered.

EXPERIMENT 2: EFFECTS OF ORTHOGRAPHICAL SIMILARITY ON AUDITORY WORD PERCEPTION

Seidenberg and Tanenhaus (1979) used the rhyme detection task to look for orthographic effects on auditory word perception. Their participants heard two words and they had to press a yes-button in case the two words rhymed and a no-button in case they did not rhyme. The rhyme words were either orthographically similar, *bum-gum* or orthographically dissimilar, *thumb-gum*. They found that reaction times for orthographically similar rhyme pairs were faster than for orthographically dissimilar rhyme pairs.

Zecker (1991) used the rhyme detection task to find out how the orthographic code develops in normal-reading children and reading-disabled children. All normal-reading children and the older reading-disabled children were faster in detecting similar rhyme pairs. For the younger reading-disabled children it did not matter whether the rhyme pairs were similarly spelled or not. The difference in reaction time between the similar rhyme pairs and the dissimilar rhyme pairs is called the orthographic facilitation effect. According to Zecker this effect shows that participants are capable of 'automatically accessing, using, and integrating orthographic and phonological lexical information'.

In Experiment 2 our participants were also presented with pairs of rhyming and non-rhyming words. Half of the rhyming pairs had similar spelling, for example *paus-saus*, and the other half had dissimilar spelling, for example *paus-kous*. Both pairs rhyme; the *ou* and the *au* are two graphemes that represent the same phoneme.

The orthographic facilitation effect was explained by Zecker in terms of the dual-route theory. When a word is activated in the mental lexicon, all entries with the same orthographic code will also become activated or primed. These words will have a lower threshold and as a result these words will be activated much faster. So when a rhyme word with the same orthographic structure follows the prime, it can benefit from priming. Thus, in the orthographically similar rhyme condition priming will take place since cue-word and target word share the same orthography.

Zecker explained the small or absent orthographic facilitation effect by stating that the orthographic code in these children develops at a slower rate. He found that reading level was strongly correlated with the amount of orthographic facilitation; the higher the reading level the bigger the orthographic facilitation effect. That is why young disabled readers with a low reading level did not show this facilitation effect. Moreover, the more children come in contact with words, the better their orthographic code will be. The young reading-disabled

children had a low reading level and they had little experience in reading and writing, so they were unable to use orthographic information.

However, it is odd that Zecker predicted an orthographic effect for reading-disabled children, because the dual-route model predicts that dyslexic readers will never be able to automatically access orthographic information. They will be forced to use the grapheme-phoneme rules.

The phonological coherence model, on the other hand, expects an orthographic effect for the normal-reading children and for the dyslexic readers. In the model, words that have a sound that can be spelled several ways will initially also activate these different spellings. The wrong spelling must get inhibited and the correct spelling will become strongly activated. When the next word appears and this words has the same spelling as the previous word it can benefit from a priming effect.

Dyslexic readers will also show an orthographic effect. The model states that even dyslexic readers can develop word-size feedback loops when they have a lot of experience with a particular word. A word that is read many times will instantly be recognized; the feedback loops will very quickly form a stable coherence. If the next word has similar word structure, this word can benefit from priming.

Summarized, the phonological coherence model predicts that our participants, including the dyslexic, will detect similar rhyming pairs faster. The dual route model only predicts an orthographic effect for the normal-reading children. The dyslexic children should not show this effect.

Method

Participants

Due to illnesses not all children from Experiment 1 were able to participate in Experiment 2. The ill normal-reading children were replaced by children with either comparable word-reading scores and pseudoword-reading scores or with a comparable chronological age. These children that replaced the ill children had also previously been matched with one of the dyslexic children. It was, however, not possible to find a replacement for one ill dyslexic child. Therefore are there 22 children in each group. Table 7 shows the scores on the reading test and the mean ages of the children in the three groups

The children in the age-match group were as old as the children with dyslexia (mean age 10 years and 3 months), and the word-reading and pseudoword-reading levels of the age-match group were significantly higher than that of the children with dyslexia ($F(1, 42) = 139.2$, $p < .001$ for word reading, and $F(1, 42) = 165.2$, $p < .001$ for pseudoword reading). The children in the reading-match group (mean age 7 years and 7 months) were on average 2 years and 8 months younger than the children with dyslexia. Performance on the word-reading test of the children in the reading-match group was not different from that of the children with dyslexia ($F < 1$), but on the pseudoword-reading test they outperformed the dyslexic children ($F(1, 42) = 5.3$, $p < .05$).

Table 7

Mean age in months, mean word-reading level, mean pseudoword-reading level, and sex ratio of the three reader groups (with standard deviations in brackets).

Readers	Age	Word reading	Pseudoword reading	N	Girls/Boys
Dyslexic	123.8 (8.8)	31.7 (9.6)	21.0 (10.9)	22	11/11
Reading-match	92.5 (5.5)	31.1 (8.7)	27.9 (8.9)	22	13/ 9
Age-match	122.7 (8.5)	68.9 (11.2)	64.4 (11.5)	22	11/11

Materials

The experiment consisted of 88 items, each item consisted of a pair of words. On one-half of the items the two words rhymed (a 'yes'-response) while the other half did not rhyme (a 'no'-response). Of the 44 rhyming pairs, 22 formed orthographically similar rhymes (e.g., *zucht-lucht*), while the other 22 pairs were orthographically dissimilar (e.g., *mug-kuch*). The 44 non-rhyming pairs were created by using the same words from the rhyming condition; however, by taking one word from each of two rhyming pairs, a non-rhyme pair was created (e.g., *zucht-mouw*). A female speaker recorded the stimuli. Appendix A, Table A2 shows the items of Experiment 2.

The words were selected from the Woordfrequentielijst (word frequency list) van Staphorsius, Krom, and De Geus (1998). All words were inconsistent in their sound-to-spelling relationship. As in Experiment 1 the inconsistent words contained either an *ou/au*,

ei/ij, *ch/g*, or a *d/t*. The average frequency for the orthographically similar rhyming pairs (the frequency of a rhyming pair is the sum of the frequencies of the two words) was 44.4 (SD = 59.2) and 80.6 for the orthographically dissimilar rhyming pairs (SD = 96.6). The difference in frequency was, although large, not significant ($F(1, 42) = 2.3, p > .1$).

The orthographically similar rhyming pairs had an average number of letters of 4.0 (this is the mean average of the number of letters of the two words) and the dissimilar rhyming pairs had an average number of letters of 3.7. The difference in number of letters was also not significant ($F(1, 42) = 1.9, p > .1$).

The difference in number of phonemes was, however, significant. The orthographically similar rhyming pairs had an average number of phonemes of 3.4, the orthographically dissimilar rhyming pairs had an average number of phonemes of 3.1 ($F(1, 42) = 4.7; p < .05$).

Note that if a bias is present, the factors frequency, letter average, and phoneme average work against our predictions. The dissimilar rhyme pairs have an advantage in that they have a higher frequency and a lower average number of letters and phonemes.

Design

The items were presented in a pseudo-random order. There were never more than two yes-items (rhyme pairs) or no-items (non-rhyme pairs) in succession. Care was also taken to present rhyme pairs with the same word as far from each other as possible. The orthographic similarity was also taken in consideration. There were never more than two rhyme pairs with dissimilar or similar orthographic structure in succession. Appendix B, Table B3 shows the design of Experiment 2.

Two experimental lists were constructed in order to control for order effects. The only difference was the order of the items. The order of the items in list A was from item 1 to item 88. List B had the order of first item 45 to 88 and then item 1 to 44. In each list each item occurred only once. The children heard each item only once, but each particular word twice (since the non-rhymes were made by taking one word from each of two rhyming pairs). Participants were randomly assigned to one of the two versions.

Procedure

The children were told that they would hear, over stereo headphones, two words after each other and that they had to indicate whether these two words rhymed or not. Decisions about whether the word pairs rhymed were indicated by pressing the appropriate button. They

were told to respond rapidly and accurately. Appendix C, Table C2 shows the instruction of Experiment 2.

Each trial consisted of two spoken words; 500 ms after the offset of the first word, the second word was presented. Reaction times were measured from the offset of the second word until the participant gave a response by pressing either the yes-button or the no-button on the panel. If the participant, for whatever reason, did not respond within 10.0 seconds the next trial would automatically start, without a warning signal. The inter-trial interval was 1.0 second.

Experimental items were preceded by 3 practice items that were similar to the experimental items. After these practice items the children had the possibility to ask questions. The experimental series started with three warming-up trials for which the reaction times were not analysed. Participants were tested individually. Experimental sessions lasted about 15 minutes.

Results

Before reading times were analysed the reaction times for the error responses, reaction times faster than 50 ms, time-out responses, and reaction times for the error responses due to panel key failure were removed. After that a subject mean and item mean were assessed for rhyme items and non-rhyme items separately. Responses more than three standard deviations above the subject mean and the item mean were removed. So outliers were removed separately for rhyme items and non-rhyme items.

In total 6.9 % of the reaction times of the rhyme-items were removed from the data set (errors 5.3 %, errors due to panel-key failure 0.3 %, time-out responses 0.1 %, responses faster than 50 ms 0.4 %, and extremely long responses, more than 3 SD above the subject mean or item mean 0.7 %).

In total 2.8 % of reaction times of the non-rhyme items were removed from the data set (errors 1.3 %, errors due to panel-key failure 0.7 %, time-out responses 0.1 %, responses faster than 50 ms 0.2 %, and extremely long responses 0.5 %).

For the error-analysis only responses with reaction times faster than 50 ms (0.3 %) and panel-key failures (0.5 %) were removed.

Rhyme Pairs

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), spelling (similar spelling rhyme pairs, dissimilar spelling rhyme pairs), and list. The factors group and list were between-subjects factors and the factor spelling was a within-subjects factor. The factor list will not be discussed. Table 8 presents the mean latencies of the participants.

Table 8.

Mean reaction times on rhyme pairs (in ms, with standard deviations in brackets) for dyslexic, reading-match and, age-match readers dependent on similarity of the spelling of the rhyme pairs (Experiment 2).

	Spelling	
	Similar	Dissimilar
Readers		
Dyslexic	1056 (1041)	1126 (1066)
Reading-match	1446 (1247)	1434 (1209)
Age-match	632 (408)	691 (490)
Total	1038 (1016)	1078 (1013)

The effect of the spelling was not significant, indicating that rhyme pairs with similar spelling were not detected faster than rhyme pairs with dissimilar spelling ($F < 1$). The effect of the factor group was significant ($F(2, 60) = 12.3$, $p < .01$). The children in the age-match had the fastest times, and the longest reading times came from the reading-match group (Tukey, $p < .05$). The factors spelling and group did not interact ($F < 1$). We also compared the dyslexic group with only one of the two control groups. The dyslexic group vs. the age-match group showed no interaction between group and spelling ($F < 1$), just like the dyslexic group versus the reading-match group ($F < 1$).

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), spelling (similar spelling rhyme pairs, dissimilar spelling rhyme pairs), and list. The

factors group and list were between-subjects factors and the factor spelling was a within-subjects factor. Table 9 presents the mean error percentages of the participants.

Table 9

Mean error percentages on rhyme pairs (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on similarity of the spelling of the rhyme pairs (Experiment 2).

	Spelling	
	Similar	Dissimilar
Readers		
Dyslexic	11.1 (18.2)	10.2 (6.1)
Reading-match	3.4 (7.8)	5.2 (1.2)
Age-match	0.8 (3.5)	1.7 (6.1)
Total	5.1 (12.4)	5.8 (12.5)

The effect of the factor spelling was not significant ($F < 1$), indicating that the percentage errors made on similarly spelled rhyme pairs and dissimilarly spelled rhyme pairs did not differ. The effect of the factor group was significant ($F(2, 60) = 7.8$, $p < .01$). All three groups differed from each other (Tukey, $p < .05$). The dyslexic group made the most errors of all groups and the age-match group made the least number of errors. The factors spelling and group did not interact ($F < 1$).

Non-rhyme pairs

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), rhyme (rhyme pairs, non-rhyme pairs), and list. The factors group and list were between-subjects factors and the factor rhyme was a within-subjects factor. The factor list will not be discussed. Table 10 presents the mean latencies of the participants.

The effect of the factor rhyme was not significant, showing that rhyme pairs were not detected more slowly than non-rhyme pairs ($F < 1$). The effect of the factor group was significant ($F(2, 60) = 10.1$, $p < .01$), namely the children in the age-match had the fastest times, and the longest reading times came from the reading-match group and the dyslexic group (Tukey, $p < .05$). The factors rhyme and group did not interact ($F < 1$). We also compared the dyslexic group with only one of the two control groups. The dyslexic group

versus the age-match group did not an interaction between group and rhyme (F < 1), nor did the dyslexic group versus the reading-match group (F(1, 40) = 1.0, p < .1).

Table 10

Mean reaction times (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on rhyme of the pairs (Experiment 2).

Readers	Rhyme	Non-Rhyme
Dyslexic	1091 (1054)	1136 (693)
Reading-match	1440 (1227)	1375 (1226)
Age-match	661 (451)	693 (468)
Total	1058 (1015)	1065 (1057)

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), rhyme (rhyme pairs, non-rhyme pairs), and list. The factors group and list were between-subjects factors and the factor rhyme was a within-subjects factor. Table 11 presents the mean error percentages of the participants

Table 11

Mean error percentages (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on rhyme of the pairs (Experiment 2).

Readers	Rhyme	Non-Rhyme
Dyslexic	10.7 (13.1)	1.8 (4.5)
Reading-match	4.3 (5.3)	2.0 (3.9)
Age-match	1.3 (2.8)	0.5 (1.2)
Total	5.4 (9.1)	1.4 (3.5)

The effect of the factor rhyme was significant (F(1, 60) = 20.6, p < .01). The factors rhyme and group interacted (F(2, 60) = 8.3, p < .01). The age-match group showed no effect of rhyme (F(1, 20) = 1.0, p > .1), while the dyslexic group (F(1, 20) = 13.8, p < .01) and the

reading-match group ($F(1, 20) = 10.4$, $p < .05$) made more errors on rhyme pairs than on non-rhyme pairs. The effect of the factor group was significant ($F(1, 20) = 6.1$, $p < .01$). The dyslexic group made the most errors (Tukey, $p<.05$). The reading-match children and the age-match children did not differ from each other.

Discussion

Previous experiments with adult readers, beginning readers, and children with a reading disability showed that similar rhyme pairs had significantly faster reaction times. The only exception to this was a group of young reading-disabled children. They showed no facilitation effect. Zecker explained this finding by saying that only when an orthographic code has been formed, facilitation of equally spelled words is possible.

In this experiment the spelling similarity of the rhyme pairs had no influence on the reaction times. The children in our study did not find it easier to detect a rhyme pair like *paus-saus* than to detect a rhyme pair like *paus-kous*. This result was unlike that of Zecker (1991) and Seidenberg and Tanenhaus (1979). Neither the dual-route model, nor the phonological coherence model predicted these effects.

No orthographic effect may have been found because of the significant phoneme difference in the stimuli. The similar rhyme pairs had a higher mean number of phonemes than the dissimilar rhyme pairs. Besides that, the similar rhyme pairs had a numerically lower average frequency and a higher letter average. It is possible that the orthographic effect was cancelled out by the fact that more phonemes and letters had to be processed. There are, however, alternative explanations.

It is imaginable that participants developed a strategy by which they could participate in the task. For instance they could think of possible rhyme words and as a result it was easy for them to make a decision about whether the words rhymed or not. Donnenwerth-Nolan, Tanenhaus, and Seidenberg (1981) performed a similar rhyme experiment. They argued that participants require about 500 ms to generate a prediction about the words that will follow. In our experiment the second words was presented 500 ms after the offset of the first word. If the children indeed used this time to correctly predict rhyme words, including rhyme words with a different spelling than it will become very difficult to find an orthographic effect.

The inter-stimulies-interval between the words may have affected the results in another way. If the time between the two words is too long, the orthographic information

might not be active anymore and cannot be of any influence. At first the orthographic information becomes active, just like the auditory information. But this orthographic information is not the most important information given the task (which basically can be resolved using auditory information only) and will rapidly decay. So when the interval between the two words is too long, the orthographic information will decay and will neither slow down nor speed up the perception of the next word. This could be an explanation for our result. Besides the reading time analysis, the error analysis did not show an effect of orthography either.

There was no difference in reaction times between rhyme pairs and non-rhyme pairs. The error-analysis showed that the dyslexic children and the reading-match children made more mistakes on rhyme pairs than on non-rhyme pairs. The age-match children had no problems with correctly detecting rhyme pairs. They made as many mistakes on rhyme pairs as on non-rhyme pairs. For these older children the rhyme detection task was very easy. All the children from the age-match group found it somewhat surprising that they had to do something so simple. The dyslexic children and the reading-match children had more problems with it.

Dyslexic readers have problems with processing phonological information and rhyming is rather difficult for them. Tasks, that involve manipulating phonology, appear to be an obstacle for these children. It was harder for them, just like the beginning readers, to correctly say yes to a rhyming pair than correctly say no to a non-rhyming pair. Further more, it was very clear to them that two words did not rhyme, but not that they rhymed. They did not immediately sense that words had a similar sound at the end. They often repeated both words in order to help them making the correct decision.

It is, however, important to notice that again no interaction appeared between group and orthographic effect. None of the three groups showed an orthographic effect. The dyslexic group had longer reaction times and they made a lot of mistakes but they did not show anything extraordinary. They did not resort to different ways of dealing with the task.

EXPERIMENT 3: EFFECTS OF LETTER PRESENCE IN PSEUDOHOMOPHONES ON VISUAL WORD PERCEPTION

Ziegler and Jacobs (1995) and Ziegler et al. (1997) performed a letter search task to find out how phonological properties of printed words can influence word perception. Their participants had to decide whether a pre-designated letter was present or absent in briefly presented words and pseudohomophones. A pseudohomophone is a word with identical phonology to a word, but with a different spelling, for example *pous* is a pseudohomophone of *paus*. Previous tasks had already shown that phonology often hurts word perception.

An example of influence of phonology on word perception is the pseudohomophone-effect. This effect, which means that a pseudohomophone is being judged as an existing word, was found, for example, in categorization tasks. In such a task participants had to say whether a word belongs to a certain category. For example is the word *brain* an example of the category human body parts? The critical variable in such an experiment was wordtype. Participants saw words, pseudohomophones, and pseudowords such as respectively *brain, brane,* and *brate*. Participants made more false positive errors saying that *brane* is a part of the human body, compared to saying that *brate* (orthographic spelling control) is a part of the human body. So, phonology hurts the correct identification of pseudohomophones. The phonology of the peudohomophone (*brane*) activates the lexical entry of the homophonic mate (*brain)* and if no extra spelling check is involved, mistakes are made. Also in lexical-decision tasks participants made more errors and had slower decisions to pseudohomophones.

As said, Ziegler and Jacobs (1995) and Ziegler et al. (1997) used the letter search task, in which participants had to decide as quickly and as accurately as possible whether a previously indicated target-letter is part of a briefly visually presented letter string. Participants saw for instance the letter *i* followed by the pseudohomophone *brane* or the letter *i* followed by the pseudoword *brate*. Ziegler and his co-workers found a pseudohomophone disadvantage. Participants made more errors and gave slower responses to pseudohomophones than to control words. This showed that participants did not make a decision purely based on visual information and it showed that phonology plays a role in word identification.

In Experiment 3 we also used words and pseudohomophones in a letter search task. Again the participants were normal readers and dyslexic readers. According to the phonological coherence model it was expected that letters that are absent in pseudo-homophones, but that are present in their base word (e.g., *d* in *zant/zand*) are more likely to

lead to false positive judgements than letters that are absent in both the pseudohomophone and base word (e.g., *f* in *saus/sous*). Letters that are present in pseudohomophones, but absent in their base word (e.g., *ij* in *klein/klijn*) are more likely to lead to false negative judgements than letters that are present in both the pseudohomophone and base word (e.g., *p* in *paus/pous*).

The letters of the pseudohomophone will activate the phoneme nodes and in return these nodes will activate the letter nodes that are actually presented, but also the letters that represent the same sound. For instance when the word *spord* (pseudohomophone of *sport*) is presented not only the letter *d* will get activated but also the letter *t*. The existing word *sport* will have much stronger connections between letters and phonemes and as a consequence this existing word will have a better chance of becoming activated.

The dual-route theory would predict the same results because when a pseudohomophone is transformed into a phonological code, this code is identical to the code of the existing word. As a consequence the phonological code will activate the orthographic unit of the existing word in the mental lexicon. A spelling check between the presented word and the activated entry in the lexicon is necessary to make a correct decision.

On a global level both models predict the same. However, there is, a difference in what both models predict for pseudohomophones derived from high-frequency and low-frequency words. According to the dual-route model low-frequency words and high-frequency words have a spelling representation in the mental lexicon. A pseudohomophone has to be read according to the indirect route and will be transformed into a phonological representation. The phonological representation of a pseudohomophone is identical to phonological representation of an existing word. The existing word, whether it is high frequent or low frequent, has a spelling representation that will strongly compete with the pseudohomophone. In that case making a correct decision about whether a letter is present or absent is difficult.

The phonological coherence model predicts that only pseudohomophones derived from high-frequency words will have to compete with the existing word. The letters of the pseudohomophone will activate the phonemes and these phonemes will activate the letters. The high-frequency word will have such strong relations between the letters and phonemes that it will be very difficult for the pseudohomophone to compete against such strong attractors. But when the pseudohomophone is derived from a low-frequency word, the chance is much lower that the letters of the existing word eventually get activated. In that case making a correct decision about whether a letter is present or absent should be less difficult.

Method

Participants

Due to illnesses not all children from Experiment 1 were able to participate in Experiment 3. The ill normal-reading children were replaced by children with either comparable word-reading scores and pseudoword-reading scores or with a comparable chronological age. These children that replaced the ill children had also previously been matched with one of the dyslexic children. It was, however, not possible to find a replacement for one ill dyslexic child. Therefore are there 22 children in each group. Table 12 shows the scores on the reading test and the mean ages of the children in the three groups.

Table 12

Mean age in months, mean word-reading level, mean pseudoword-reading level, and sex ratio of all readers (with standard deviations in brackets).

Readers	Age	Word reading	Pseudoword reading	N	Girls/Boys
Dyslexic	123.0 (8.1)	31.1 (9.9)	20.6 (11.0)	22	11/11
Reading-match	90.6 (5.4)	31.2 (9.9)	28.7 (11.8)	22	12/10
Age-match	122.7 (8.4)	70.4 (11.5)	66.3 (11.7)	22	10/12

The children in the age-match group were as old as the children with dyslexia (mean age 10 years and 3 months) but the word-reading and pseudoword-reading levels of the age-match group were significantly higher than that of the children with dyslexia ($F(1, 42) = 148.1$, $p < .01$ for word reading and $F(1, 42) = 178.9$, $p = .01$ for pseudoword reading). The children in the reading-match group (mean age 7 years and 7 months) were on average 2 years and 8 months younger than the children with dyslexia. Performance on the word-reading test of the children in the reading-match group was not different from that of the children with dyslexia ($F < 1$), but on the pseudoword-reading test they outperformed the dyslexic children ($F(1, 42) = 5.6$, $p < .05$).

Materials

From the word frequency list by Staphorsius, Krom and, De Geus (1998) 96 words were selected. These words consisted of one syllable and contained either 4 or 5 letters. They were all inconsistent in their sound-to-spelling relationship. Just like the inconsistent words of Experiment 1 and 2 these words also contained either a *au/ou*, *ij/ei*, *ch/g*, or a *d/t*.

The words were changed into pseudohomophones by replacing the letters with an inconsistent relationship between phonology and spelling. For example, the word *sport* was changed into the pseudohomophone *spord* by changing the letter *t* in *d*. Appendix A, Table A3 shows the items of Experiment 3. Two versions were made. Each version had 48 words and 48 pseudohomophones. The paragraph Design gives information on the two versions.

In total there were 34 high-frequency words (frequency higher than 17) and 62 low-frequency words (frequency lower than 14). The high-frequency words had an average frequency of 63.6 (SD = 61.4), with a range from 18 to 352, and the low-frequency words had an average frequency of 5.1 (SD = 5.1), with a range from 1 to 13. The difference in frequency was significant ($F(1, 90) = 49.9$, $p < .01$).

The experimental (see below) 48 items consisted of 24 high-frequency items and 24 low-frequency items. The average frequency for the high-frequency items was 61.7 (SD = 67.0) with a range from 18-352 and the average frequency was 4.7 (SD = 3.3) for the low-frequency items with a range from 1-12. This difference was significant ($F(1, 47) = 17.3$, $p < .01$). The filler items had 10 high-frequency items with an average frequency of 68.1 (SD = 48.1) with a range from 18-155 and 38 low-frequency items with an average frequency of 5.3 (SD = 3.8) with a range from 1-13. There were more low-frequency items than high-frequency items, because there were no more high-frequency words left to use.

Each item was preceded by a target-letter. This target-letter was present in half of the stimuli that followed the letter and it was absent in the other half of the stimuli that followed the letter. On half of the trials (48 times) the target-letter was a so-called problem letter. The words or pseudohomophones preceded by a problem letter are the experimental items. A problem letter could be either the letter *a, o, e, ij, d, t, c,* or *g*. For the graphemes *au/ou*, the letters *a* or *o* were used. Notice that the graphemes *au/ou* consist of two letters, but that only the first letter was asked. For the graphemes *ei/ij*, either the letter *e* or the letter *ij* was used. The letter *ij* is considered as one letter in Dutch. For the graphemes *ch/g* the letter *c* or *g* was used.

The problem letter was present when the target-letter (d) is present in the pseudohomophone (kad), but absent in the spelling of its sound-alike base word (kat). On

target-absent trials, the target-letter (t) is absent in the pseudohomophone (kad), but present in the spelling of its sound-alike base word (*kat*). The problem letters were actually present in half of the trials (24 times) and absent in the other half (24 times). For an overview of the stimulus conditions we refer to Table 13.

Table 13

Average frequency (with standard deviations in brackets) for the words and pseudohomophones preceded by a present or absent problem letter (Experiment 3).

Word type	High/Low Frequent	Frequency	Letter-Presence
Word	High	51.8 (25.3)	Present
Word	Low	5.9 (3.7)	Present
Word	High	71.7 (92.4)	Absent
Word	Low	3.7 (2.5)	Absent
Pseudohomophone	High	51.8 (25.3)	Present
Pseudohomophone	Low	5.9 (3.7)	Present
Pseudohomophone	High	71.7 (92.4)	Absent
Pseudohomophone	Low	3.7 (2.5)	Absent

On the other half of the trials the letter was a non-problem letter. Words or pseudohomophones preceded by a non-problem letter were the filler items. A non-problem leter was a, *f*, *j*, *l*, *v r*, *k*, *h*, *s*, *b*, *n*, *p*, *m*, *z*, or *w*. For example, a *p* could be followed by *paus*, requiring a yes-response, or a *k* could be followed by the word *vrouw*, requiring a no-response. Even if the participate thinks that the word *pous* was presented the *p* is still present. The non-problem letters were present in half of the trials (24 times) and absent in the other half (24 times). Table 14 presents the stimulus conditions of the non-problem items.

Table 14

Stimulus conditions for the words and pseudohomophones preceded by a non-problem letter (Experiment 3).

Word type	Presence
Word	Present
Word	Absent
Pseudohomophone	Present
Pseudohomophone	Absent

Design

The items were presented in a pseudo-random order. There were never more than two yes-items or no-items in succession. There were never more than two problem items or non-problem items in succession. There were also never more than two words or pseudohomophones in succession. Appendix B, Table B4 shows the design of Experiment 3.

Two experimental versions were constructed. Each version had 96 items, 48 words, and 48 pseudohomophones. The words in Version 1 were the pseudohomophones in Version 2 and the words in Version 2 were the pseudohomophones in Version 1. If Version 1 contained for instance the word *sport*, than Version 2 contained the pseudohomophone *spord*. In each experimental version each item occurred once. Across the two experimental versions, each item occurred in both experimental conditions (as a word and as a pseudohomophone).

The target-letters were the same over the two versions. For instance, if the letter *t* preceded the word *kat* in Version 1 (requiring a 'yes'-response), the letter *t* also preceded the pseudohomophone *kad* in Version 2 (requiring a 'no'-response). Notice that the required answers were different for the two versions. With the items preceded by a non-problem letter the answer was always the same for the two versions. If in Version 1 the word *paus* was preceded by a *p* then the letter *p* also preceded the pseudohomophone *pous* in Version 2. Both times a 'yes'-response was required.

For the experimental items each version had 6 items in each condition. For example, there were 6 high-frequency words with a present target-letter in each version. For the filler-items (the non-problem items) each version had 12 items in each condition. For example there were 12 words with a present target-letter.

Each version had two lists in which the order of the items differed. The order of the items in list A was from item 1 to item 120. List B had the order of first items 61 to 120 and

then items 1 to 60. Participants were assigned randomly to either Version 1 or Version 2 (and to either list A or list B of that version).

Procedure

The presentation of the stimuli and the registration of latencies and responses were computer-controlled. Participants were seated in front of a computer at a distance of approximately 50 cm. All stimuli were typed in Arial size 32. The participants were told that a letter would appear on the screen for a very short time, followed by a word. They had to press the yes-button in case the letter they had seen appeared in the word that followed. They had to press the no-button in case the letter that they had seen did not appear in the word that followed. Appendix C, Table C3 shows the instruction of Experiment 3.

A trial started with an auditory warning signal followed by a 250 ms interval. After this interval a letter was presented for 1.0 second. After the offset of the letter there was an interval of 50 ms before a word or pseudohomophone was presented for 250 ms. Reaction latencies were measured from the onset of the word or pseudohomophone on the screen until the participant gave a response by pressing either the yes-button or the no-button of the panel. If the participant for whatever reason did not respond within 10.0 seconds the next trial would automatically start. The inter-trial interval was 1.0 second. Participants were instructed to respond rapidly, but accurately. No feedback concerning task performance was given to the participants.

Experimental items were preceded by 3 practice items that were similar to the experimental items. After these practice items the children had the possibility to ask questions. The experimental series started with three warming-up trials for which the reaction times were not analysed. Participants were tested individually. Experimental sessions lasted about 15 minutes.

Results

Before reaction times were analysed, the reaction times for the error responses, reaction times faster than 250 ms, time-out responses, and reaction times for the error responses due to panel-key failure were removed. After that subject means and item means were produced for the problem items and non-problem items separately. Responses more than three standard deviations above the subject mean and item mean were removed.

In total 9.2 % of the reaction times of the problem items were removed from the data set (errors 8.0 %, errors due to panel-key failure 0.06 %, time-out responses 0.2 % extremely long responses, more than 3 SD above the mean 0.8 %, and responses faster than 250 ms 0.1 %).

In total 8.7 % of the reaction times of the non-problem items were removed from the data set (errors 7.6 %, errors due to panel-key failure 0.2 %, time-out responses 0.1 %, responses faster than 250 ms 0.2 %, and extremely long response 0.7 %).

For the error-analysis only responses with reaction times faster than 250 ms (0.1 %) and panel-key failures (0.1 %) were removed.

Problem items with present target-letters (t *in* punt *vs.* t *in* zant)

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and frequency (high-frequency words, low-frequency words). The factor group was a between-subjects factor and the factors word type and frequency were within-subjects factors. Table 15 presents the mean latencies of the participants.

Table 15

Mean reaction times for the problem stimuli with present target-letters (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and word type (Experiment 3).

	High-frequency		Low-frequency	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	1006 (515)	1191 (685)	1142 (577)	1160 (562)
Reading-match	1600 (971)	1749 (933)	1718 (1066)	1602 (798)
Age-match	943 (494)	1108 (514)	1034 (490)	994 (432)
Mean	1182 (753)	1289 (803)	1339 (776)	1241 (660)

The effect of word type was significant ($F(1, 54) = 4.0$, $p = .05$). Word items had faster response times than pseudohomophones. The factor word did not interact with the factor group ($F < 1$). The effect of group was significant ($F(2, 54) = 15.5$, $p < .01$). The reading-

match group had the slowest reaction times (Tukey, $p<.05$). The age-match group and the dyslexic group did not differ.

The effect of frequency was not significant ($F < 1$). The factor frequency did not interact with the factor group ($F < 1$). The factors word and frequency interacted ($F(1, 54) = 6.6$, $p < .05$). An extra analysis was performed to find the locus of the interaction-effect. The factor frequency was significant in the word condition ($F(1, 54) = 4.8$, $p < .05$) and only marginally significant in the pseudohomophone condition ($F(1, 54) = 3.7$, $p = .06$). The high-frequency words had faster response times than the low-frequency words, but the high-frequency pseudohomophone items had slower response times than the low–frequency pseudohomophone items.

Two three-way analyses of variance were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group did not reach significance ($F < 1$), nor did the interaction between frequency and group ($F(1, 36) = 1.2$, $p > .1$). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance ($F < 1$), nor did the interaction between frequency and group ($F < 1$).

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and frequency (high-frequency words, low-frequency words). The factor group was a between-subjects factor and the factors word type and frequency were within-subjects factors. Table 16 presents the mean error percentages of the participants.

The effect of word was not significant ($F < 1$). No more errors were made on pseudohomophones than on words. The factor word did not interact with the factor group ($F < 1$). The effect of group was significant ($F(2, 54) = 4.5$, $p < .05$). The age-match group differed from the reading-match group, but did not differ from the dyslexic group. The dyslexic group did not differ from both control groups (Tukey, $p<.05$).

The effect of frequency was not significant ($F(1, 54)= 1.2$, $p > 1$). There was no interaction between word and frequency ($F(1, 54) = 1.0$, $p > .1$). There was a small tendency towards a significant interaction between the factors frequency and group ($F(2, 54) =$, $p = .14$).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was not significant ($F < 1$). The interaction between frequency and group was significant ($F(1, 36) = 3.7$, $p = .06$). The age-match group made more errors on high-frequency items than on low-frequency items, whereas the dyslexic group made more errors on low-frequency items than on high-frequency items. In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance ($F < 1$), nor did the interaction between frequency and group ($F < 1$).

Table 16

Mean error percentages for problem stimuli with present target-letters (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and word type (Experiment 3).

	High-frequency		Low-frequency	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	7.6 (11.2)	6.8 (8.4)	12.9 (13.5)	10.6 (17.5)
Reading-match	7.6 (8.5)	12.9 (15.4)	13.6 (16.8)	12.9 (17.0)
Age-match	6.8 (9.8)	5.3 (10.7)	4.7 (7.9)	2.3 (5.9)
Mean	7.3 (9.8)	8.3 (12.1)	10.4 (13.7)	8.6 (15.0)

Problem items with absent target-letters (t *in* pund *vs.* t *in* zand)

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and frequency (high-frequency words, low-frequency words). The factor group was a between-subjects factor and the factors word type and frequency were within-subjects factors. Table 17 presents the mean latencies of the participants.

Table 17

Mean reaction times for the problem stimuli with absent target-letters (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and word type (Experiment 3).

	High-frequency		Low-frequency	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	1376 (702)	1276 (615)	1321 (693)	1259 (496)
Reading-match	1824 (819)	1776 (753)	1716 (947)	1800 (927)
Age-match	1187 (449)	1122 (441)	1105 (408)	1166 (536)
Mean	1460 (722)	1379 (669)	1289 (803)	1412 (739)

The effect of word type was not significant ($F > 1$). Words did not have faster responses than pseudohomophones. The factor word type did not interact with the factor group ($F(2, 54) = 1.7$, $p > .1$). The effect of group was significant ($F(2, 54) = 13.3$, $p < .01$). The reading-match group had the slowest reaction times (Tukey, $p<.05$). The age-match group and the dyslexic group did not differ.

The effect of frequency was not significant ($F(1, 54) = 2.0$, $p > .1$). The factor frequency did not interact with the factor group ($F < 1$). The factors word and frequency interacted ($F(1, 54) = 4.8$, $p <. 05$). An extra analysis was performed to find out more about the interaction-effect. The factor frequency was significant in the word condition ($F(1, 54) = 4.4$, $p < .05$). Low-frequency words had faster response-times than high-frequency words. The factor frequency was not significant in the pseudohomophone condition ($F < 1$).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was marginally significant ($F(1, 36) = 3.2$, $p = .08$). The dyslexic group showed a marginally significant word effect ($F(1, 18) = 4.0$, $p = .06$), whereas the age-match group showed no word effect ($F < 1$). The interaction between frequency and group did not reach significance: ($F(1, 36) = 1.2$, $p > .1$). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance ($F(1, 36) = 2.9$, $p > .1$), nor did the interaction between frequency and group ($F < 1$).

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and frequency (high-frequency words, low-frequency words). The factor group was a between-subjects factor and the factors word type and frequency were within-subjects factors. Table 18 presents the mean error percentages of the participants.

Table 18

Mean error percentages for the problem stimuli with absent target-letters (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on frequency and word type (Experiment 3).

	High-frequency		Low-frequency	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	10.6 (17.5)	10.0 (13.4)	15.9 (16.7)	10.8 (13.3)
Reading-match	7.6 (9.9)	11.4 (13.0)	4.6 (7.6)	6.1 (9.7)
Age-match	3.8 (8.8)	4.6 (7.6)	1.5 (4.9)	7.6 (9.9)
Mean	7.3 (12.8)	8.6 (11.8)	7.3 (12.5)	8.3 (11.1)

The effect of word type was not significant ($F < 1$). There was a marginally significant interaction between the factors word type and group ($F(2, 54) = 2.4$, $p = .1$). The effect of group was significant ($F(2, 54) = 5.7$, $p < .01$). The age-match groups made fewer errors than the dyslexic group, but did not differ from the reading-match group. There was no difference between the reading-match group and the dyslexic group (Tukey, $p < .05$).

The effect of frequency was not significant ($F < 1$). The factors word and frequency did not interact ($F < 1$). The factor frequency interacted with the factor group ($F(2, 54) = 2.9$, $p = .06$).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was marginally significant ($F(1, 36) = 3.6$, $p = .07$). The age-match group showed a word effect ($F(1, 18) = 4.8$, $p < .05$). Fewer errors were made on words than on pseudohomophones. The interaction between frequency and group was not significant ($F < 1$). In the analysis that compared the reading-

match group with the dyslexic group the interaction between word type and group did not reach significance ($F(1, 36) = 2.4$, $p > .1$). The interaction between frequency and group was significant ($F(1, 36) = 4.6$, $p < .05$). The reading-match group showed a frequency effect ($F(1, 18) = 5.8$, $p < .05$), whereas the dyslexic group did not ($F(1,18) = 1.1$, $p > .1$). Fewer errors were made to low-frequency items than to high-frequency items by the reading-match group.

Problem items vs. non-problem items with present target-letters (t *in* punt, t *in* zant) *vs.* (b *in* boeg, p *in* preis)

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and problem type (problem, non-problem). The factor group was a between-subjects factor and the factors word type and problem type were within-subjects factors. Table 19 presents the mean latencies of the participants.

Table 19

Mean reaction times for the stimuli with present target-letters (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on problem type and word type (Experiment 3).

	Problem		Non-problem	
Readers	Pseudohomophone	Word	Pseudohomophone	Word
Dyslexic	1072 (549)	1176 (626)	1202 (681)	1185 (699)
Reading-match	1657 (1018)	1676 (869)	1621 (754)	1647 (873)
Age-match	989 (493)	1050 (477)	988 (345)	1037 (410)
Mean	1234 (780)	1290 (721)	1266 (669)	1288 (733)

The effect of word type was significant ($F(1, 54) = 5.3$, $p < .05$). Word items had faster response times than pseudohomophones. The factors word and group did not interact ($F < 1$). The factor group was significant ($F(2, 54) = 16.4$, $p < .01$). The reading-match group had the slowest responses (Tukey, $p < .05$). The age-match group and the dyslexic group did not differ from each other.

The effect of problem type was not significant ($F < 1$). The factors group and problem type did not interact ($F(2, 54) = 1.2$, $p > .1$). There was no interaction between word type and problem type ($F < 1$).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was not significant ($F < 1$), nor was the interaction between problem type and group ($F(1, 36) = 1.8$, $p>.1$). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance ($F < 1$), nor did the interaction between problem type and group ($F(1, 36) = 1.6$, $p > .1$).

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and problem type (problem, non- problem). The factor group was a between-subjects factor and the factors word type and problem type were within-subjects factors. Table 20 presents the mean error percentages of the participants.

Table 20

Mean error percentages for the stimuli with present target-letters (with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on problem type and word type (Experiment 3).

	Problem		Non-problem	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	10.2 (9.9)	8.7 (11.1)	14.5 (8.8)	9.6 (9.6)
Reading-match	10.6 (10.0)	12.9 (11.7)	11.8 (9.9)	9.5 (9.0)
Age-match	5.7 (6.0)	3.8 (5.6)	6.8 (6.6)	8.4 (8.6)
Mean	8.9 (9.0)	8.5 (10.4)	11.0 (9.0)	9.2 (9.0)

The effect of word type had a very small tendency towards significance ($F(1, 54) = 2.0$, $p = .16$). Fewer errors were made to pseudohomophones than to words. The factors word and group did not interact ($F(2, 54) = 1.7$, $p > .1$). The factor group was significant ($F(2, 54) = 4.8$, $p < .05$). The age-match group made fewer errors than the reading-match group, but did

not differ from the dyslexic group. The dyslexic group and the reading-match did not differ from each other (Tukey, $p < .05$)

The effect of problem type was not significant ($F(1, 54) = 1.6$, $p > .1$). No more errors were made to problem items than to non-problem items. There was no interaction between word type and problem type ($F < 1$). The factors group and problem type did not interact ($F(2, 54) = 1.2$, $p > .1$).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was marginal significant ($F(1, 36) = 3.0$, $p = .09$). An extra analysis showed that only in the dyslexic group a marginal significant word effect was found ($F(1, 18) = 4.0$, $p = .06$). The dyslexic children made fewer errors to pseudohomophones. The interaction between problem type and group was not significant ($F<1$). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance ($F(1, 36) = 1.7$, $p > .1$), nor did the interaction between problem type and group ($F(1; 36) = 1.4$, $p > .1$).

Problem items vs. non-problem items with absent target-letters (t *in* pund, t *in* zand) *vs.* (j *in* woord, v *in* kint)

Reaction times. A three-way analysis of variance was performed on the average decision latencies of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and problem type (problem, non-problem). The factor group was a between-subjects factor and the factors word type and problem type were within-subjects factors. Table 21 presents the mean latencies of the participants.

The effect of word type was not significant ($F(1, 54) = 1.7$, $p > .1$). The factors word and group did not interact ($F < 1$). The factor group was significant ($F(2, 54) = 13.1$, $p < .01$). The reading-match group had the slowest reaction times (Tukey, $p < .05$). The age-match group and the dyslexic group did not differ.

The effect of problem type was significant ($F(1, 54) = 5.7$, $p < .05$). Non-problem items had faster response times than problem items. There was no interaction between word type and problem type ($F < 1$).

The factors problem type and group marginally interacted ($F(2, 54) = 2.5$, $p = 1.0$). Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group

the interaction between word type and group was not significant (F(1, 36) = 1.7, p > .1), nor was the interaction between problem type and group (F < 1). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group did not reach significance (F < 1). The interaction between problem type and group was significant: (F(1, 36) = 3.8, p = .06). The reading-match group showed a problem effect (F(1, 18) = 13.4, p < .05): non-problem items had faster responses than problem items.

Table 21

Mean reaction times for the stimuli with absent target-letters (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on problem type and word type (Experiment 3).

	Problem		Non-problem	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	1350 (696)	1268 (559)	1334 (810)	1290 (752)
Reading-match	1769 (886)	1788 (846)	1672 (877)	1614 (730)
Age-match	1146 (730)	1143 (490)	1092 (490)	1077 (447)
Mean	1420 (741)	1396 (705)	1361 (777)	1322 (690)

Errors. A three-way analysis of variance was performed on the average error percentages of the participants with the factors group (dyslexic group, reading-match group, age-match group), word type (words, pseudohomophones), and problem type (problem, non-problem). The factor group was a between-subjects factor and the factors word type and problem type were within-subjects factors. Table 22 presents the mean error percentages of the participants.

The effect of word type was not significant (F < 1). The interaction between the factors word and group was marginally significant (F(2, 54) = 2.7, p = .08). The factor group was significant (F(2, 54) = 10.8, p < .01). The age-match group made fewer errors than the dyslexic group, but did not differ from the reading-match group. The dyslexic group did not differ from the reading-match group (Tukey, p < .05).

The effect of problem type was significant (F(1, 54) = 6.8, p < .05). Fewer errors were made to non-problem items. There was no interaction between word type and problem type (F < 1). The factors group and problem type did not interact (F < 1).

Two three-way analyses were performed to compare the dyslexic group with the two control groups separately. In the analysis that compared the age-match group with the dyslexic group the interaction between word type and group was significant ($F(1, 36) = 4.8$, $p < .05$). The age-match group showed a word effect ($F(1, 18) = 7.0$, $p < .05$). Fewer errors were made to words than to pseudohomophones. The interaction between problem type and group did not reach significance ($F < 1$). In the analysis that compared the reading-match group with the dyslexic group the interaction between word type and group had a small tendency towards significance ($F(1, 36) = 2.6$, $p =.11$). The dyslexic group made more errors on words than pseudohomophones whereas the reading-match group made more errors on pseudohomophones than on words. The interaction between problem type and group was not significant ($F < 1$).

Table 22

Mean reaction times for the stimuli with absent target-letters (in ms, with standard deviations in brackets) for dyslexic, reading-match, and age-match readers dependent on problem type and word type (Experiment 3).

	Problem		Non-problem	
	Word	Pseudohomophone	Word	Pseudohomophone
Readers				
Dyslexic	13.3 (13.8)	10.4 (11.3)	9.9 (10.2)	9.2 (9.3)
Reading-match	6.1 (7.4)	8.7 (8.7)	4.6 (6.2)	6.1 (9.4)
Age-match	2.7 (4.7)	6.1 (7.4)	0.8 (2.5)	2.3 (4.6)
Mean	7.3 (10.3)	8.4 (9.3)	5.1 (7.9)	5.9 (8.4)

Discussion

We will first give a short overview of the results in the target-present problem items and discuss these results. We will do the same for the target-absent problem items, target-present problem and non-problem items, and the target-absent problem and non-problem items, respectively.

The analysis of the problem items with present letters showed that participants responded faster to words than to pseudohomophones and that participants responded faster to high-frequency words than low-frequency words. Participants however responded faster to low-frequency pseudohomophones than to high-frequency pseudohomophones.

Target-present high-frequency words got faster responses than target-present low-frequency words. The explanation is that high-frequency words were very common to the children and it was very clear to them that the target-letter was indeed present in the word. Target-present low-frequency words, such as *t* in *kuit*, would be more difficult. As a result of weak relations between letters and phonemes the children may not be sure whether a word like for example *kuit* is spelled with a *t* or a *d*. The children probably needed time to judge whether the target-letter *t* was present in the word or not.

Participants responded slower to pseudohomophones derived from high-frequency words than pseudohomophones derived from low-frequency words. Target-present pseudohomophones, such as *ei* in *blei* derived from high-frequency words would be easier mistaken for their homophonic mates. It is plausible that children think they saw the word *blij* when they really saw the pseudohomophone *blei*. The relations between letters and phonemes in words, such as *blij* are so strong that the nodes will cohere very quickly. Initially the children probably thought there was no *ei* in *blij*. They would have to correct their initial choice and that lead to long reaction times. Only the phonological coherence model predicted this difference between pseudohomophones derived from low-frequency words and high-frequency words. The dual-route model did not predict the effect. According to the dual-route model any pseudohomophone will have to compete with the existing word. It should not matter whether the existing word is high frequent or low frequent.

There were no differences between the groups when looking at reading times, but the groups showed some different patterns with respect to the error percentage. The dyslexic group and the age-match group showed an interaction-effect between frequency and group in the error analysis. The age-match group made more errors on high-frequency items than on low-frequency items, whereas the dyslexic group made more errors on low-frequency items than on high-frequency items. The fact that the age-match group made more errors on pseudohomophones derived from high-frequency words than pseudohomophones derived from low-frequency words shows that it was indeed very difficult to correctly say yes to such an item. The fact that high-frequency words got so many errors means that the fast decision times to target-present high-frequency words were often wrong. The dyslexic group made more errors on low-frequency items than on high-frequency items. This shows that they found

the target-present low-frequency words difficult, just like the pseudohomophones from low-frequency words. The pseudohomophones derived from low-frequency words, however, got the fastest response times. The fact that so many errors are made to these items is probably due to a speed-accuracy trade-off.

For target-absent problem items we did not find a word effect. Responses to words were not different from responses to pseudohomophones. Participants responded slower to the high-frequency words than to low-frequency words. There was no difference in reaction times between high-frequency or low-frequency pseudohomophones.

In contrast to the results from the target-present problem items, there was no difference between the pseudohomophones derived from high-frequency words or low-frequency words. This is a result that the dual-route model predicted, but the phonological coherence model did not predict this. The dual-route states that every pseudohomophone would have to compete with the existing word it is derived from. This is a plausible explanation in this case. In the target-absent pseudohomophones, a letter was asked that was present in the existing word, such as a *d* in *hont* (*hond*). Especially in these target-absent condition the competition with the existing word was very big. Every time a letter was presented, that letter was present in the existing word. This existing word always becomes activated, according to the dual-route model.

The longest reaction times came from target-absent high-frequency words. Apparently, the target-absent items were difficult. It seems that the children always had an expectation that the letter they had seen would be present in the word that followed. That would explain why it took so much time to say no to a letter that was absent in a high-frequency word. They 'wanted' the letter to be present, but then they found out that the letter was actually absent. They needed time to adjust their first thought and that costed time.

The error analysis showed that the reading-match group made more errors on low-frequency items. Again, a result that does not combine with the results found in the reaction time analysis. Low-frequency words were got faster decision times than high-frequency words, and for the pseudohomophones we did not find an effect of frequency. Still, more errors were made by the reading-match group on low-frequency items than on high-frequency items.

For target-present problem items and non-problem items there was only a difference in word type: participants responded faster to words than to pseudohomophones. There was no effect of problem type. All three groups showed the word type effect. Again reading a pseudohomophone will cause confusion. The chance is very high that the existing word also

will become activated and the competition between activating the existing word and the pseudohomophone takes time. The dual-route model and the phonological coherence model both predicted that seeing a pseudohomophone activates the existing word. The dual-route model stated that the spelling representation of the existing word reaches a sufficient activation level in the mental lexicon. The phonological coherence model states that the relations between the letters and phonemes of the existing word would be rather strong, such that it would be much more likely that this existing word would become activated.

The groups showed no effect of problem type, judging whether a *t* is present in *punt* did not take more time than judging whether a *b* is present in *boeg*. There is no explanation for this. We expected that children would react faster to non-problem items than to problem items, because the letter that was asked in the non-problem condition was completely unambiguous. For instance if the children saw the letter *b* followed by the pseudohomophone *boech* , it should not matter if the existing word *boeg* got activated. The letter *b* is present in the word and pseudohomophone.

The error percentage showed that the age-match group and the dyslexic group differed on the factor word type. The dyslexic group made more errors on words than on pseudohomophones, whereas the age-match group did not show an effect of word type. The dyslexic children needed more time to think about the pseudohomophones, but they did not make more errors on these items.

For target-absent letters in problem items and non-problem items there was an effect of problem type, namely non-problem items had faster decision times than problem items. The factor problem type however interacted with group: only the reading-match group showed this effect of problem type.

Again, we cannot explain why the dyslexic children and the age-match children did not react faster to non-problem items. The reading-match children however did find it easier to say no to a *f* in *vlieg* than no to a *t* in *hond*. So when a non-problem letter preceded the word or pseudohomophone it was quickly clear to them that that letter was absent.

The error analysis showed that there was an interaction-effect between word type and group. The dyslexic group was the only group that made more errors on words than on pseudohomophones. The normal-reading children made more errors on pseudohomophones than on words. It is plausible that the normal reading children made more errors on pseudohomophones since these items were the problematic items. The pseudohomophones were the words that had to fear competition from the existing words. When a pseudoword had to be read the chance was big that the existing word got activated, since word and

pseudohomophone shared the same pronunciation. When the children thought that they had seen the word instead of the pseudohomophone, they would make errors. But looking at the errors from the dyslexic children the opposite pattern seemed to be the case. Words were more difficult to them.

Summary and Conclusion

This study investigated the influence of inconsistent words on word perception. Inconsistent words are words with a spelling that can be pronounced in more than one way or/and with a pronunciation that can be spelled in more than one way. Previous studies had shown that inconsistent words lead to longer reading times than consistent words. We wanted to find out whether normal reading children and dyslexic children would show the same effect. Two models were used to generate predictions. These models wêre the dual-route model and the phonological coherence model.

The phonological coherence model is a dynamic model in which information streams forwards and backwards. The dual-route model is a static model in which information goes from one stage to the next. The lexical-decision experiment gave us clear evidence which model correctly describes the process of word perception. We found that sound-to-spelling inconsistent words are read slower than sound-to-spelling consistent words. So reading involves not only the relations between letters and their sound, but also the relations between sound and their letters. The dual-route model is too strict a model, it does not foresee the interactive nature of spelling and sound. The dual-route model would only predict an effect of sound-to-spelling inconsistent words on spelling, but not on reading.

A further important difference between the two models is how low-frequency and high-frequency words are read. The dual-route model claims that only for low-frequency words the indirect route sometimes produces an output that is faster than the output from the direct route. That is why phonological effects (such as a consistency effect) should only be found for low-frequency words. The phonological coherence model states that phonology always plays a role in word perception, regardless whether the word is high frequent or low frequent. The lexical-decision experiment showed that high-frequency words and low-frequency words showed a consistency effect. So even when a person has to read a word that he or she has seen often, this person will still be influenced by the consistency of that word. The assumption that high-frequency words immediately activate the spelling representation in the mental lexicon cannot be right.

The models also differ in their explanations of dyslexia. According to the dual-route model the indirect route is out of operation. The reason for this is the poor pseudoword-reading skills of dyslexic readers. Pseudoword reading requires that the reader converges letters into phonemes, because a pseudoword cannot be read through a direct match with a representation previously stored in the lexicon. The inventors of the phonological coherence

model managed to implicate the most important aspect of dyslexic readers, namely problematic pseudoword reading, into the model. The problems with pseudoword reading get translated into the model by partial relations between letters and phonemes. The lack of these partial relations is the cause of the phonogical problems. Normally the relations between letters and phonemes are recurrent, so that the relations between letters and phonemes can become very strong. Only then is it possible to read new words and pseudowords, because reading a pseudoword involves knowledge about how a letter gets transformed into a sound. Dyslexic readers only have knowledge about word-size correspondences between letters and phonemes and that will not help them reading a pseudoword.

In this study the participants consisted of two groups of children. One group consisted of dyslexic children and the other group was a control group. This control group was divided in two groups of normal reading children. One control group consisted of children with the same age in months as the dyslexic children. The other control group consisted of children with the same score on a word-reading test. The children also had to take a pseudoword-reading test. The children that were matched on word-reading level, had a higher score on the pseudoword-reading test than the dyslexic children. This is not unexpected, since the characteristic of dyslexia is problematic pseudoword reading.

It should be no surprise that the age-match children who outperformed the dyslexic children on the word-reading test and the pseudoword-reading test were superior to the dyslexic children. They were much faster and more accurate than the dyslexic children. The reading-match children were also faster and more accurate than the dyslexic children. Again, this is no surprise. The important finding, however, is that the dyslexic group does not differ qualitatively from the control groups. They do not have different ways of dealing with the tasks. They only seem to process information more slowly.

The letter search task (Experiment 3) showed that target-present high-frequency words got faster response times than target-present low-frequency words. All three groups showed this effect. Target-present pseudohomophone derived from high-frequency words got slower response times than target-present pseudohomophones derived from low-frequency words. The groups also did not differ on this point. This result was predicted by the phonological coherence model, not by the dual-route model. The dual-route model states that any pseudohomophone will have to compete with the word it is derived from, whether that word is high frequent or low frequent.

The results from the target-absent problem items, however, could only be explained by the dual-route model. No difference was found between pseudohomophones derived from

high-frequency words or low-frequency words. The phonological coherence model would have expected that only pseudohomophones derived from high-frequency words would have to compete with the existing word. If this would have been true, the response times to these high-frequency pseudohomophones should have been longer than the reaction times to the pseudohomophones derived from low-frequency words.

This letter search experiment could not tell which model is the 'correct' model. Both models can explain part of the results. This experiment, however, could be replicated and this time we would have to use spelling control words. If for instance the word *sport* and the pseudohomophone *spord* is used, then there should also be a spelling control word *spork*. If it takes more time to respond to *spord* than to *spork*, we can for certain say that the slow response times to *spord* are caused by the fact that *spord* sounds the same as *sport*.

In the rhyme experiment (Experiment 2) rhyme pairs with similar spelling were not detected faster than rhyme pairs with dissimilar spelling. Thus, we did not find an orthographic effect. We gave several explanations for why we did not find an effect, one of them was the interval-time between the two words. If we decrease the time between the two words we will be certain that the children will not use the time to predict which rhyme-word can follow. It would also be better if we choose the items in such a way that there is no bias in phoneme average, letter average, and frequency average. In the present experiment the dissimilar rhyme pairs had an advantage in that they had a higher average frequency, a lower letter average, and a lower phoneme average than the similar rhyme pairs. This causes fast response times for these pairs and as a result there will not be much difference in reaction times between similar and dissimilar rhyme pairs.

Another possibility for not finding an orthographic effect is the lack of statistical power. There were only 6 items in each condition in the present experiment. Increasing the number of items could result in finding an orthographic effect. The dual-route model and the phonological coherence model both did not predict the results that we found. Therefore we cannot conclude from the results of this experiment which model best describes word perception. Again, only quantitative differences were found between the groups. The dyslexic children were slower and less accurate, but no interaction was found between the factor group and the factor spelling. The quantitative differences do not result in qualitative differences.

Only the lexical-decision experiment (Experiment 1) gave clear evidence that the phonological coherence model most correctly describes the process of word perception. In this experiment we found a consistency effect. Words that were inconsistent from sound-to-spelling had longer decision times than words that were consistent from sound-to-spelling.

The only model that can explain this effect is the phonological coherence model. The dual-route model only predicted a consistency effect of words that are inconsistent from spelling-to-sound. The dual-route model is a bottom-up model in which the letters of a word activate the sound of the word. The sound of the word will never have influence on the letters. A further more important finding is that the consistency effect was also found on high-frequency words. This is absolute prove that the dual-route model does not explain word perception in a good way. Phonology only mediates word perception in low-frequency words in this model.

In this experiment we found a difference between the dyslexic readers and the normal readers. The dyslexic readers also showed a consistency effect but only on the low-frequency words. Again the dual-route model cannot explain a sound-to-spelling consistency effect. The effect is difficult to explain, but is is possible that when fine-grain relations are not present, high-frequency words are not affected by inconsistency.

We did not find serious differences between the dyslexic group and one of the two control groups. This could be caused by the tasks that they had to perform. Maybe the tasks were not difficult enough or maybe the items were not different enough. For example Snowling (1981) found no differences between dyslexic readers and normal readers when both groups had to read one-syllable pseudowords. But when they had to read two-syllable pseudowords there was a difference between the reading-disabled group and normal-reading group. Maybe we will also find bigger differences between the groups if we use two-syllable words in the tasks. It would be also interesting to compare in a future experiment the dyslexic children with children with the same pseudoword-reading level. We could then see how the partially connected relations between letters and phonemes influence reading, because that is the only difference between the groups. The only disadvantage of this way of matching would be that the pseudoword-match children would be very young.

The lexical-decision experiment gave clear evidence in favour of the phonological coherence model. This experiment proved the influence of inconsistent relationships between sound and spelling on reading. The phonological coherence model however, has shown its quality on another level of word perception. Pecher (2000) performed a study on the influence of feedback semantics on word recognition. The term feedback semantics refers to whether a specific meaning can be represented by only one word (a consistent word) or by several words (an inconsistent word). A semantic inconsistent word is for example *jail*. This word is inconsistent because it has a synonym, namely *prison*. A semantic consistent word is for example the word *milk*. When a word like *jail* is presented to the network, not only the semantic nodes of *jail* will become activated, but also the semantic nodes of the word *prison*.

These semantic nodes will in return activate several patterns in the phonological and orthographic nodes, namely those of *jail* and *prison*. The wrong nodes have to be inhibited. When a word like *milk* is presented to the network only the orthographic and phonological nodes of *milk* will get activated. Reaction times to *milk* were expected to be faster than reaction times to *jail*. Pecher indeed found that both naming times and lexical-decision times were faster and more accurate for consistent words than for inconsistent words.

What does the interactive nature of spelling and sound mean for word perception models or even for cognitive models other than reading? First it shows that a good word perception model should incorporate a feedback principle. Only then the word perception models will explain the consistency effects found in sound-to-spelling inconsistent words. Secondly, and that is an important implication for word perception models: speaking of 'representations' does no longer make sense. If the interaction between spelling and sound proves that both principles influence each other one can not speak of a basic, stable, representation of a word and of terms like pre-lexical access and post-lexical access. Once the feedback and feedforward loops start streaming, one cannot make a distinction between the beginning and the end. The only thing that is left is a continuous interaction in which for example letters influence the sound, but in which the sound immediately influences the letters.

According to Van Orden and co-workers (Van Orden, Holden, Podgornik, & Aitchison, 1999) the interactive nature of reading is not a specific finding that is only true for reading. They generalise it to other parts of cognition. Cognition cannot be separated from the contexts in which it is embedded. 'Cognitive systems are causally embedded in their environments and thus always entail their environmentals with regard to cognitive performances'. To come back to reading Van Orden used swimming as a metaphor for reading. He stated that it would make 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. Each body movement of the swimmer changes the trajectory of the water molecules, which simultaneously affect the trajectory of the body, which again changes the context for swimming, and so on. Reading is just like swimming contextually situated. According to Van Orden in order to explore the role of phonology in reading we have to manipulate context to reveal patterns of interaction.

If we assume that not only experimental factors represent a context, but also group membership, it becomes clear why there are both differences and similarities in reading behaviour between children with reading problems and children without reading problems.

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Appendix Information

Appendix A presents the items of the three experiments.

Table A1 presents the items of Experiment 1.

Table A2 presents the items of Experiment 2.

Table A3 presents the items of Experiment 3.

Appendix B presents the designs (order of presentation of the items) of the three experiments.

Tables B1 and B2 present the design of Experiment 1.

Table B3 presents the design of Experiment 2.

Table B4 presents the design of Experiment 3.

Appendix C presents the instructions of the three experiments.

Table C1 presents the instruction of Experiment 1.

Table C2 presents the instruction of Experiment 2.

Table C3 presents the instruction of Experiment 3.

Appendix D presents an overview of the statistical results of the three experiments.

Tables D1 and D2 present the results of Experiment 1.

Tables D3 and D4 present the results of Experiment 2.

Tables D5-D12 present the results of Experiment 3.

Appendix A: Items of Experiments, 1, 2, and 3

Table A1: Items of Experiment 1

	regel	Stimulus	Freq	Consisteny	Word structu...	Vowel	Staphor F...	N Letters	Nonwoord
1	1	mens	High	Consistent	MKMM	BK	63	4	bins
2	2	kans	High	Consistent	MKMM	BK	33	4	wans
3	3	lang	High	Consistent	MKMM	BK	175	4	kang
4	4	niks	High	Consistent	MKMM	BK	48	4	sils
5	5	soms	High	Consistent	MKMM	BK	140	4	noms
6	6	bruin	High	Consistent	MMKM	TK	29	5	gruin
7	7	broer	High	Consistent	MMKM	TK	31	5	droer
8	8	stoel	High	Consistent	MMKM	TK	33	5	broel
9	9	klas	High	Consistent	MMKM	BK	76	4	klaan
10	10	toen	High	Consistent	MMKM	TK	437	4	moen
11	11	deur	High	Consistent	MKM	TK	48	4	meus
12	12	ziek	High	Consistent	MKM	TK	20	4	bien
13	13	huis	High	Consistent	MKM	TK	217	4	huim
14	14	neer	High	Consistent	MKM	BK	29	4	neek
15	15	vuur	High	Consistent	MKM	BK	33	4	duuk
16	16	leeg	High	Inconsistent	MKM	BK	19	4	heeg
17	17	huid	High	Inconsistent	MKM	TK	36	4	muid
18	18	fijn	High	Inconsistent	MKM	TK	44	3	hijn
19	19	reis	High	Inconsistent	MKM	TK	31	4	deis
20	20	gauw	High	Inconsistent	MKM	TK	72	4	sauw
21	21	touw	High	Inconsistent	MKM	TK	22	4	jeut
22	22	trein	High	Inconsistent	MMKM	TK	28	5	vlein
23	23	klein	High	Inconsistent	MMKM	TK	99	5	krein
24	24	droog	High	Inconsistent	MMKM	BK	19	5	stoog
25	25	vrouw	High	Inconsistent	MMKM	TK	44	5	krouw
26	26	vlug	High	Inconsistent	MMKM	BK	63	4	drot
27	27	best	High	Inconsistent	MKMM	BK	90	4	kest
28	28	rond	High	Inconsistent	MKMM	BK	76	4	gond
29	29	zich	High	Inconsistent	MKMM	BK	422	4	pich
30	30	toch	High	Inconsistent	MKMM	BK	352	4	voch
31	33	koers	Low	Consistent	MKMM	TK	3	4	doers
32	34	heks	Low	Consistent	MKMM	BK	2	4	huks
33	35	romp	Low	Consistent	MKMM	BK	2	4	somp
34	36	pink	Low	Consistent	MKMM	BK	2	4	dink
35	37	mals	Low	Consistent	MKMM	BK	2	4	raks
36	38	stoom	Low	Consistent	MMKM	BK	12	5	zwoom
37	39	knul	Low	Consistent	MMKM	BK	2	4	knum
38	40	vloer	Low	Consistent	MMKM	TK	13	5	kloer
39	41	pruik	Low	Consistent	MMKM	TK	2	5	vluik
40	42	spier	Low	Consistent	MMKM	TK	1	5	blier
41	43	reus	Low	Consistent	MKM	TK	2	4	weuf
42	44	kuil	Low	Consistent	MKM	TK	2	4	duil
43	45	zuur	Low	Consistent	MKM	BK	3	4	luun
44	46	lief	Low	Consistent	MKM	TK	11	4	liek
45	47	doos	Low	Consistent	MKM	BK	11	4	poor
46	48	deeg	Low	Inconsistent	MKM	BK	5	4	keeg
47	49	teil	Low	Inconsistent	MKM	TK	5	4	seis
48	50	saus	Low	Inconsistent	MKM	TK	1	4	baus
49	51	zoet	Low	Inconsistent	MKM	TK	1	4	noet
50	52	dijk	Low	Inconsistent	MKM	TK	9	3	hijf
51	53	mouw	Low	Inconsistent	MKM	TK	2	4	sauw
52	54	slijm	Low	Inconsistent	MMKM	TK	7	4	brijm
53	55	dweil	Low	Inconsistent	MMKM	TK	1	5	breil
54	56	kraag	Low	Inconsistent	MMKM	BK	8	5	braag
55	57	pret	Low	Inconsistent	MMKM	BK	2	4	kret
56	58	brug	Low	Inconsistent	MMKM	BK	10	4	prug
57	59	vloot	Low	Inconsistent	MMKM	BK	1	5	ploot
58	60	pech	Low	Inconsistent	MKMM	BK	2	4	bech

	regel	Stimulus	Freq	Consisteny	Word structu...	Vowel	Staphor F...	N Letters	Nonwoord
59	61	tand	Low	Inconsistent	MKMM	BK	5	4	tard
60	62	hemd	Low	Inconsistent	MKMM	BK	4	4	hers

Table A2: items of Experiment 2

	line	Rhime	Orthogr	Target	word 1	Let 1	Fon 1	Fr 1	Fam 1	Word 2	Let 2	Fon 2	Fr 2	Fam 2	Let tot	Fon tot	Fr tot	Fam tot	OS	Input Column
1	1	rhime	similar	au-ou	saus	4	3	1	84	paus	4	3	0	39	8	6	1	123	57	
2	2	rhime	similar	au-ou	blauw	5	4	16	97	flauw	5	4	7	89	10	8	23	186	61	
3	3	rhime	similar	au-ou	zout	4	3	8	98	fout	4	3	9	100	8	6	17	198	57	
4	4	rhime	similar	au-ou	vrouw	5	4	44	96	trouw	5	4	3	50	10	8	47	146	61	
5	5	rhime	dissimilar	au-ou	mouw	4	3	2	80	pauw	4	3	0	75	8	6	2	155	42	
6	6	rhime	dissimilar	au-ou	touw	4	3	22	97	gauw	4	3	72	96	8	6	94	193	42	
7	7	rhime	dissimilar	au-ou	bouw	4	3	4	100	klauw	5	4	0	52	10	7	4	152	39	
8	8	rhime	dissimilar	au-ou	vouw	4	3	0	90	lauw	4	3	1	76	8	6	1	166	42	
9	9	rhime	similar	ch-g	zucht	5	4	14	93	lucht	5	4	110	97	10	8	124	190	61	
10	10	rhime	similar	ch-g	bocht	5	4	10	89	kocht	5	4	3	•	10	8	13	89	61	
11	11	rhime	similar	ch-g	wacht	5	4	33	97	lacht	5	4	15	100	10	8	48	197	61	
12	12	rhime	similar	ch-g	dag	3	3	207	100	zag	3	3	96	•	6	6	303	100	50	
13	13	rhime	similar	ch-g	brug	4	4	10	93	vlug	4	4	63	97	8	8	73	190	42	
14	14	rhime	similar	ch-g	boog	4	3	8	76	hoog	4	3	50	100	8	6	58	176	60	
15	15	rhime	dissimilar	ch-g	zich	4	3	422	77	lig	3	3	3	98	7	6	425	175	7	
16	16	rhime	dissimilar	ch-g	pech	4	3	2	92	weg	3	3	275	97	7	6	277	189	7	
17	17	rhime	dissimilar	ch-g	log	3	3	1	•	toch	4	3	352	82	7	6	353	82	7	
18	18	rhime	dissimilar	ch-g	mug	3	3	0	80	kuch	4	3	0	56	7	6	0	136	7	
19	19	rhime	dissimilar	ch-g	ach	3	2	19	65	mag	3	3	146	•	6	5	165	65	9	
20	20	rhime	dissimilar	ch-g	vecht	5	4	0	100	zegt	4	4	325	97	9	8	325	197	27	
21	21	rhime	similar	d-t	hond	4	4	76	100	mond	4	4	46	100	8	8	122	200	57	
22	22	rhime	similar	d-t	rand	4	4	25	93	zand	4	4	35	100	8	8	60	193	57	
23	23	rhime	similar	d-t	bad	3	3	8	93	had	3	3	462	•	6	6	470	93	50	
24	24	rhime	similar	d-t	hut	3	3	18	93	put	3	3	2	92	6	6	20	185	50	
25	25	rhime	similar	d-t	giet	4	3	3	94	riet	4	3	7	72	8	6	10	166	57	
26	26	rhime	similar	d-t	pet	3	3	5	98	vet	3	3	8	77	6	6	13	175	50	
27	27	rhime	dissimilar	d-t	paard	5	4	41	97	kaart	5	4	15	97	10	8	56	194	35	
28	28	rhime	dissimilar	d-t	rood	4	3	32	100	poot	4	3	4	97	8	6	36	197	29	
29	29	rhime	dissimilar	d-t	blad	4	4	8	100	mat	3	3	4	96	7	7	12	196	7	
30	30	rhime	dissimilar	d-t	stad	4	4	138	94	gat	3	3	12	96	7	7	150	190	19	
31	31	rhime	dissimilar	d-t	goed	4	3	395	96	zoet	4	3	1	92	8	6	396	188	23	
32	32	rhime	dissimilar	d-t	god	3	3	17	78	pot	3	3	16	94	6	6	33	172	9	
33	33	rhime	similar	ij-ei	lijkt	4	4	60	80	kijkt	4	4	92	97	8	8	152	177	61	
34	34	rhime	similar	ij-ei	fijn	3	3	44	97	lijn	3	3	16	84	6	6	60	181	57	
35	35	rhime	similar	ij-ei	blij	3	3	54	100	jij	2	2	224	100	5	5	278	200	44	
36	36	rhime	similar	ij-ei	klei	4	3	7	100	prei	4	3	1	52	8	6	8	152	42	
37	37	rhime	similar	ij-ei	zeil	4	3	6	80	teil	4	3	5	78	8	6	11	158	57	
38	38	rhime	similar	ij-ei	trein	5	4	28	100	plein	5	4	14	86	9	8	42	186	49	
39	39	rhime	dissimilar	ij-ei	wijn	3	3	3	90	klein	5	4	99	100	8	7	102	190	26	
40	40	rhime	dissimilar	ij-ei	pijn	3	3	29	100	sein	4	3	1	43	7	6	30	143	29	
41	41	rhime	dissimilar	ij-ei	bij	2	2	699	98	ei	2	1	29	100	4	3	728	198	9	
42	42	rhime	dissimilar	ij-ei	bijt	3	3	6	96	geit	4	3	19	97	7	6	25	193	29	
43	43	rhime	dissimilar	ij-ei	mijn	3	3	324	•	gein	4	3	0	53	7	6	324	53	29	
44	44	rhime	dissimilar	ij-ei	wijs	3	3	8	55	zeis	4	3	0	25	7	6	8	80	29	
45	45	non-rhime	•	•	saus	4	3	1	84	lucht	5	4	110	97	9	7	111	181	•	
46	46	non-rhime	•	•	blauw	5	4	16	97	prei	4	3	1	52	9	7	17	149	•	
47	47	non-rhime	•	•	zout	4	3	8	98	vlug	4	4	63	97	8	7	71	195	•	
48	48	non-rhime	•	•	vrouw	5	4	44	96	kijkt	4	4	92	97	9	8	136	193	•	
49	49	non-rhime	•	•	mouw	4	3	2	80	jij	2	2	224	100	6	5	226	180	•	
50	50	non-rhime	•	•	touw	4	3	22	97	zand	4	4	35	100	8	7	57	197	•	

	line	Rhime	Orthogr	Target	word 1	Let 1	Fon 1	Fr 1	Fam 1	Word 2	Let 2	Fon 2	Fr 2	Fam 2	Let tot	Fon tot	Fr tot	Fam tot	OS	Input Column
51	51	non-rhime	•	•	bouw	5	3	4	100	mat	3	3	4	96	8	6	8	196	•	
52	52	non-rhime	•	•	vouw	4	3	0	90	mag	3	3	146	•	7	6	146	90	•	
53	53	non-rhime	•	•	zucht	5	4	14	93	gein	4	3	0	53	9	7	14	146	•	
54	54	non-rhime	•	•	bocht	5	4	10	89	geit	4	3	19	97	9	7	29	186	•	
55	55	non-rhime	•	•	wacht	5	4	33	97	paus	4	3	0	39	9	7	33	136	•	
56	56	non-rhime	•	•	dag	3	3	207	100	plein	5	4	14	86	8	7	221	186	•	
57	57	non-rhime	•	•	brug	4	4	10	93	zegt	4	4	325	97	8	8	335	190	•	
58	58	non-rhime	•	•	boog	4	3	8	76	kocht	5	4	3	•	9	7	11	76	•	
59	59	non-rhime	•	•	zich	4	3	422	77	fout	4	3	9	100	8	6	431	177	•	
60	60	non-rhime	•	•	pech	4	3	2	92	lauw	4	3	1	76	8	6	3	168	•	
61	61	non-rhime	•	•	log	3	3	1	•	flauw	5	4	7	89	8	7	8	89	•	
62	62	non-rhime	•	•	mug	3	3	0	80	kaart	5	4	15	97	8	7	15	177	•	
63	63	non-rhime	•	•	ach	3	2	19	65	klein	5	4	99	100	8	6	118	165	•	
64	64	non-rhime	•	•	vecht	5	4	0	100	ei	2	1	29	100	7	5	29	200	•	
65	65	non-rhime	•	•	hond	4	4	76	100	vet	3	3	8	77	7	7	84	177	•	
66	66	non-rhime	•	•	rand	4	4	25	93	put	3	3	2	92	7	7	27	185	•	
67	67	non-rhime	•	•	bad	3	3	8	93	hoog	4	3	50	100	7	6	58	193	•	
68	68	non-rhime	•	•	hut	3	3	18	93	trouw	5	4	3	50	8	7	21	143	•	
69	69	non-rhime	•	•	giet	4	3	3	94	lacht	5	4	15	100	9	7	18	194	•	
70	70	non-rhime	•	•	pet	3	3	5	98	sein	4	3	1	43	7	6	6	141	•	
71	71	non-rhime	•	•	paard	5	4	41	97	teil	4	3	5	78	9	7	46	175	•	
72	72	non-rhime	•	•	rood	4	3	32	100	zeis	4	3	0	25	8	6	32	125	•	
73	73	non-rhime	•	•	blad	4	4	8	100	lig	3	3	3	98	7	7	11	198	•	
74	74	non-rhime	•	•	stad	4	4	138	94	mond	4	4	46	100	8	8	184	194	•	
75	75	non-rhime	•	•	goed	4	3	395	96	lijn	3	3	16	84	7	6	411	180	•	
76	76	non-rhime	•	•	god	3	3	17	78	riet	4	3	7	72	7	6	24	150	•	
77	77	non-rhime	•	•	lijkt	4	4	60	80	klauw	5	4	0	52	9	8	60	132	•	
78	78	non-rhime	•	•	fijn	3	3	44	97	zoet	4	3	1	92	7	6	45	189	•	
79	79	non-rhime	•	•	blij	3	3	54	100	weg	3	3	275	97	6	6	329	197	•	
80	80	non-rhime	•	•	klei	4	3	7	100	gat	3	3	12	96	7	6	19	196	•	
81	81	non-rhime	•	•	zeil	4	3	6	80	pauw	4	3	0	75	8	6	6	155	•	
82	82	non-rhime	•	•	trein	4	4	28	100	pot	3	3	16	94	7	7	44	194	•	
83	83	non-rhime	•	•	wijn	3	3	3	90	gauw	4	3	72	96	7	6	75	186	•	
84	84	non-rhime	•	•	pijn	3	3	29	100	kuch	4	3	0	56	7	6	29	156	•	
85	85	non-rhime	•	•	bij	2	2	699	98	poot	4	3	4	97	6	5	703	195	•	
86	86	non-rhime	•	•	bijt	3	3	6	96	toch	4	3	352	82	7	6	358	178	•	
87	87	non-rhime	•	•	mijn	3	3	324	•	had	3	3	462	•	6	6	786	•	•	
88	88	non-rhime	•	•	wijs	3	3	8	55	zag	3	3	96	•	6	6	104	55	•	

Table A3: Items of Experiment 3

	regel	Lijst	Woo...	Stimulus	Freq	Klank	Structuur	Stap...	N Le...	N Fo...	Vraag	Target	EFFE	Presence	OS	probleem	Input Column
1	123	1	WrD	sport	High	BK	MMKMM	30	5	5	intuin	d	sport	Absent	•	•	
2	3	1	WrD	soort	High	BK	MKMM	71	5	4	intuin	d	soort	Absent	•	•	
3	8	1	WrD	REIS	High	TK	MKM	31	4	3	intuin	ij	REIS	Absent	•	•	
4	122	1	WrD	noord	High	BK	MKMM	23	5	4	intuin	t	noord	Absent	•	•	
5	124	1	WrD	mond	High	BK	MKMM	46	4	4	intuin	t	mond	Absent	•	•	
6	2	1	WrD	hand	High	BK	MKMM	114	4	4	intuin	t	hand	Absent	•	•	
7	9	1	WrD	HUID	High	TK	MKM	36	4	3	twijfel/in	d	HUID	Present	•	•	
8	13	1	WrD	KLEIN	High	TK	MMKM	99	5	4	twijfel/in	ei	KLEIN	Present	•	•	
9	121	1	WrD	sloeg	High	TK	MMKM	18	5	4	twijfel/in	g	sloeg	Present	•	•	
10	120	1	WrD	kijk	High	TK	MKM	89	3	3	twijfel/in	ij	kijk	Present	•	•	
11	10	1	WrD	pijn	High	TK	MKM	29	3	3	twijfel/in	ij	pijn	Present	•	•	
12	121	1	WrD	kant	High	BK	MKMM	51	4	4	twijfel/in	t	kant	Present	•	•	
13	12	1	WrD	VROUW	High	TK	MMKM	44	5	4	geentwijfel	h	VROUW	Absent	•	•	
14	5	1	WrD	woord	High	BK	MKMM	51	5	4	geentwijfel	j	woord	Absent	•	•	
15	157	1	WrD	berg	High	BK	MKMM	37	4	4	geentwijfel	j	berg	Absent	•	•	
16	14	1	WrD	groot	High	BK	MMKM	155	5	4	geentwijfel	k	groot	Absent	•	•	
17	158	1	WrD	blij	High	TK	MMK	54	3	3	geentwijfel	k	blij	Absent	•	•	
18	15	1	WrD	stad	High	BK	MMKM	138	4	4	geentwijfel	l	stad	Absent	•	•	
19	21	1	WrD	trouw	Low	TK	MMKM	2	5	4	intuin	au	trouw	Absent	•	•	
20	28	1	WrD	taart	Low	BK	MKMM	3	5	4	intuin	d	taart	Absent	•	•	
21	127	1	WrD	kuit	Low	TK	MKM	1	4	3	intuin	d	kuit	Absent	•	•	
22	19	1	WrD	wijk	Low	TK	MKM	4	3	3	intuin	ei	wijk	Absent	•	•	
23	26	1	WrD	PECH	Low	BK	MKMM	2	4	3	intuin	g	PECH	Absent	•	•	
24	24	1	WrD	gloed	Low	TK	MMKM	3	5	4	intuin	t	gloed	Absent	•	•	
25	30	1	WrD	TAND	Low	BK	MKMM	5	4	4	twijfel/in	d	TAND	Present	•	•	
26	125	1	WrD	haag	Low	BK	MKM	12	4	3	twijfel/in	g	haag	Present	•	•	
27	18	1	WrD	DEEG	Low	BK	MKM	5	4	3	twijfel/in	g	DEEG	Present	•	•	
28	22	1	WrD	vlag	Low	BK	MMKM	7	4	4	twijfel/in	g	vlag	Present	•	•	
29	126	1	WrD	wijs	Low	TK	MKM	8	3	3	twijfel/in	ij	wijs	Present	•	•	
30	23	1	WrD	zwijn	Low	TK	MMKM	4	4	4	twijfel/in	ij	zwijn	Present	•	•	
31	149	1	WrD	breed	Low	BK	MMKM	7	5	4	geentwijfel	b	breed	Present	•	•	
32	17	1	WrD	boeg	Low	TK	MKM	4	4	3	geentwijfel	b	boeg	Present	•	•	
33	154	1	WrD	bloed	Low	TK	MMKM	13	5	4	geentwijfel	f	bloed	Absent	•	•	
34	144	1	WrD	lijf	Low	TK	MKM	11	3	3	geentwijfel	f	lijf	Present	•	•	
35	155	1	WrD	draad	Low	BK	MMKM	5	5	4	geentwijfel	h	draad	Absent	•	•	
36	156	1	WrD	kwart	Low	BK	MMKMM	4	5	5	geentwijfel	i	kwart	Absent	•	•	
37	146	1	WrD	lijk	Low	TK	MKM	3	3	3	geentwijfel	k	lijk	Present	•	•	
38	148	1	WrD	maart	Low	BK	MKMM	12	5	3	geentwijfel	m	maart	Present	•	•	
39	153	1	WrD	vent	Low	BK	MKMM	2	4	4	geentwijfel	o	vent	Absent	•	•	
40	20	1	WrD	toet	Low	TK	MKM	1	4	3	geentwijfel	oe	toet	Present	•	•	
41	27	1	WrD	poort	Low	BK	MKMM	8	5	4	geentwijfel	p	poort	Present	•	•	
42	152	1	WrD	snuit	Low	TK	MMKM	1	5	4	geentwijfel	p	snuit	Absent	•	•	
43	145	1	WrD	rijp	Low	TK	MKM	7	3	3	geentwijfel	r	rijp	Present	•	•	
44	29	1	WrD	bord	Low	BK	MKMM	13	4	4	geentwijfel	r	bord	Present	•	•	

	regel	Lijst	Woo...	Stimulus	Freq	Klank	Structuur	Stap...	N Le...	N Fo...	Vraag	Target	EFFE	Presence	OS	probleem	Input Column
45	147	1	WrD	prei	Low	TK	MMKM	1	4	4	geentwijfel	r	prei	Present	•	•	
46	151	1	WrD	klant	Low	BK	MMKMM	2	5	5	geentwijfel	s	klant	Absent	•	•	
47	150	1	WrD	ruit	Low	TK	MKM	2	4	3	geentwijfel	ui	ruit	Present	•	•	
48	143	1	WrD	vlieg	Low	TK	MMKM	7	5	4	geentwijfel	v	vlieg	Present	•	•	
49	32	1	PsH	hont	High	BK	MKMM	76	4	4	intuin	d	hont	Absent	.66	•	
50	38	1	PsH	hooch	High	BK	MKMM	50	4	3	intuin	g	hooch	Absent	.63	•	
51	41	1	PsH	vluch	High	BK	MMKMM	63	5	4	intuin	g	vluch	Absent	.61	•	
52	37	1	PsH	fein	High	TK	MKM	44	4	3	intuin	ij	fein	Absent	.59	•	
53	39	1	PsH	jauw	High	TK	MKM	35	4	3	intuin	ou	jauw	Absent	.72	•	
54	34	1	PsH	buurd	High	BK	MKMM	31	5	4	intuin	t	buurd	Absent	.72	•	
55	44	1	PsH	zward	High	BK	MMKMM	19	5	5	twijfel/in	d	zward	Present	.70	•	
56	40	1	PsH	veif	High	TK	MKM	39	4	3	twijfel/in	ei	veif	Present	.59	•	
57	31	1	PsH	tog	High	BK	MKM	352	3	3	twijfel/in	g	tog	Present	.52	•	
58	42	1	PsH	trijn	High	TK	MMKM	28	4	4	twijfel/in	ij	trijn	Present	.68	•	
59	36	1	PsH	gouw	High	TK	MKM	72	4	3	twijfel/in	ou	gouw	Present	.72	•	
60	35	1	PsH	zant	High	BK	MKMM	35	4	4	twijfel/in	t	zant	Present	.66	•	
61	45	1	PsH	plad	High	BK	MMKM	18	4	4	geentwijfel	o	plad	Absent	.72	•	
62	43	1	PsH	krand	High	BK	MMKMM	36	5	4	geentwijfel	s	krand	Absent	.70	•	
63	171	1	PsH	hooft	High	BK	MKMM	111	5	4	geentwijfel	v	hooft	Absent	•	•	
64	33	1	PsH	kint	High	BK	MKMM	37	4	4	geentwijfel	v	kint	Absent	.66	•	
65	56	1	PsH	waart	Low	BK	MKMM	12	5	4	intuin	d	waart	Absent	.72	•	
66	49	1	PsH	sijn	Low	TK	MKM	1	3	3	intuin	ei	sijn	Absent	.59	•	
67	51	1	PsH	traach	Low	BK	MMKMM	4	6	4	intuin	g	traach	Absent	.67	•	
68	47	1	PsH	vaach	Low	BK	MKMM	2	5	3	intuin	g	vaach	Absent	.63	•	
69	128	1	PsH	steif	Low	TK	MMKM	7	4	4	intuin	ij	steif	Absent	•	•	
70	60	1	PsH	lind	Low	BK	MKMM	4	4	4	intuin	t	lind	Absent	.66	•	
71	46	1	PsH	mauw	Low	TK	MKM	2	4	3	twijfel/in	au	mauw	Present	.72	•	
72	130	1	PsH	reim	Low	TK	MKM	1	3	3	twijfel/in	ei	reim	Present	•	•	
73	54	1	PsH	greis	Low	TK	MMKM	6	5	4	twijfel/in	ei	greis	Present	.68	•	
74	53	1	PsH	brijn	Low	TK	MMKM	2	4	4	twijfel/in	ij	brijn	Present	.60	•	
75	129	1	PsH	glat	Low	BK	MMKM	8	4	4	twijfel/in	t	glat	Present	•	•	
76	50	1	PsH	hoet	Low	TK	MKM	9	4	3	twijfel/in	t	hoet	Present	.66	•	
77	167	1	PsH	kreed	Low	BK	MMKM	1	5	4	geentwijfel	a	kreed	Absent	•	•	
78	159	1	PsH	bruch	Low	BK	MMKMM	10	4	4	geentwijfel	b	bruch	Present	•	•	
79	168	1	PsH	plaad	Low	BK	MMKM	4	4	4	geentwijfel	e	plaad	Absent	•	•	
80	58	1	PsH	lifd	Low	BK	MKMM	7	4	4	geentwijfel	f	lifd	Present	.66	•	
81	164	1	PsH	blont	Low	BK	MMKMM	6	5	5	geentwijfel	l	blont	Present	•	•	
82	52	1	PsH	ploech	Low	TK	MMKMM	6	6	4	geentwijfel	l	ploech	Present	.66	•	
83	163	1	PsH	leim	Low	TK	MKM	1	3	3	geentwijfel	m	leim	Present	•	•	
84	170	1	PsH	blat	Low	BK	MMKM	8	4	4	geentwijfel	m	blat	Absent	•	•	
85	59	1	PsH	koort	Low	BK	MKMM	1	5	4	geentwijfel	m	koort	Absent	.72	•	
86	169	1	PsH	vloet	Low	TK	MMKM	6	5	4	geentwijfel	n	vloet	Absent	•	•	
87	166	1	PsH	kraach	Low	BK	MMKMM	8	5	4	geentwijfel	n	kraach	Absent	•	•	
88	48	1	PsH	preis	Low	TK	MMKM	11	5	4	geentwijfel	p	preis	Present	.68	•	

	regel	Lijst	Woo...	Stimulus	Freq	Klank	Structuur	Stap...	N Le...	N Fo...	Vraag	Target	EFFE	Presence	OS	probleem	Input Column
89	174	1	PsH	blint	Low	EK	MMKMM	2	5	5	geentwijfel	p	blint	Absent	•	•	
90	161	1	PsH	peip	Low	TK	MKM	10	3	3	geentwijfel	p	peip	Present	•	•	
91	165	1	PsH	roed	Low	TK	MKM	2	4	3	geentwijfel	r	roed	Present	•	•	
92	160	1	PsH	sous	Low	TK	MKM	1	4	3	geentwijfel	s	sous	Present	•	•	
93	162	1	PsH	tijl	Low	TK	MKM	5	4	3	geentwijfel	t	tijl	Present	•	•	
94	55	1	PsH	bruit	Low	TK	MMKM	1	5	4	geentwijfel	ui	bruit	Present	.70	•	
95	172	1	PsH	prend	Low	EK	MMKMM	2	5	5	geentwijfel	w	prend	Absent	•	•	
96	173	1	PsH	stard	Low	EK	MMKMM	5	5	5	geentwijfel	z	stard	Absent	•	•	
97	74	2	WrD	zwart	High	EK	MMKMM	19	5	5	intuin	d	zwart	Absent	•	•	
98	70	2	WrD	vijf	High	TK	MKM	39	3	3	intuin	ei	vijf	Absent	•	•	
99	61	2	WrD	TOCH	High	EK	MKMM	352	4	3	intuin	g	TOCH	Absent	•	•	
100	72	2	WrD	TREIN	High	TK	MMKM	28	5	4	intuin	ij	TREIN	Absent	•	•	
101	66	2	WrD	GAUW	High	TK	MKM	72	4	3	intuin	ou	GAUW	Absent	•	•	
102	65	2	WrD	zand	High	EK	MKMM	35	4	4	intuin	t	zand	Absent	•	•	
103	62	2	WrD	hond	High	EK	MKMM	76	4	4	twijfel/in	d	hond	Present	•	•	
104	71	2	WrD	vlug	High	EK	MMKM	63	4	4	twijfel/in	g	vlug	Present	•	•	
105	68	2	WrD	hoog	High	EK	MKM	50	4	3	twijfel/in	g	hoog	Present	•	•	
106	67	2	WrD	FIJN	High	TK	MKM	44	3	3	twijfel/in	ij	FIJN	Present	•	•	
107	69	2	WrD	jouw	High	TK	MKM	35	4	3	twijfel/in	ou	jouw	Present	•	•	
108	64	2	WrD	buurt	High	EK	MKMM	31	5	4	twijfel/in	t	buurt	Present	•	•	
109	75	2	WrD	plat	High	EK	MMKM	18	4	4	geentwijfel	o	plat	Absent	•	•	
110	73	2	WrD	krant	High	EK	MMKMM	36	5	4	geentwijfel	s	krant	Absent	•	•	
111	203	2	WrD	hoofd	High	EK	MKMM	111	5	4	geentwijfel	v	hoofd	Absent	•	•	
112	63	2	WrD	kind	High	EK	MKMM	37	4	4	geentwijfel	v	kind	Absent	•	•	
113	76	2	WrD	MOUW	Low	TK	MKM	2	4	3	intuin	au	MOUW	Absent	•	•	
114	142	2	WrD	rijm	Low	TK	MKM	1	3	3	intuin	ei	rijm	Absent	•	•	
115	84	2	WrD	grijs	Low	TK	MMKM	6	4	4	intuin	ei	grijs	Absent	•	•	
116	83	2	WrD	brein	Low	TK	MMKM	2	5	4	intuin	ij	brein	Absent	•	•	
117	80	2	WrD	hoed	Low	TK	MKM	9	4	3	intuin	t	hoed	Absent	•	•	
118	141	2	WrD	glad	Low	EK	MMKM	8	4	4	intuin	t	glad	Absent	•	•	
119	86	2	WrD	waard	Low	EK	MKMM	12	5	4	twijfel/in	d	waard	Present	•	•	
120	79	2	WrD	sein	Low	TK	MKM	1	4	3	twijfel/in	ei	sein	Present	•	•	
121	77	2	WrD	vaag	Low	EK	MKM	2	4	3	twijfel/in	g	vaag	Present	•	•	
122	81	2	WrD	traag	Low	EK	MMKM	4	5	4	twijfel/in	g	traag	Present	•	•	
123	140	2	WrD	stijf	Low	TK	MMKM	7	4	4	twijfel/in	ij	stijf	Present	•	•	
124	90	2	WrD	lint	Low	EK	MKMM	4	4	4	twijfel/in	t	lint	Present	•	•	
125	199	2	WrD	kreet	Low	EK	MMKM	1	5	4	geentwijfel	a	kreet	Absent	•	•	
126	191	2	WrD	brug	Low	EK	MMKM	10	4	4	geentwijfel	b	brug	Present	•	•	
127	200	2	WrD	plaat	Low	EK	MMKM	4	4	4	geentwijfel	e	plaat	Absent	•	•	
128	88	2	WrD	lift	Low	EK	MKMM	7	4	4	geentwijfel	f	lift	Present	•	•	
129	196	2	WrD	blond	Low	EK	MMKMM	6	5	5	geentwijfel	l	blond	Present	•	•	
130	82	2	WrD	ploeg	Low	TK	MMKM	6	5	4	geentwijfel	l	ploeg	Present	•	•	
131	89	2	WrD	koord	Low	EK	MKMM	1	5	4	geentwijfel	m	koord	Absent	•	•	
132	195	2	WrD	lijm	Low	TK	MKM	1	3	3	geentwijfel	m	lijm	Present	•	•	

	regel	Lijst	Woo...	Stimulus	Freq	Klank	Structuur	Stap...	N Le...	N Fo...	Vraag	Target	EFFE	Presence	OS	probleem	Input Column
133	202	2	WrD	blad	Low	BK	MMKM	8	4	4	geentwijfel	m	blad	Absent	•	•	
134	201	2	WrD	vloed	Low	TK	MMKM	6	5	4	geentwijfel	n	vloed	Absent	•	•	
135	198	2	WrD	kraag	Low	BK	MMKM	8	5	4	geentwijfel	n	kraag	Absent	•	•	
136	193	2	WrD	pijp	Low	TK	MKM	10	3	3	geentwijfel	p	pijp	Present	•	•	
137	78	2	WrD	prijs	Low	TK	MMKM	11	4	4	geentwijfel	p	prijs	Present	•	•	
138	206	2	WrD	blind	Low	BK	MMKMM	2	5	5	geentwijfel	p	blind	Absent	•	•	
139	197	2	WrD	roet	Low	TK	MKM	2	4	3	geentwijfel	r	roet	Present	•	•	
140	192	2	WrD	saus	Low	TK	MKM	1	4	3	geentwijfel	s	saus	Present	•	•	
141	194	2	WrD	teil	Low	TK	MKM	5	4	3	geentwijfel	t	teil	Present	•	•	
142	85	2	WrD	bruid	Low	TK	MMKM	1	5	4	geentwijfel	ui	bruid	Present	•	•	
143	204	2	WrD	prent	Low	BK	MMKMM	2	5	5	geentwijfel	w	prent	Absent	•	•	
144	205	2	WrD	start	Low	BK	MMKMM	5	5	5	geentwijfel	z	start	Absent	•	•	
145	99	2	PsH	huit	High	TK	MKM	36	4	3	intuin	d	huit	Absent	.67	•	
146	103	2	PsH	klijn	High	TK	MMKM	99	4	4	intuin	ei	klijn	Absent	.68	•	
147	133	2	PsH	sloech	High	TK	MMKM	18	5	4	intuin	g	sloech	Absent	•	•	
148	131	2	PsH	keik	High	TK	MKM	89	3	3	intuin	ij	keik	Absent	•	•	
149	100	2	PsH	pein	High	TK	MKM	29	4	3	intuin	ij	pein	Absent	.78	•	
150	132	2	PsH	kand	High	BK	MKMM	51	4	4	intuin	t	kand	Absent	•	•	
151	135	2	PsH	spord	High	BK	MMKMM	30	5	5	twijfel/in	d	spord	Present	•	•	
152	93	2	PsH	soord	High	BK	MKMM	71	5	4	twijfel/in	d	soord	Present	.72	•	
153	98	2	PsH	rijs	High	TK	MKM	31	3	3	twijfel/in	ij	rijs	Present	.59	•	
154	134	2	PsH	noort	High	BK	MKMM	23	5	4	twijfel/in	t	noort	Present	•	•	
155	92	2	PsH	hant	High	BK	MKMM	114	4	4	twijfel/in	t	hant	Present	.66	•	
156	136	2	PsH	mont	High	BK	MKMM	46	4	4	twijfel/in	t	mont	Present	•	•	
157	102	2	PsH	vrauw	High	TK	MMKM	44	5	4	geentwijfel	h	vrauw	Absent	.78	•	
158	95	2	PsH	woort	High	BK	MKMM	51	5	5	geentwijfel	j	woort	Absent	.72	•	
159	189	2	PsH	berch	High	BK	MKMMM	37	4	4	geentwijfel	j	berch	Absent	•	•	
160	104	2	PsH	grood	High	BK	MMKM	155	5	4	geentwijfel	k	grood	Absent	.72	•	
161	190	2	PsH	blei	High	TK	MKM	54	3	3	geentwijfel	k	blei	Absent	•	•	
162	105	2	PsH	stat	High	BK	MMKM	138	4	4	geentwijfel	l	stat	Absent	.60	•	
163	120	2	PsH	tant	Low	BK	MKMM	5	4	4	intuin	d	tant	Absent	.66	•	
164	137	2	PsH	haach	Low	BK	MKMM	12	4	3	intuin	g	haach	Absent	•	•	
165	108	2	PsH	deech	Low	BK	MKMM	5	5	3	intuin	g	deech	Absent	.66	•	
166	112	2	PsH	vlach	Low	BK	MMKMM	7	5	4	intuin	g	vlach	Absent	.70	•	
167	138	2	PsH	weis	Low	TK	MKM	8	3	3	intuin	ij	weis	Absent	•	•	
168	113	2	PsH	zwein	Low	TK	MMKM	4	5	4	intuin	ij	zwein	Absent	.68	•	
169	111	2	PsH	trauw	Low	TK	MMKM	2	5	4	twijfel/in	au	trauw	Present	.68	•	
170	118	2	PsH	taard	Low	BK	MKMM	3	5	4	twijfel/in	d	taard	Present	.66	•	
171	139	2	PsH	kuid	Low	TK	MKM	1	4	3	twijfel/in	d	kuid	Present	•	•	
172	109	2	PsH	weik	Low	TK	MKM	4	4	3	twijfel/in	ei	weik	Present	.78	•	
173	116	2	PsH	peg	Low	BK	MKM	2	3	3	twijfel/in	g	peg	Present	.72	•	
174	114	2	PsH	gloet	Low	TK	MMKM	3	5	4	twijfel/in	t	gloet	Present	.52	•	
175	181	2	PsH	breet	Low	BK	MMKM	7	4	4	geentwijfel	b	breet	Present	•	•	
176	107	2	PsH	boech	Low	TK	MKMM	4	5	3	geentwijfel	b	boech	Present	.59	•	

	regel	Lijst	Woo...	Stimulus	Freq	Klank	Structuur	Stap...	N Le...	N Fo...	Vraag	Target	EFFE	Presence	OS	probleem	Input Column
177	186	2	PsH	bloet	Low	TK	MMKM	13	5	4	geentwijfel	f	bloet	Absent	•	•	
178	176	2	PsH	leif	Low	TK	MKM	11	3	3	geentwijfel	f	leif	Present	•	•	
179	187	2	PsH	draat	Low	BK	MMKM	5	5	4	geentwijfel	h	draat	Absent	•	•	
180	188	2	PsH	kward	Low	BK	MMKMM	4	5	5	geentwijfel	i	kward	Absent	•	•	
181	178	2	PsH	leik	Low	TK	MKM	3	3	3	geentwijfel	k	leik	Present	•	•	
182	180	2	PsH	maard	Low	BK	MKMM	12	5	3	geentwijfel	m	maard	Present	•	•	
183	185	2	PsH	vend	Low	BK	MKMM	2	4	4	geentwijfel	o	vend	Absent	•	•	
184	110	2	PsH	toed	Low	TK	MKM	1	4	3	geentwijfel	oe	toed	Present	.61	•	
185	184	2	PsH	snuid	Low	TK	MMKM	1	5	4	geentwijfel	p	snuid	Absent	•	•	
186	117	2	PsH	poord	Low	BK	MKMM	8	5	4	geentwijfel	p	poord	Present	.66	•	
187	119	2	PsH	bort	Low	BK	MKMM	13	4	4	geentwijfel	r	bort	Present	.66	•	
188	179	2	PsH	prij	Low	TK	MMK	1	4	4	geentwijfel	r	prij	Present	•	•	
189	177	2	PsH	reip	Low	TK	MKM	7	3	3	geentwijfel	r	reip	Present	•	•	
190	183	2	PsH	kland	Low	BK	MMKMM	2	5	5	geentwijfel	s	kland	Absent	•	•	
191	182	2	PsH	ruid	Low	TK	MKM	2	4	3	geentwijfel	ui	ruid	Present	•	•	
192	175	2	PsH	vliech	Low	TK	MMKMM	7	5	4	geentwijfel	v	vliech	Present	•	•	

Table B1. Design of 60 items from Experiment 1.

consistent word high-frequency	consistent word low-frequency	inconsistent word high-frequency	inconsistent word low-frequency	consistent nonword	inconsistent nonword
1					
					2
	3				
					4
				5	
			6		
				7	
		8			
					9
				10	
11					
			12		
				13	
		14			
15					
					16
				17	
			18		
				19	
					20
		21			
				22	
	23				
		24			
					25
	26				
			27		
				28	
					29
30					
					31
	32				
				33	
					34
		35			
	36				
					37
38					
				39	
			40		
	41				
					42
43					
			44		
				45	
			46		
47					
					48
				49	
		50			
					51
	52				
					53
				54	
			55		
					56
				57	
		58			
				59	
60					
245	213	210	248	457	457

Table B2. Design of the other 60 items from Experiment 1.

consistent word high-frequency	consistent word low-frequency	inconsistent word high-frequency	inconsistent word low-frequency		consistent nonword		inconsistent nonword
	1						
							2
3							
							4
						5	
		6					
						7	
				8			
							9
						10	
	11						
		12					
						13	
				14			
	15						
							16
						17	
		18					
						19	
							20
				21			
						22	
23							
				24			
							25
26							
			27				
						28	
							29
	30						
							31
32							
						33	
							34
					35		
36							
							37
	38						
						39	
			40				
41							
							42
	43						
			44				
						45	
			46				
	47						
							48
						49	
					50		
							51
52							
							53
						54	
			55				
							56
						57	
					58		
						59	
	60						
213	245		248		210	457	457

Table B3. Design of Experiment 2

Rhyme pairs with similar spelling	Rhyme pairs with dissimilar spelling	Non-Rhyme pairs
1		
		2
	3	
	4	
		5
6		
	7	
		8
		9
10		
		11
		12
13		
		14
		15
	16	
		17
18		
19		
		20
	21	
		22
		23
	24	
		25
		26
27		
	28	
		29
		30
	31	
		32
33		
	34	
		35
	36	
37		
		38
		39
40		
		41
	42	
		43
44		
248	246	497

Table B4. Design of Experiment 3

Word Problem Present	Word Problem Absent	Word Non-problem Present	Word Non-problem Absent	Pseudohomophone Problem Present	Pseudohomophone Problem Absent	Pseudohomophone Non-problem Present	Pseudohomophone Non-problem Absent
			1				
					2		
3							
							4
				5			
		6					
	7						
				8			
		9					
			10				
					11		
						12	
13							
							14
	15						
		16					
					17		
						18	
	19						
						20	
				21			
			22				
							23
				24			
25							
			26				
						27	
28							
							29
		30					
	31						
						32	
					33		
	34						
				35			
							36
		37					
38							
					39		
			40				
41							
							42
	43						
						44	
					45		
			46				
		47					
				48			
148	149	145	145	141	153	147	148

Appendix C: Instructions of Experiment 1, 2, and 3

C1: Instructions of Experiment 1

Je ziet dadelijk steeds woordjes op dit beeldscherm. Die woordjes krijg je één voor één te zien. Sommige woorden ken je, je weet wat die betekenen. Andere woorden ken je niet, die heb je nog nooit gezien of gehoord. Hier zie je twee knoppen, de ja-knop en de nee-knop. Als je een woord ziet en je kent het, druk je zo snel mogelijk op de ja-knop. Zie je een woord dat je niet kent, dan druk je zo snel mogelijk op de nee-knop. Je moet dus snel drukken, maar je moet niet zo snel drukken dat je fouten gaat maken. Je krijgt ook deze koptelefoon op. Hierdoor hoor je steeds een piep en daarna komt er een woord op het scherm. Dus wanneer je een piep hebt gehoord, moet je goed opletten, want dan zie je een woordje. Je krijgt dadelijk eerst drie woordjes om te oefenen. Daarna mag je mij nog vragen stellen als je iets niet snapt.

C2: Instructions of Experiment 2

Je weet vast wel wat rijmwoorden zijn. Rijmwoorden zijn woorden die aan het eind precies hetzelfde klinken, zoals mes-zes. Dadelijk krijg je steeds twee woorden achter elkaar te horen. Soms rijmen de woorden, soms rijmen ze niet. Je moet steeds zeggen of de woorden rijmen of niet. Wanneer je denkt dat de woorden rijmen, druk je zo snel mogelijk op de ja-knop. Wanneer je denkt dat de woorden niet rijmen. Druk je zo snel mogelijk op de nee-knop. Je moet dus snel drukken, maar je moet niet zo snel drukken dat je foutjes gaat maken. Je krijgt dadelijk eerst drie woordjes om te oefenen. Daarna mag je mij nog vragen stellen als je iets niet snapt.

C3: Instructions of Experiment 3

Gisteren moest je een experiment doen waarbij je echte woorden zag en woorden die helemaal niet bestaan. Nu gaan we iets anders doen. Je ziet dadelijk een letter op het beeldscherm. Daar moet je goed naar kijken, want die letter gaat weer weg. Als de letter weg is, komt er een woord op het scherm. Ook hier moet je goed naar kijken, want het woord is maar heel even te zien. Hier heb je weer de twee knoppen. Als de letter die je hebt gezien, in het woord staat dan druk je zo snel mogelijk op de ja-knop. Je moet dus snel drukken, maar je moet niet zo snel drukken dat je foutjes gaat maken. Je krijgt nu ook weer deze koptelefoon op. Hierdoor hoor je steeds een piep en daarna komt er een letter op het scherm. Dus wanneer je een piep hebt gehoord, moet je goed opletten, want dan zie je daarna een letter. Je krijgt dadelijk eerst drie woordjes om te oefenen. Daarna mag je mij nog vragen stellen als je iets niet snapt.

Appendix D: Overview of the statistical analyses of Experiments 1, 2, and 3

Table D1: Statistical results of the words of Experiment 1.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	F(1, 21)	p	F(1, 21)	p	F(1, 21)	p
	Consistency								
RT	F1 (1, 63)	8.6	.005	6.0	.023	4.7	.041	2.4	.14
	F2 (1, 52)	1.3	.26	<1		<1		<1	
FT	F1 (1, 63)	<1		<1		<1		<1	
	F2 (1, 56)	<1		<1		<1		<1	
	Frequency								
RT	F1 (1, 63)	71.9	.000	14.2	.001	33.5	.000	26.9	.000
	F2 (1, 52)	14.7	.000	5.2	.027	14.9	.000	7.7	.008
FT	F1 (1, 63)	152.4	.000	25.9	.000	76.4	.000	80.0	.000
	F2 (1, 56)	10.3	.002	5.9	.018	9.2	.004	11.9	.001
	Group								
RT	F1 (2, 63)	29.4	.000						
	F2 (1, 52)	639.5	.000						
FT	F1 (2, 63)	14.8	.000						
	F2 (1, 56)	26.0	.000						
	List								
RT	F1(1, 63)	<1		5.1	.035	1.7	2.1	<1	
	F2 (1,52)	16.1	.000	54.4	.000	40.4	.000	3.4	0.7
FT	F1 (1, 63)	1.3	.252	<1		<1		1.4	.246
	F2 (1, 56)	2.9	.09	<1		<1		2.1	.15
	Consistency x Frequency								
RT	F1 (1, 63)	2.6	.11	<1		<1		3.1	.095
	F2 (1, 52)	<1		<1		<1		1.3	.259
FT	F1 (1, 63)	3.5	.07	<1		3.3	.08	1.2	.282
	F2 (1, 56)	<1		<1		<1		<1	

	Consistency x Group								
RT	F1 (2, 63)	<1							
	F2 (1, 52)	<1							
FT	F1 (2, 63)	<1							
	F2 (1, 56)	<1							
	Frequency x Group								
RT	F1 (2, 63)	8.3	**.001**						
	F2 (1, 52)	4.9	**.032**						
FT	F1 (2, 63)	4.5	**.014**						
	F2 (1, 56)	3.8	**.057**						
	Consistency x Frequency x Group								
RT	F1 (2, 63)	2.3	.11						
	F2 (1, 52)	1.7	.201						
FT	F1 (2, 63)	<1							
	F2 (1, 56)	<1							
	Consistency x List								
RT	F1 (1, 63)	1.1	.29	<1		3.1	.091	<1	
	F2 (1, 52)	<1		<1		1.2	.28	<1	
FT	F1 (1, 63)	<1		<1		3.8	.06	<1	
	F2 (1, 56)	1.2	.27	<11		3.9	**.05**	1.4	.25
	Frequency x List								
RT	F1 (1, 63)	<1		<1		<1		<1	
	F2 (1, 52)	<1		<1		<1		<1	
FT	F1 (1, 63)	1.8	.19	<1		2.0	.17	<1	
	F2 (1, 56)	2.9	0.94	<1		3.1	.08	<1	
	Group x List								
RT	F1 (2, 63)	<1							
	F2 (1, 52)	19.8	**.000**						
FT	F1 (2, 63)	<1							
	F2 (1, 56)	<1							

Table D2: Statistical results of the words and nonwords of Experiment 1.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1(1, 21)**	**p**	**F1(1, 21)**	**p**	**F1 (1, 21)**	**p**
	Word								
RT	F1 (1, 63)	148.7	**.000**	58.2	**.000**	64.2	**.000**	91.6	**.000**
	F2 (1, 109)	167.8	**.000**	73.2	**.000**	133.1	**.000**	103.1	**.000**
FT	F1 (1, 63)	2.17	.146	13.1	**.002**	32.1	**.000**	2.1	.159
	F2 (1, 56)	<1		5.5	**.020**	3.8	**.053**	2.4	.123
	Consistency								
RT	F1 (1, 63)	<1		2.1	.16	<1		<1	
	F2 (1, 109)	<1		<1		<1		<1	
FT	F1 (1, 63)	2.9	.092	2.0	.215	<1		5.7	**.026**
	F2 (1, 56)	<1		<1		<1		1.3	.251
	Group								
RT	F1 (2, 63)	32.7	**.000**						
	F2 (1, 109)	1945.7	**.000**						
FT	F1 (2, 63)	30.1	**.000**						
	F2 (1, 56)	104.3	**.000**						
	List								
RT	F1(1, 63)	<1		1.0	.322	<1		<1	
	F2 (1,109)	13.8	**.000**	119.8	**.000**	59.2	**.000**	24.0	**.000**
FT	F1 (1, 63)	<1		<1		<1		<1	
	F2 (1, 56)	2.4	.126	<1		<1		1.14	.288
	Word x Consistency								
RT	F1 (1, 63)	13.5	**.000**	2.7	.11	8.6	**.008**	11.4	**.002**
	F2 (1, 109)	1.4	.24	1.1	.303	<1		2.1	.15
FT	F1 (1, 63)	3.6	**.06**	2.4	.217	1.0	.321	2.4	.136
	F2 (1, 56)	<1		<1		<1		<1	

	Word x Group								
RT	F1 (2, 63)	16.6	**.000**						
	F2 (1, 109)	63.1	**.000**						
FT	F1 (2, 63)	7.5	**.001**						
	F2 (1, 56)	14.4	**.000**						
	Consistency x Group								
RT	F1 (2, 63)	<1							
	F2 (1, 109)	<1							
FT	F1 (2, 63)	3.5	**.036**						
	F2 (1, 56)	2.5	.116						
	Word x Consistency x Group								
RT	F1 (2, 63)								
	F2 (1, 109)	1.5	.23						
FT	F1 (2, 63)								
	F2 (1, 56)								
	Word x List								
RT	F1 (1, 63)	<1		<1		1.9	.18	<1	
	F2 (1, 109)	3.7	**.056**	3.6	**.059**	<1		7.0	**.009**
FT	F1 (1, 63)	3.8	**.056**	1.7	.207	3.3	.085	1.3	.274
	F2 (1, 56)	14.0	**.000**	3.3	.073	3.2	.075	8.7	**.004**
	Consistency x List								
RT	F1 (1, 63)	<1		<1		<1		<1	
	F2 (1, 109)	<1		<1		<1		<1	
FT	F1 (1, 63)	<1		<1		<1		<1	
	F2 (1, 56)	<1		<1		<1		<1	
	Group x List								
RT	F1 (2, 63)	<1							
	F2 (1, 109)	62.5	**.000**						
FT	F1 (2, 63)	<1							
	F2 (1, 56)	<1							

Table D3: Statistical results of the rhyme pairs of Experiment 2.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	**F1**(1, 21)	p	**F1**(1, 21)	p	**F1**(1, 21)	p
	Spelling								
RT	F1 (1, 60)	1.0	.308	4.8	**.041**	<1		<1	
	F2 (1, 42)	1.0	.3121	2.7	.14	<1		1.2	.277
FT	F1 (1, 60)	<1		3.0	.096	2.7	.116	<1	
	F2 (1, 42)	<1		<1		2.2	.147	<1	
	Group								
RT	F1 (2, 60)	12.3	**.000**						
	F2 (1, 42)	129.1	**.000**						
FT	F1 (2, 60)	7.8	**.001**						
	F2 (1, 42)	71.7	**.000**						
	List								
RT	F1 (1, 60)	<1		<1		<1		<1	
	F2 (1, 42)	<1		2.3	.14	<1		1.5	.235
FT	F1 (1, 60)	1.5	.227	<1		<1		1.4	.244
	F2 (1, 42)	6.8	**.013**	<1		<1		7.9	**.007**
	Spelling x Group								
RT	F1(2, 60)	<1							
	F2 (1,42)	<1							
FT	F1 (2, 60)	<1							
	F2 (1, 42)	<1							
	Spelling x List								
RT	F1 (1, 60)	<1		<1		1.9	.18	<1	
	F2 (1, 42)	<1		<1		<1		4.0	**.05**
FT	F1 (1, 60)	<1		<1		1.7	.20	1.9	.183
	F2 (1, 42)	<1		<1		1.3	.256	1.3	.269

Table D4: Statistical results of the rhyme pairs and non-rhyme pairs of Experiment 2

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1(1, 20)**	**p**	**F1(1, 20)**	**p**	**F1(1, 20)**	**p**
	Rhyme								
RT	F1 (1, 60)	<1		1.5	.242	1.7	.204	<1	
	F2 (1, 86)	<1		1.4	.248	2.2	.14	<1	
FT	F1 (1, 60)	20.5	**.000**	1.0	.324	10.4	**.004**	13.8	**.001**
	F2 (1, 86)	55.8	**.000**	1.7	.190	7.6	**.007**	70.3	**.000**
	Group								
RT	F1 (2, 60)	10.2	**.000**						
	F2 (1, 86)	235.7	**.000**						
FT	F1 (2, 60)	6.1	**.004**						
	F2 (1, 86)	81.9	**.000**						
	List								
RT	F1 (1, 60)	<1		<1		<1		1.5	.230
	F2 (1, 86)	10.9	**.001**	2.3	.133	<1		25.3	**.000**
FT	F1 (1, 60)	2.1	.15	<1		<1		1.9	.177
	F2 (1, 86)	12.6	**.001**	1.4	.233	<1		13.4	**.000**
	Rhyme x Group								
RT	F1(2, 60)	<1							
	F2 (1,86)	<1							
FT	F1 (2, 60)	8.3	**.001**						
	F2 (1, 86)	47.0	**.000**						
	Rhyme x List								
RT	F1 (1, 60)	2.2	.143	<1		<1		2.4	.137
	F2 (1, 86)	4.5	**.036**	<1		<1		12.5	**.000**
FT	F1 (1, 60)	<1		<1		<1		<1	
	F2 (1, 86)	1.3	.261	<1		<1		2.5	.115

Table D5: Statistical results of the problem items with present target-letters of Experiment 3.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	**F1**(1, 18) **F2**(1, 80)	**p**	**F1**(1, 18) **F2**(1, 80)	**p**	**F1**(1, 18) **F2**(1, 80)	**p**
	Word								
RT	F1 (1, 54)	4.0	**.05**	5.6	**.03**	<1		2.0	.171
	F2 (1, 240)	2.5	.116	1.9	.166	<1		3.5	.064
FT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 240)	<1		1.1	.299	<1		<1	
	Frequency								
RT	F1 (1, 54)	<1		<1		<1		1.2	.280
	F2 (1, 240)	<1		<1		<1		<1	
FT	F1 (1, 54)	1.2	.282	1.5	.233	1.3	.264	2.2	.152
	F2 (1, 240)	1.4	.245	1.9	.171	1.3	.259	2.7	.102
	Group								
RT	F1 (2, 54)	15.4	**.000**						
	F2 (2, 240)	134.2	**.000**						
FT	F1 (2, 54)	4.6	**.015**						
	F2 (2, 240)	7.5	**.001**						
	Version								
RT	F1(1, 54)	1.9	.177	<1		<1		1.3	.266
	F2 (1,240)	19.3	.000	4.0	**.05**	13.6	**.000**	2.6	.113
FT	F1 (1, 54)	<1		2.4	.142	1.3	.275	<1	
	F2 (1, 240)			<1		<1		1.9.	169
	List								
RT	F1 (1, 54)	<1		<1		1.1	.309	2.2	.155
	F2 (1, 240)	10.3	**.001**	4.4	**.039**	14.5	**.000**	5.4	**.022**
FT	F1 (1, 54)	1.0	.318	13.4	**.002**	<1		<1	
	F2 (1, 240)	1.6	.211	5.4	**.023**	<1		<1	

	Word x Frequency								
RT	F1 (1, 54)	6.6	**.013**	7.5	**.013**	<1		5.0	**.037**
	F2 (1, 109)	10.5	**.001**	6.3	**.014**	3.4	.07	2.6	.113
FT	F1 (1, 54)	1.0	.310	<1		<1		<1	
	F2 (1, 56)	1.2	.281	<1		1.4	.240	<1	
	Word x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							
FT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							
	Word x Version								
RT	F1 (2, 54)	<1		<1		2.1	.162	<1	
	F2 (1, 240)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 240)	<1		<1		<1		1.0	.314
	Word x List								
RT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 240)	<1		<1		1.2	.284	<1	
FT	F1 (1, 54)	1.6	.212	<1		<1		1.8	.195
	F2 (1, 240)	1.8	.185	<1		<1		1.9	.169
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							
FT	F1 (2, 54)	2.0	.14						
	F2 (2, 240)	2.2	.112						
	Frequency x Version								
RT	F1 (1, 54)	2.5	.123	<1		<1		1.3	.266
	F2 (1, 240)	1.8	.179	<1		<1		1.4	.246
FT	F1 (1, 54)	<1		<1		2.1	.163	<1	
	F2 (1, 240)	<1		<1		1.8	.189	1.0	.314

	Frequency x List					
RT	F1 (1, 54)	<1		<1	<1	<1
	F2 (1, 240)	<1		<1	<1	<1
FT	F1 (1, 54)	<1		<1	<1	<1
	F2 (1, 240)	<1		<1	<1	<1
	Version x Group					
RT	F1 (2, 54)	<1				
	F2 (2, 240)	3.5	**.031**			
FT	F1 (2, 54)	1.7	.191			
	F2 (2, 240)	2.6	.073			
	List x Group					
RT	F1 (2, 54)	1.2	.305			
	F2 (2, 240)	10.1	**.000**			
FT	F1 (2, 54)	<1				
	F2 (2, 240)	1.4	.259			

Table D6: Statistical results of the problem items with absent target-letters of Experiment 3.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	**F1**(1, 18) **F2**(1, 80)	**p**	**F1**(1, 18) **F2**(1, 80)	**p**	**F1**(1, 18) **F2**(1, 80)	**p**
	Word								
RT	F1 (1, 54)	<1		<1		<1		4.0	.061
	F2 (1, 240)	<1		<1		<1		1.8	.181
FT	F1 (1, 54)	<1		4.8	**.042**	1.6	.218	1.0	.322
	F2 (1, 240)	<1		2.9	.094	1.0	.315	1.2	.272
	Frequency								
RT	F1 (1, 54)	2.0	.165	<1		<1		2.2	.159
	F2 (1, 240)	1.2	.276	<1		<1		<1	
FT	F1 (1, 54)	<1		<1		5.8	**.027**	1.1	.306
	F2 (1, 240)	<1		<1		2.8	.100	1.1	.295
	Group								
RT	F1 (2, 54)	13.3	**.000**						
	F2 (2, 240)	137.2	**.000**						
FT	F1 (2, 54)	5.7	**.006**						
	F2 (2, 240)	9.5	**.000**						
	Version								
RT	F1(1, 54)	<1		<1		<1		<1	
	F2 (1,240)	7.7	**.006**	4.5	**.037**	4.3	**.040**	1.2	.285
FT	F1 (1, 54)	<1		1.6	.222	1.2	.285	5.3	**.033**
	F2 (1, 240)	<1		2.1	.152	1.7	.195	11.0	**.001**
	List								
RT	F1 (1, 54)	1.6	.216	1.8	.197	1.9	.184	2.8	.113
	F2 (1, 240)	13.6	**.000**	16.8	**.000**	22.5	**.000**	14.1	**.000**
FT	F1 (1, 54)	1.7	.199	<1		1.9	.178	<1	
	F2 (1, 240)	2.7	.099	<1		2.8	.100	1.3	.250

	Word x Frequency								
RT	F1 (1, 54)	4.8	**.032**	3.4	.08	2.5	.132	<1	
	F2 (1, 109)	2.5	.116	2.2	.149	1.6	.203	<1	
FT	F1 (1, 54)	<1		2.5	.131	<1		<1	
	F2 (1, 56)	<1		1.6	.210	<1		<1	
	Word x Group								
RT	F1 (2, 54)	1.7	.187						
	F2 (2, 240)	<1							
FT	F1 (2, 54)	2.4	.100						
	F2 (2, 240)	2.1	.128						
	Word x Version								
RT	F1 (2, 54)	2.2	.144	<1		<1		2.3	.144
	F2 (1, 240)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		2.7	.120	<1		<1	
	F2 (1, 240)	<1		1.6	.210	<1		<1	
	Word x List								
RT	F1 (1, 54)	<1		1.1	.312	<1		<1	
	F2 (1, 240)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		1.3	.264	2.0	.171	2.2	.153
	F2 (1, 240)	<1		<1		1.3	.262	2.8	.096
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							
FT	F1 (2, 54)	2.9	.063						
	F2 (2, 240)	2.1	.122						
	Frequency x Version								
RT	F1 (1, 54)	<1		<1		<1		1.0	.322
	F2 (1, 240)	<1		<1		<1		<1	
FT	F1 (1, 54)	2.8	.102	<1		9.6	**.006**	<1	
	F2 (1, 240)	2.0	.158	<1		4.6	**.035**	<1	

	Frequency x List								
RT	F1 (1, 54)	<1		<1		1.1	.302	3.1	.096
	F2 (1, 240)	<1		<1		<1		1.9	.168
FT	F1 (1, 54)	3.9	**.052**	4.1	**.058**	<1		1.3	.263
	F2 (1, 240)	2.9	.085	2.3	.135	<1		1.5	.229
	Version x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							
FT	F1 (2, 54)	5.0	**.010**						
	F2 (2, 240)	8.4	**.000**						
	List x Group								
RT	F1 (2, 54)	2.3	.111						
	F2 (2, 240)	20.7	**.000**						
FT	F1 (2, 54)	<1							
	F2 (2, 240)	<1							

Table D7: Statistical results of the problem items and non-problem items with present target-letters of Experiment 3

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1**(1, 18) **F2**(1, 176)	**p**	**F1**(1, 18) **F2**(1, 176)	**p**	**F1**(1, 18) **F2**(1, 176)	**p**
	Word								
RT	F1 (1, 54)	5.4	**.024**	9.2	**.007**	<1		1.3	.274
	F2 (1, 528)	2.2	.136	4.4	**.037**	<1		<1	
FT	F1 (1, 54)	2.0	.164	<1		<1		4.0	**.06**
	F2 (1, 528)	1.3	.263	<1		<1		3.1	.078
	Problem								
RT	F1 (1, 54)	<1		<1		<1		1.8	.198
	F2 (1, 528)	<1		<1		<1		1.9	.164
FT	F1 (1, 54)	1.6	.213	5.8	**.026**	<1		1.8	.202
	F2 (1, 528)	1.5	.222	3.0	.085	<1		1.9	.174
	Group								
RT	F1 (2, 54)	16.3	**.000**						
	F2 (2, 528)	275.3	**.000**						
FT	F1 (2, 54)	4.8	**.012**						
	F2 (2, 528)	8.0	**.000**						
	Version								
RT	F1(1, 54)	1.8	.183	<1		<1		1.3	.266
	F2 (1,528)	33.9	**.000**	7.6	**.007**	24.3	**.000**	4.9	**.027**
FT	F1 (1, 54)	<1		2.4	.140	3.0	.100	<1	
	F2 (1, 528)	<1		2.7	.102	3.6	**.060**	1.7	.198
	List								
RT	F1 (1, 54)	1.3	.264	<1		1.5	.231	1.8	.200
	F2 (1, 528)	25.2	**.000**	10.5	**.001**	43.7	**.000**	9.9	**.002**
FT	F1 (1, 54)	2.5	.117	2.2	.151	1.9	.190	<1	
	F2 (1, 528)	4.1	**.042**	2.7	.102	2.3	.131	<1	

	Word x Problem								
RT	F1 (1, 54)	<1		<1		<1		1.1	.306
	F2 (1, 528)	<1		<1		<1		2.5	.116
FT	F1 (1, 54)	<1		1.3	.267	1.7	.207	1.1	.306
	F2 (1, 528)	<1		1.9	.174	1.3	.257	<1	
	Word x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 528)	<1							
FT	F1 (2, 54)	1.7	.196						
	F2 (2, 528)	<1							
	Word x Version								
RT	F1 (2, 54)	<1		1.5	.232	<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		1.9	.186	<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
	Word x List								
RT	F1 (1, 54)	<1		<1		1.1	.314	<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	5.4	**.023**	1.7	.208	1.5	.241	2.4	.139
	F2 (1, 528)	3.3	.070	<1		<1		1.9	.174
	Problem x Group								
RT	F1 (2, 54)	1.2	.321						
	F2 (2, 528)	1.4	.239						
FT	F1 (2, 54)	1.2	.301						
	F2 (2, 528)	1.3	.264						
	Problem x Version								
RT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		1.8	.186	<1	
FT	F1 (1, 54)	1.4	.245	<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	

	Problem x List								
RT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		2.8	.107	<1		1.3	.265
	F2 (1, 528)	<1		1.6	.215	<1		1.4	.239
	Version x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 528)	4.3	**.014**						
FT	F1 (2, 54)	2.6	.083						
	F2 (2, 528)	4.1	**.017**						
	List x Group								
RT	F1 (2, 54)	1.5	.234						
	F2 (2, 528)	25.4	**.000**						
FT	F1 (2, 54)	<1							
	F2 (2, 528)	<1							

Table D8: Statistical results of the problem items and non-problem items with absent target-letters of Experiment 3

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1**(1, 18) **F2**(1, 176)	**p**	**F1**(1, 18) **F2**(1, 176)	**p**	**F1**(1, 18) **F2**(1, 176)	**p**
	Word								
RT	F1 (1, 54)	1.7	.197	<1		<1		2.7	.117
	F2 (1, 528)	1.5	.226	<1		<1		1.7	.198
FT	F1 (1, 54)	<1		7.0	**.016**	1.5	.234	1.2	.292
	F2 (1, 528)	<1		4.4	**.037**	1.6	.213	1.2	.285
	Problem								
RT	F1 (1, 54)	5.8	**.02**	3.8	.068	13.4	**.002**	<1	
	F2 (1, 528)	7.5	**.006**	3.8	.052	8.2	**.005**	<1	
FT	F1 (1, 54)	6.8	**.012**	5.4	**.032**	1.4	.259	1.9	.180
	F2 (1, 528)	7.9	**.005**	5.6	**.020**	2.3	.130	1.7	.205
	Group								
RT	F1 (2, 54)	13.1	**.000**						
	F2 (2, 528)	211.1	**.000**						
FT	F1 (2, 54)	10.8	**.000**						
	F2 (2, 528)	24.4	**.000**						
	Version								
RT	F1(1, 54)	1.4	.235	<1		<1		<1	
	F2 (1,528)	20.7	**.000**	15.7	**.000**	14.6	**.000**	<1	
FT	F1 (1, 54)	1.4	.241	<1		<1		5.5	**.031**
	F2 (1, 528)	3.2	.074	<1		1.5	.230	17.8	**.000**
	List								
RT	F1 (1, 54)	1.4	.247	2.2	.152	1.8	.198	2.8	.111
	F2 (1, 528)	17.2	**.000**	40.4	**.000**	33.6	**.000**	19.9	**.000**
FT	F1 (1, 54)	<1		<1		1.8	.199	<1	
	F2 (1, 528)	1.9	.173	<1		3.1	.082	<1	

	Word x Problem								
RT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
	Word x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 528)	<1							
FT	F1 (2, 54)	2.7	.079						
	F2 (2, 528)	2.5	.085						
	Word x Version								
RT	F1 (2, 54)	<1		<1		1.1	.315	<1	
	F2 (1, 528)	<1		<1		1.3	.259	<1	
FT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
	Word x List								
RT	F1 (1, 54)	<1		<1		<1		<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		<1		1.7	.204	2.6	.127
	F2 (1, 528)	<1		<1		1.8	.182	2.8	.097
	Problem x Group								
RT	F1 (2, 54)	2.5	.096						
	F2 (2, 528)	2.7	.07						
FT	F1 (2, 54)	<1							
	F2 (2, 528)	<1							
	Problem x Version								
RT	F1 (1, 54)	<1		<1		2.2	.151	<1	
	F2 (1, 528)	<1		<1		1.0	.309	<1	
FT	F1 (1, 54)	<1		2.6	.122	<1		<1	
	F2 (1, 528)	<1		2.7	.101	<1		<1	

	Problem x List								
RT	F1 (1, 54)	<1		<1		1.2	.291	<1	
	F2 (1, 528)	<1		<1		<1		<1	
FT	F1 (1, 54)	1.2	.274	<1		<1		<1	
	F2 (1, 528)	1.4	.234	<1		<1		<1	
	Version x Group								
RT	F1 (2, 54)	<1							
	F2 (2, 528)	3.5	**.032**						
FT	F1 (2, 54)	4.9	**.011**						
	F2 (2, 528)	11.3	**.000**						
	List x Group								
RT	F1 (2, 54)	2.4	.097						
	F2 (2, 528)	35.4	**.000**						
FT	F1 (2, 54)	<1							
	F2 (2, 528)	1.5	.227						

Table D9: Statistical results of the factor frequency over the words with present target-letters.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)	
	Frequency								
RT	F1 (1, 54)	4.8	**.032**	2.6	.0123	<1		5.5	**.03**
	F2 (1, 120)	5.6	**.019**	2.4	.126	<1		3.0	.089
FT	F1 (1, 54)	2.6	.110	<1		<1		2.35	.142
	F2 (1, 120)	2.2	.139	<1		1.5	.237	1.5	.237
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2(2,120)	<1							
FT	F1(2, 54)	1.9	.163						
	F2(2, 120)	1.5	.221						

Table D10: Statistical results of the factor frequency over the words with absent target-letters.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	**p**	**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1,40)	
	Frequency								
RT	F1 (1, 54)	4.4	**.040**	3.6	.072	1.3	.262	1.4	.255
	F2 (1, 120)	3.3	.071	1.9	.170	1.6	.206	<1	
FT	F1 (1, 54)	<1		<1		1.9	.18	1.2	.281
	F2 (1, 120)	<1		<1		1.1	.296	1.7	.198
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2(1, 120)	<1							
FT	F1(2, 54)	1.9	.151						
	F2 (2, 120)	2.1	.126						

Table D11: Statistical results of the factor frequency over the pseudohomophones with present target-letters.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)	
	Frequency								
RT	F1 (1, 54)	3.7	**.059**	6.6	**.019**	<1		<1	
	F2 (1, 120)	4.9	**.030**	4.1	**.050**	2.3	.133	<1	
FT	F1 (1, 54)	<1		1.1	.306	<1		1.0	.329
	F2 (1, 120)	<1		1.4	.245	1.3	.254	1.4	.254
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2(1, 120)	<1							
FT	F1(2, 54)	<1							
	F2 (2, 120)	1.0	.355						

Table D12: Statistical results of the factor frequency over the pseudohomophones with absent target-letters.

	Factor(s)	Overall		Age-match group		Reading-match group		Dyslexic group	
		F	p	**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)		**F1**(1, 18) **p** **F2**(1, 40)	
	Frequency								
RT	F1 (1, 54)	<1		1.3	.276	<1		<1	
	F2 (1, 120)	<1		<1		<1		<1	
FT	F1 (1, 54)	<1		1.7	.206	2.9	.102	<1	
	F2 (1, 120)	<1		<1		1.7	.206	<1	
	Frequency x Group								
RT	F1 (2, 54)	<1							
	F2(1, 120)	<1							
FT	F1(2, 54)	2.0	**.042**						
	F2 (2, 120)	1.2	.292						