The phonological representations hypothesis of dyslexia: consequences for the formation of associations
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CHAPTER 1

General Introduction
1. General Introduction

Reading acquisition

It is commonly accepted that fluent identification of words is the result of a long and complex process. Beginning readers identify words by sequentially recoding each letter into the corresponding sound and then blending these sounds together to form the word (Share, 1995). Compared to skilled readers, the manner in which beginning readers identify words is error prone, effortful, and slow.

Necessary prerequisites for the development of accurate decoding ability are phonological awareness and letter knowledge (Byrne, 1998). Letter knowledge refers to the ability to recognize the various letters (i.e., graphemes) and to the understanding that each letter represents a sound (i.e., phoneme). Phonological awareness is the awareness that spoken words can be analyzed into smaller sound units such as syllables, onsets and rimes, and phonemes (Perfetti, 1985). The recognition of the constituent sounds in a word is a difficult process as the phonemes in words are usually co-articulated. As a result, there are no clear boundaries between the sounds of the individual phonemes in a spoken word. Moreover, because of co-articulation, the sound of a particular phoneme is not constant throughout different words, but is affected by the surrounding phonemes in a word.

The ability to recognize sounds in the spoken word form and the ability to recognize letters in the written word form enable the beginning reader to learn the systematic grapheme-to-phoneme correspondences between the written and spoken form of words. Both letter knowledge and phonological awareness have been found to develop concurrently and are promoted through reading itself (e.g., Morais, Alegria, & Content, 1987). They are critical for the development of detailed orthographic representations, which, in turn, are necessary for rapid visual word recognition.

Reading by phonological recoding is especially supportive in languages with fairly consistent grapheme-to-phoneme mappings such as Dutch, German, or Spanish. The English orthography, however, is very inconsistent, especially with respect to the pronunciation of the vowel (Treiman, Mullennix, Bijeljac-Babic, & Richmond-Welty, 1995). For example, in Dutch the vowel a in the words hand (hand), ball (bal), and cat (kat) has a similar sound, whereas in English the vowel sound is different in each word (Landerl, Wimmer, & Frith, 1997). Therefore, in addition to phonological recoding, English beginning readers also tend to use strategies that exploit analogies to existing words to identify a new word (e.g., Goswami, 1993, 2002).

Phonological recoding ability provides the beginning reader with a self-teaching mechanism for the identification of new words (Share, 1995). In normal readers, after only a few successful encounters with a novel word, phonological recoding becomes less dominant.
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because sufficient orthographic knowledge about that specific word has been acquired. In other words, a long-term representation between its written and spoken form is established (Ehri, 1992; also see Rack, Hulme, Snowling, & Wightman, 1994) that enables the reader to recognize the word more or less directly on the basis of its orthographic appearance (Perfetti, 1992; Reitsma, 1990). It remains unclear if these long-term representations contain word-specific or more general orthographic knowledge.

Ehri (1992, 1995, 1998) argued that the nature of the associations between the written and the spoken form of words differs considerably over time. Prereaders remember how to read words by forming connections between selected visual characteristics of words and their pronunciations or meanings and storing these associations in memory (Ehri & Saltmarsh, 1995; Ehri & Wilce, 1985). These visual characteristics are cues accompanying the printed word and do not involve letter-sound relations as the children are not yet aware of the systematic relations between letters and sounds. Accordingly, this phase is called the pre-alphabetic phase. Once children acquire some knowledge about the alphabetic writing system, the formation of associations involves connections between the letters in written words and the sounds in their pronunciations. At first, connections are made among some of the letters in written words and sounds detected in their pronunciations. This phase is called the partial alphabetic or phonetic cue reading phase. Subsequently, in the full alphabetic phase readers acquire full knowledge of the alphabetic system. The reader is able to form fine-grained associations between the graphemes in written and the phonemes in spoken words (Ehri, 1998). In this process spellings become amalgamated to pronunciations of words in memory (Ehri, 1992, 1998). In the final consolidated alphabetic phase readers learn to make functional use of general orthographic knowledge in the form of sensitivity to the regularities and redundancies in spellings, for example, the recognition of ‘at’ in cat, fat, and rat and ‘ing’ in walking and running (Vellutino, Fletcher Snowling, & Scanlon, 2004). Additionally, spelling and pronunciation become firmly connected with meaning.

Children with reading difficulties: The Phonological Representations Hypothesis

There are many children that have difficulty with the acquisition of reading. The majority of these children do not acquire enough orthographic knowledge to be able to recognize words quickly. They continually need to address a lot of attention to the decoding of words.

Research has shown that children with reading difficulties are impaired on a wide range of phonological processing abilities such as phonological awareness (Goswami & Bryant, 1990; Wagner & Torgesen, 1987), verbal short-term memory (Brady, 1991; de Jong, 1998; Jorm, 1983; McDougall, Hulme, Ellis, & Monk, 1994; Stone & Brady, 1995), the rapid retrieval of the names of familiar symbols such as objects, digits, letters, and colors (see for a review Wolf & Bowers, 1999). A phonological deficit is generally seen as the cause of these problems in phonological processing and is also considered to be the primary cause of dyslexia. The phonological deficit explanation of dyslexia states that a specific deficit in
phonological processing impedes the development of the spelling-to-sound (e.g., grapheme-to-phoneme) translation. In turn, this failure to master spelling-to-sound correspondences is considered a primary source of dyslexic children's word recognition problems (Snowling, 1980; Stanovich & Siegel, 1994; Wagner & Torgesen, 1987).

More recently, the phonological deficit has been characterized as a deficit in the quality of the phonological representations of words in the mental lexicon of dyslexic children. The Phonological Representations Hypothesis states that: “dyslexic children have poorly specified phonological representations” (Snowling, 2000). Several researchers have argued that words in each individual's mental lexicon are restructured in segmental organization (Fowler, 1991; Walley, 1993). In their lexical restructuring hypothesis, Metsala and Walley (1998) state that children's initial holistic phonological representations become increasingly more segmentalized during the preschool and early school years, and eventually will be restructured to phoneme level representations (also see Studdert-Kennedy, 1987). Also, Fowler (1991) proposed that dyslexic children's phonological representations lack full segmental organization into a sequence of discrete phonemic elements. Vocabulary growth is assumed to be the driving force behind lexical restructuring, because the increase in words to be stored in long-term memory requires a more efficient storage system. According to the lexical restructuring theory, the need for segmentalized representations is most acute for words in dense neighborhoods. Such words are harder to differentiate from other lexical candidates.

Elbro (1996) has adopted the slightly different view that dyslexic children's phonological representations are less distinct from one another (1996, 1998). He argued that the quality of phonological representations varies according to their distinctness, that is, 'the magnitude of the difference between a lexical representation and its neighbors' (p. 454).

As a consequence of the assumed lower quality phonological representations of words in the mental lexicon of dyslexic children, operations on words that have lower quality phonological representations may be hampered as compared to the performance of normal reading children. Dyslexic children are known to perform poorly on phonological awareness tasks that use nonword stimuli (Wagner & Torgesen, 1987). As these nonwords do not have a phonological representation in long-term memory, dyslexic children are assumed to set up underspecified representations for novel stimuli. Accordingly, these instable representations are harder to process in phonological awareness tasks.

However, phonological awareness tasks using familiar words have also been found to pose a problem for dyslexic children (Swan & Goswami, 1997a). If not all phonological features of these words are represented adequately, deleting a specific phoneme, for example, is difficult. Accordingly, lower performance on these phonological awareness tasks is assumed to reflect inaccuracies in the phonological representations of the words that dyslexic children are asked to analyze.

Also, the shorter memory spans for verbal items observed in dyslexic children can be explained by a deficiency in the phonological representations of words. Hulme, Maughan, and Brown (1991) argued that long-term phonological representations support the retrieval of partially decayed words held in a phonological store. If these long-term representations are
qualitatively inferior, this process will be disadvantaged. For reading, underspecified phonological representations might impair the temporary storage of the sequence of sounds, obtained through phonological recoding, before the full sequence can be blended into a word (de Jong, in press).

Furthermore, dyslexic children's subtle and pervasive, lexical retrieval difficulties of familiar symbols such as objects, digits, letters, and colors might also be due to, at least in part, their inferior phonological representations (see for a review Wolf & Bowers, 1999; Swan & Goswami, 1997b; Fowler & Swainson, 2004). When phonological representations are inaccurate or more difficult to distinguish from neighboring representations, this may result in slower retrieval of the correct pronunciations or in recurring pronunciation errors.

Finally, the impaired speech perception of dyslexic readers needs to be mentioned. Research in this area has shown that dyslexic children have difficulty with the identification and discrimination of stimuli on a phonetic continuum (i.e., categorical perception). Compared to normal reading children, dyslexic children have less well-defined phoneme boundaries, that is, they have more difficulty distinguishing two phonemes that sound alike, for example, /d/ and /b/ (Manis, McBride-Chang, Seidenberg, Keating, Doi, Munson, & Petersen, 1997; McBride-Chang, 1995; Mody, Studdert-Kennedy, & Brady, 1997). In contrast to the previously discussed phonological processing abilities, the speech perception findings could be seen as a cause of the formation of qualitatively underspecified phonological representations in dyslexic children rather than as manifestations of these underspecified phonological representations.

Of the above-mentioned phonological processing problems, impairments in phonological awareness, that is the sensitivity for the sound units in spoken words, are the most prominent. As stated earlier, a large body of evidence supports a relationship between phonological awareness and learning to read. Especially an awareness of phonemes is considered as a prerequisite for the discovery of the alphabetic principle (Byrne, 1998), and for the formation of fine-grained associations between the graphemes in written and the phonemes in spoken words (e.g., Ehri, 1998). Thus, a deficiency in the quality of phonological representations affects reading indirectly via problems in a range of phonological processing abilities, which, in turn, are assumed to affect reading acquisition.

The Phonological Representations Hypothesis and the formation of associations

Although dyslexic children’s impairments in phonological awareness are the most prominent predictor of reading difficulties, a growing number of studies tend to suggest that dyslexic children’s reading problems might depend on other phonological processing impairments (Mayringer & Wimmer, 2000; see also Landerl, Wimmer, & Frith, 1997; Vellutino et. al., 2004). In the more transparent orthographies, such as Greek, German or Dutch, phonological awareness problems have been found to be less pervasive than in English with its opaque orthography (de Jong & van der Leij, 2003; Landerl & Wimmer, 2000;
Wimmer, 1996). As a result, in transparent orthographies even dyslexic children learn to read accurately. Nevertheless, their reading speed remains very slow (van der Leij & van Daal, 1999).

Reading speed is, in part, dependent on the proportion of words read by sight (de Jong, 2000; Torgesen, 2001). For sight words, the view of the written form immediately activates its pronunciation and meaning in memory, because detailed connections between the spoken and the written form of the word have been developed (Ehri, 1998). The ease with which printed words are recognized and pronounced is dependent on the quality and number of connections between the spelling and the pronunciation (Booth, Perfetti & MacWhinney, 1999; Ehri, 1992). Accordingly, the question becomes whether impoverished phonological representations might affect the formation and storage of connections between spoken and written forms of words, that is, the acquisition of orthographic knowledge.

There is ample evidence that dyslexic children have problems with the formation of associations. Many studies investigating visual-verbal paired associate learning have found that especially associating new, phonologically unfamiliar words with pictures was more difficult for dyslexic children than for children without reading problems (Aguiar & Brady, 1991; Vellutino & Scanlon, 1989; Vellutino et al., 1995). In some studies, however, dyslexic children were also found to have more difficulty learning to associate familiar words with pictures (Vellutino, Bentley, & Phillips, 1978; Vellutino, Scanlon, & Bentley, 1983). Nonetheless, the evidence here remains equivocal (compare Vellutino & Scanlon, 1989; Vellutino et al. 1995). Visual-visual (e.g., nonverbal) paired associate learning is not impaired in dyslexic children (Liberman, Mann, Shankweiler, & Werfman, 1982; Nelson & Warrington, 1980; Rapala & Brady, 1990; Vellutino, Steger, & Prouzek, 1973).

The paired associate learning problems of dyslexic children seem to be confined to the verbal domain, which suggests that they are part of the phonological processing impairments characteristic for dyslexia. Hence, both paired associate learning difficulties and phonological awareness problems of dyslexic children could be seen as manifestations of a deficiency of the quality of the phonological representations (see also Snowling, 2000).

However, unlike phonological awareness, paired associate learning might reflect a direct consequence of underspecified phonological representations for the formation of associations between the written and spoken forms of words.

Research questions and outline of this thesis

The Phonological Representations Hypothesis can be seen as an explanation for the well-documented phonological processing difficulties shown by dyslexic children. Though a major part of the research done in the last decade has focused on the quality of phonological representations as an underlying deficit of reading related difficulties in dyslexia, little research has been done on the consequences of these assumed underspecified phonological representations, for example, for the formation of visual-verbal associations as required in
vocabulary and reading acquisition. The research presented in this thesis tried to explore these consequences. We first addressed the question whether dyslexic children have problems with the formation of visual-verbal associations. In addition, we investigated if these problems are manifestations of the phonological deficit characteristic for dyslexia. Second, we investigated whether dyslexic children have problems with the formation of associations between the spoken and written forms of words, that is, when learning to read.

In the study described in Chapter 2 we investigated the paired associate learning performance of dyslexic and age-matched and younger normal reading children. Both word and nonword learning were addressed to examine whether dyslexic children had problems with the formation of associations between pictures and unfamiliar words as well as between pictures and familiar words. We further examined if the problems with the formation of associations could be considered as manifestations of a phonological deficit.

The study reported in Chapter 3 was, in part, a replication of the study reported in Chapter 2. The paired associate learning performance of dyslexic children was compared to the performance of age-matched and younger normal readers. In addition to verbal learning, however, we also addressed nonverbal learning to investigate whether dyslexic children’s paired associate learning problems were confined to the verbal learning domain or extended to nonverbal learning as well. Additionally, the relationship between phonological awareness problems and verbal paired associate learning problems was examined. Finally, we also considered the long-term retention of the learned associations to examine whether underspecified phonological representations primarily affect the establishment of associations or also their long-term retention.

In Chapter 4 a series of three experiments is reported that aimed to test the phonological representations hypothesis in the context of visual-verbal learning. Phonological representations of words in the mental lexicons of dyslexic children are assumed to be less well specified. The implication of this hypothesis is that underspecified phonological representations are more similar than fully specified phonological representations. Accordingly, it follows that for dyslexic children, having underspecified representations, words from the same neighborhood (i.e., words that differ on one phoneme) are relatively more similar than for normal readers. From this assumption, it was hypothesized that for dyslexic children the visual-verbal paired associate learning of a set of words with many neighbors would be more difficult than the learning of a set of words that are phonologically distinct as compared to normal reading peers. For example, in the indistinct context, children had to associate knip, knik, klip, and klik with four pictures. In the distinct context, knip, staaf, brom, and sloot had to be associated with pictures.

Furthermore, the effect of visual distinctness on paired associate learning performance of dyslexic and age-matched normal readers was examined as well. One of the reasons was that in transparent orthographies phonologically similar words are also orthographically similar, which makes it very difficult to examine the separate effects of visual and phonological effects on reading performance. In paired associate learning, however, the effects of phonological and visual distinctness can be dissociated. Analogue to the manipulation of the
distinct and indistinct word sets, sets of distinct and indistinct black and white pictures were constructed. From the phonological representations hypothesis it follows that dyslexic and normal readers should be equally affected by the visual distinctness of pictures.

In *Chapter 5*, a study is reported in which the effects of phonological and visual distinctness in reading were examined. The main aim of this study was to investigate the consequences of impaired phonological representations for the acquisition of orthographic knowledge. From the assumption that dyslexic children have underspecified phonological representations of words, we hypothesized that learning to read words in a context of orthographically and phonologically similar words might pose specific problems as compared to learning to read words in an orthographically and phonologically distinct context. Dyslexic children and groups of reading and age-matched normal readers repeatedly read lists of nonwords presented in a distinct (*kwog* with *kwes, snar, and skal*) or an indistinct context (*kwog* with *kwos, knos, and knog*). Both reading speed and accuracy were registered.

Finally, in the concluding *Chapter 6* the main results of the presented studies in this thesis are reviewed. Links and inconsistencies across the studies are subsequently discussed leading to an overall conclusion.