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Psycholinguistic treatment of dyslexia:

Evaluation of the LEXY-treatment

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Psycholinguistic treatment of dyslexia: Evaluation of the LEXY-treatment

ACADEMISCH PROEFSCHRIFT

ter verkrijging van de graad van doctor
aan de Universiteit van Amsterdam
op gezag van de Rector Magnificus
prof. mr. P. F. van der Heijden
ten overstaan van een door het college voor promoties ingestelde
commissie, in het openbaar te verdedigen in de Aula der Universiteit
op donderdag 24 februari 2005, te 10:00 uur

door Jurgen Tijms
geboren te Haarlem

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prof. dr. H. L. J. van der Maas
prof. dr. J. Rispens

Faculteit Maatschappij- en Gedragswetenschappen

Contents

Chapter 1

General introduction

"When he was reading, his eyes ran over the page and his heart perceived the sense, but his voice and tongue were silent." .. "the need to preserve his voice, which used easily become hoarse, could have been a very fair reason for silent reading."

> St. Augustine (Confessiones, book 6.3.3 [trans. H. Chadwick]) witnessing a for his time unique occurrence of reading without overt articulation by the archbishop of Milan, St. Ambrose.

Dyslexia, which includes difficulties in the acquisition of reading and spelling as core symptoms, is the most common of the learning disabilities (Shaywitz, 1998). Most estimates of prevalence rates range from 3 to 10% of the general population (Baker et al., 1996; Warnke, 1999). Recently, a study on prevalence of dyslexia in The Netherlands has been conducted (Blomert, 2002). Using a sample of 46300 children in the last grade of elementary school, prevalence of dyslexia was estimated to be 3.6%. This estimation amounts to a total of 36.000 dyslexic children in elementary education.

Despite being often labeled as a childhood disorder, the disorder not only affects children but persists into adulthood (Bast, 1995; Beitchman & Young, 1997; Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997; Jacobson, 1999). Most studies have shown a sex difference in prevalence of dyslexia. Even when a male bias (boys are easier noticed due to more externalizing behavior) is taken into consideration, a slight preponderance of males (1.5 male : female) is observed (Galaburda, 1999a; Pennington, 1999). In modern literate societies, dyslexia can have serious implications for both individual and society. Dyslexia is found to be associated, among other things, with the attendance of special schools, lower achieved academic levels, increased vulnerability to unemployment, and lower self-esteem (Beitchman & Young, 1997; Pennington, 1991; Van der Leij, 1991; Warnke, 1999). With the rise of the information society, the burden of dyslexia on both individual and society will be increasingly high. Thus, a focus on adequate treatment for dyslexia seems crucial. The present study aimed to contribute to this by providing a comprehensive evaluation of the efficacy of a psycholinguistic treatment method for dyslexia, called LEXY.

In the present study, dyslexia is defined in accordance with the definition of the International Dyslexia Association (IDA), which states:

> "Dyslexia is one of several distinct learning disabilities. It is a specific language-based disorder of constitutional origin characterized by difficulties in single word decoding, usually reflecting insufficient phonological processing. These difficulties in single word decoding are often unexpected in relation to age and other cognitive and academic abilities; they are not the result of generalized developmental disability

> or sensory impairment. Dyslexia is manifest by variable difficulty with different forms of language, often including, in addition to problems with reading, a conspicuous problem with acquiring proficiency in writing and spelling" (Lyon, 1995a, p. 9).

The definition of the IDA relates the reading and spelling disabilities to a causal factor, i.e., insufficient phonological processing, which reflects ample research evidence (to be discussed later in this chapter).

In order to present a sound context for interpreting dyslexia and its treatment, a reversed engineering approach (cf. Pinker, 1997) is applied in this introductory chapter; the concept 'dyslexia' is first broken down into its base and than carefully built up again. Starting at the most superficial level, the term 'dyslexia' is encountered, which is constructed out of the Greek *dys*, meaning difficulty and *lexis*, from *legein*, meaning to read (but also to speak). Reading, in its turn, is a function of writing systems. This written form of language, as illustrated eloquently by St. August, is generally assumed to be a direct consequence of speech. Thus, a proper start appears to be a description of the processing of spoken language, especially of the part that is devoted to the processing of speech sounds.

Spoken Language

Spoken language is generally considered to be the product of biological evolution; it is a species-specific human trait with a specific module in the brain dedicated to it, sometimes referred to as the language faculty (Jackendoff, 2002; Nowak & Komarova, 2001; Pinker, 2003; Pinker & Bloom, 1990).

According to the principles and parameters framework (Chomsky, 1995, 2000), this species-unique system can be considered a constellation of general principles which are properties of the language faculty as such and slight options for variation, which are called parameters. The principles hold across languages and across constructions. The parametric variations seem to be a finite space, which means that there is only a limited set of possible languages that satisfy them. Furthermore they seem to be limited to certain parts of the language; some parts of the lexicon and certain aspects of the phonological module.

In this sense, language acquisition is the process of fixing the parameters of the initial state in one of the permissible ways. The final parameter settings determine the person's individual language. This process is controlled by the language acquisition device, which is the (genetically determined) initial state of the system, including the principles and their parameters and which has to fix those principles by experience into an attained language state (Chomsky, 1995, 2000).

To be of any use, the language faculty has to interface with external systems that use the information provided by the language faculty to perform various actions. The two external systems that are distinguished are the articulatory-perceptual (A-P) system and the conceptual-intentional (C-I) system. Accordingly there are two interface levels, phonetic form (specifying aspects of sound) at the A-P interface and logical form (specifying semantic aspects) at the C-I interface. The external systems can only access information presented in certain forms, and, consequently, impose legible conditions on the language faculty

(Chomsky, 1995, 2000). The A-P system and the C-I system are related to the internal computational system by the mental lexicon. This lexicon can be considered a repository of all idiosyncratic properties of particular lexical items, including a representation of the phonological form, a specification of its syntactic category, and its semantic representation (Chomsky, 1995; Pinker, 1999). In this sense, the lexicon forms the bridge between the different representational formats (Jackendoff, 1999; Marlsen-Wilson, 1987). This central place of the lexicon within the language system implicates that the unit of processing in the mental lexicon is the element with a singular, indivisible attribute of meaning, which usually reflects the unit of a morpheme.[1]

Phonological Module

As stated above, the phonological module is the part of the language faculty that interfaces with the sensorimotor system. In the case of speech recognition this interface is the auditory system. Perception starts as a physical speech signal, produced by the articulatory system and consisting of a quasi-continuous stream of acoustic energy, is presented to the peripheral auditory system. As people listen to spoken utterances, they rapidly map these acoustic waveforms onto the discrete phonological units used to store words in the mental lexicon (McQueen, 2004; Phillips, 2001).

This recognition process entails a complex decoding problem. First of all, the acoustic realisation of phonetic segments (and spoken words) is highly variant. This variance is partly due to coarticaluation processes. For example, the /s/ segments of *strew* and *street* are uttered differently as a consequence of anticipatory coarticulation of the vowel (lip-rounding for /u/ and lip-spreading for /i/; Cutler & Clifton, 2003). Another phonological context factor which contributes to the variation of the acoustic realisation is the position of words and sounds in the prosodic structure of an utterance. In addition, the speech signal is effected by a number of characteristics of the speaker, such as sex, age, dialect, idiosyncracies of the vocal tract, rate and style of speaking, as well as the amount and nature of the accompanying background noice (McQueen, 2004; Cutler & Clifton, 2003; Pinker & Jackendoff, in press). Besides the variance of the acoustic realisation of words, the phonological space of possible words can be dense, that is, many words share the same sequences of sounds. Words frequently share onsets or rhyme and short words may be embedded in longer words or combinations of words. Especially given the quasi-continuous character of the speech stream this phonological density adds to the complexity of the decoding process (McQueen, 2004).

In view of the complex relation between the acoustic realisation of words and the phonological representations in the lexicon, it is generally considered that lexical word forms cannot be accessed directly from the acoustic input (e.g., Price, Indefrey, & Van Turenhout, 2003). Listeners derive an abstract representation of the sounds in the speech signal before lexical access (McQueen , 2004). The majority of spoken word recognition models therefore assume that word recognition includes both a prelexical and a lexical stage (e.g., McQueen, Cutler, & Norris, 2003). During the prelexical or intermediary phonetic-phonological stage (or series of stages), an abstract description of an incoming utterance is generated. This stage includes processes of normalization and abstraction which mediate between the acoustic speech signal and (abstract phonological representations in) the mental lexicon (McQueen et

al., 2003). Uncovering the constituant parts of which the speech signal is composed, is essential in this stage. An important language structure used herein is the rhythmic regularity. For instance, in English and Dutch, the stress based rhythm defined in terms of the pattern of strong and weak syllables is an important marker for segmentation (Christophe, Gout, Peperkamp, & Morgan, 2003; Cutler & Clifton, 2003). Allophonic differences in the articulation of segments depending on their position in words or syllables and duration diffences between segments and syllables in short and long words can also be used as prelexical cues to word boundaries (Christophe et al., 2003; McQueen et al., 2003; Davis, Marlsen-Wilson & Gaskell, 2002). In addition, phonotactic constraints provide segmentational cues. For example, the sequence /mr/ is not legal within syllables in Dutch, indicating that there must be a syllable boundary between /m/ and /r/. In reverse, chunking the speech stream into frequently occuring phoneme sequences will produce segmentation into linguistically coherent units (Davis et al., 2002). Another phonological regularity which listeners can call upon in unfolding the incoming signal are the assimilation patterns of their native language.

The endproduct of the prelexical stage, the online generated intermediary representation, forms the lexical access code which activates the candidate word forms in the mental lexicon. In this lexical access, word onsets seem to be of particular importance. It appears that word onsets are phonologically more stable than segments in other positions (Gow, Melvold, & Manuel, 1996). Additionally, lexical candidates which begin in the same way as the input and then diverge from it will be activated earlier and more strongly than candidates which end the same way but mismatch initially. This is due to the fact that candidates with initial overlap will initially be as strongly activated as the actual word in the input, while those with final overlap will never be as good a match as the actual word (McQueen, 2004).

The lexical component of the recognition process involves the activation of the multiple candidate words which match the prelexical representation of the input to some extent, and the competition between these word forms (McQueen et al., 2003). As well as activation, lexical processing also includes the rapid rejection of candidates as soon as the signal mismatches. Finally, the system settles on the best fitting candidate. (McQueen, 2004)

Speaking and speech recognition are intimately related, and speech production can thus be assumed to be compatible to speech recognition in its general architecture (Norris, McQueen, & Cutler, 2000; Price et al., 2003). One of the most sophisticated models of speech production is the one of Levelt (1989, 2001).

According to this model, target lexical concepts are selected in the mental lexicon, based on their semantic and syntactic properties. This selection triggers the phonological module: a phonological representation is activated for each of the selected morphemes. A phonological representation consists of an ordered set of phonological segments (Levelt, 2001; Schriefers & Vigliocco, 2001). Subsequently, the process of prosodification is activated, in which the ordered segments are incrementally strung together to form legal syllables.

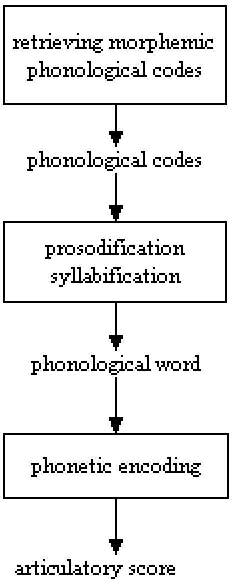


Figure 1.1. Model of phonological processing

It is assumed that the syllabic structure of an item is not a lexical element, but emerges *on the fly* during prosodification and is, as opposed to lexical processes, to some degree consciously accessible as internal speech (Levelt, 1989, 2001; Schiller, 1997). Syllabification does not necessarily respect lexical boundaries. For example, both the slogan 'I love MTV' and the TV show 'Isle of MTV', notwithstanding the words' different syntactic and semantic properties, are syllabified as *i-love-m-t-v*. The incrementally formed syllables are the input for the phonetic encoding, which involves a smooth concatenation of retrieved syllabic routines. During this process of phonetic implementation, the phonological representation is related to a different system of parameters, e.g. targets in articulatory space (Pinker & Prince, 1988). This process implies that the retrieved phonological codes undergo a series of adjustments, referred to as phonological rules (Fowler, 1992; Levelt, 1989; Pinker, 2003). These phonological rules are triggered by a class of phonemes that share one or more features (e.g. voicing), which suggests that phonological rules are not directed at the phonemes as such, but at the features they are made from (Pinker, 1994). Finally, the output product of phonetic encoding, referred to as the articulatory or gestural score, activates (in normal conditions) the laryngeal and supralaryngeal apparatus, creating overt speech (Levelt, 1989, 2001).

It is important to note here that the phonological module functions as an interface to connect the language faculty to peripheral sensomotoric systems, normally represented by the articulatory and auditory system, but is not part of these systems and should be considered an autonomous and amodal function. Neuroimaging studies indicate that partly distinct sets of brain areas subserve speech and nonspeech sounds (Hickok & Poeppel, 2000; Pinker & Jackendoff, in press; Trout, 2001). Research on congenitally deaf children has further supported this notion. Research revealed that children growing up in a sign language environment naturally develop speech equivalent capabilities by means of manual signing and vision. In natural sign languages, the manual signs that profoundly deaf babies acquire are shown to be built up from the same phonetic elements that are distinguishable in speech of hearing humans (Pettito & Marentette, 1991). Furthermore, the development follows the same timetable and comparable stages (e.g. syllabic babbling) as present in the development of speech (Pettito, 2000; Petitto & Marette, 1991).

In concordance, ample evidence indicates that the processing of perceived speech sounds is basically different from the processing of other acoustic signals. The McGurk effect (McGurk & McDonald, 1976) demonstrates that speech processing is not unimodally dependent on auditory perception. When people were shown a video tape of somebody making the sound "ga" while at the same time an audio syllable "ba" was played, they perceived the sound "da", which indicates that both sources of sensory information are used for speech perception. Furthermore, numerous studies at the Haskins laboratories (e.g., on coarticulation, categorical perception and duplex perception; Liberman, 1996) indicated that the processing of speech is principally different from auditory processing. Based on their results, Liberman and co-workers assumed that the phonological module is a neuromotor-alike system (Liberman, 1996; Mattingly & Studdert-Kennedy, 1991). Research by Kimura (1993), that related speech processing to an evolutionary older haptic system, as well as research on mirror neurons in speech processing areas (Rizzolatti & Arbib, 1998) have been supportive of this assumption.

Neuroanatomy of phonological processes

An extensive review of neuroanatomical findings by Hickok and Poeppel (2000; 2004) indicated that two pathways can be distinguished in phonological processing. Tasks that require conscious access to speech segments (i.e. phonetic awareness) appear to rely on a dorsal pathway, which involves left inferior parietal and frontal systems. This pathway seems to refer to the post-lexical phases of syllabification and preparation for articulation in the above presented model of speech production

The second pathway that Hickok and Poeppel distinguished is a ventral one. It involves cortex in the vicinity of the temporal-parietal-occipital junction, including posterior-superior temporal lobe areas as Wernicke’s area. This ventral pathway is considered to be important for interfacing sound-based representations with conceptual representations. It appears to play an important role in the process of constructing phonological representations of heard speech for acces to the mental lexicon. A meta-analysis of neuro-functional research of language processing by Indefrey and Levelt (2000) as well as a recent study of Heim, Opitz, Müller and Friederici (2003) supports the involvement of these two pathways in phonological processing.

Lesion research as well as functional imaging research on sign language indicates that the neural basis of signed and spoken language is basically the same, suggesting that these pathways are specialized linguistic systems (Hickok, Bellugi & Klima, 1998, 2002; Petitto et al., 2000).

Writing Systems

In contrast to our inherited spoken language system, writing systems are human artifacts in which visual form perception and speech processing are connected (Liberman, 1992; Pennington, 1999; Pinker, 1994). This contrast in naturalness clearly expresses itself in the fact that speech is as old as our species, whereas written language is a development of the last few thousand years, and that speech is universal whereas only a minority of language communities possesses a

writing system (Liberman, 1992; Pennington, 1999). Scripts, like the alphabetic script, are the product of both discovery and invention. The discovery was that words are not holistic entities, but are constructed from the building blocks of a closed system of meaningless units; the invention was the notion that each of these units were to be represented by a distinctive optical shape (Liberman, 1992).

Writing systems can thus be considered an artificial extension that is attached to the spoken language system. This close relation of writing systems with language processing is reflected in the unit of scripts. In all known writing systems, the units describe natural linguistic units (Pinker, 1994). Units that are from a linguistic point of view unnatural (e.g. a phoneme and a half) do not exist. More precisely, all scripts are significantly phonological (DeFrancis, 1989; Liberman, 1992; Perfetti, Zhang, & Berent, 1992). Some scripts (like Finnish or Serbo-Croatian) approximately contain a pure phonological transcription, whereas in others morphology is also a productive element (English and Chinese are often positioned at the morphophonological end of this line). Transcription at a perceivable phonic level, however, is non-existent, presumably due to inefficiency of decoding by factors as coarticulation and phonetic changes in context as well as changes in pronunciation over space and time (Liberman, 1992; Pinker, 1994, 1999).

When reading is placed in a historical perspective, the importance of speech as underlying base of scripts is also clearly visible. In Greek and Roman times (and most likely in foregoing periods), texts were always read aloud; there was an explicit co-occurrence of reading and articulation. It was only at the late Middle Ages that silent reading became a normal practice of literate society (Saenger, 1997). Nowadays, the relationship between reading and articulation becomes evident when, under difficult circumstances, reading is supported by whispering or overt articulation to improve reading performance.

The dependency of writing systems on language abilities is also reflected in childhood development. With advancing age, the emergence of language capacities always precedes the acquisition of reading and spelling skills (Pinker, 1994). Moreover, in situations where a young child is not exposed to an adequate language environment, as in congenitally deaf children who have not been exposed to natural sign language in their early years, not only their language acquisition is distorted, but they are also presented with difficulties in learning to read. In general, these children do not obtain functional reading levels (King & Quigley, 1985; Mann, 1991).

Although the foregoing emphasizes the importance of phonological processing in deciphering a script, there is some controversy as to whether the phonological module is a necessary or only a possible route for reading. A widely-used model of reading, the dual-route model, assumes that reading can take place by a fast ‘direct route’ in which the visual characteristics of printed words directly access meaning or by a slow ‘indirect route’ in which the printed word recognition is mediated by phonological recoding (Coltheart, 1978; Coltheart, Curtis, Atkins, & Haller, 1993). Others have argued in favor of a strong phonological model, which regards (prelexical) phonological processing as the primary operation launched in the reading process (Ernestus & Mak, 2004; Frost, Ahissar, Gotesman, & Tayeb, 2003; Liberman, 1992; Perfetti, 1999a). For beginning readers, the situation appears to be straightforward in favor of an essential phonologically mediated reading process. Only those children who have grasped the relation between the graphs of their script and the phonic elements of spoken language will

be able to decipher graphic transcriptions of words that they have not previously encountered. This however would be impossible when reading is based on a direct mapping of visual information to semantics without phonological mediation. Rack, Hulme, Snowling and Wightman (1994) examined the role of phonology in the earliest stages of learning to read. In this study, young children who possessed only minimal letter knowledge were learned to associate three-letter acronyms with spoken words. Two of the letters corresponded with the phonemes of the spoken word. The third letter was in one condition close to the target pronunciation and phonetically distant in the other conditions, whereas the visual overlap between acronym and target word was similar in both conditions (e.g. ‘bzn’ vs. ‘bfn’ for the word *basin*). The results revealed that the children learned to read phonetically close acronyms more easily than those that were phonetically distant and, therefore, underpin the importance of phonology in learning to read (Rack et al., 1994).

Thus, it seems safe to conclude that in the early stages of learning to read as well as in the decoding of unfamiliar printed representations of words, phonological processing is crucial. The dual-route model of reading acknowledges the role of phonology in these situations, but argues that in the processing of familiar words by more experienced readers a direct route is involved and preferred. However, in the case of skilled reading, accumulating evidence indicates that the role of phonological processing in printed word recognition is fundamental (for a review, see Frost, 1998). For example, Van Orden (1987) reported an experiment in which a semantic classification task was used. The results revealed that skilled readers produced more false positive errors on stimuli that were homophonic to the category exemplars (e.g. *rows* for the category *a flower*) than on visual control stimuli (e.g. *robs*). This effect was found under brief-exposure masking conditions and was independent of word frequencies. Lukatela and Turvey (1994a, 1994b) showed a priming-effect of pseudohomophones relative to visually controlled non-homophonic stimuli, even at intervals between the onset of prime and target (SOAs) of 30 ms, indicating that the access of meaning through a phonological code is very fast. In sum, it appears that the notion that reading is primary tied to the phonological module provides the best fitting and most parsimonious account of the reading process.

The above mentioned origins and underlying processes of reading are consequential for the acquisition of literacy skills. First of all, whereas for the emergence of speech a minimal exposure to a surrounding language community is sufficient, reading and writing have to be learned consciously. Furthermore, writing systems encode spoken language at the level of the (morpho)phonological representation. Consequently, the phonological adjustments that take place during the process of speech production result in critical differences between the perceived, spoken word and its orthographic representation. The basic task of learning to read and write, therefore, appears to be learning the basic principles by which one’s writing system encodes the characteristics of the spoken language system (Olson, 1994; Perfetti, 2003). As stated, the components of the language system of most importance for reading are phonology and morphology. For example in Dutch, as in all alphabetic scripts, a level of grapho-phonic concordance is provided by the alphabetic principle. Another productive linguistic principle of the Dutch written language is morphological constancy, the wish to show in the spelling the common root of words (Booij, 1990). This principle can break the grapho-phonic relation, and, elicits a need for repair. Both the principle and the

repair are very productive. An example of the principle is: *baard – baarden* (beard - beards); the letter 'd' is written in *baard* analogous to *baarden*, although the consonant /d/ loses the property voiced in its articulated form when it is positioned as the final phonic element of the spoken syllable and is therefore pronounced as /t/ in the word *baard*. An example of repair of the grapho-phonic relation is: (*hoop*) *hopen* – (*hop*) *hoppen* (in English: (hope) hoped – (hop) hopped), here the shortness of the vowel is repaired by doubling the consonant.

Dyslexia as a disorder in the domain of the language function

A milestone in the field of dyslexia has been the seminal work of Vellutino (1979), revealing that dyslexics have systematically difficulties on tasks incorporating a verbal component, whereas they perform equal to non-dyslexics on comparable tasks without a verbal component. These results undermined several explanatory models of dyslexia, e.g. a visual processing problem, a temporal ordering disorder, or a deficit in cross-modal transfer, and led to the conclusion that the cause of dyslexia is within the verbal learning and memory domain.

Consequently, over the last two decades various linguistic components have been analyzed to reveal the part of the language process that is dysfunctional. Dyslexic persons were shown to have no specific deficits in syntactic or semantic processing (Shankweiler et al., 1995; Shaywitz, 1996; Vellutino, Fletcher, Snowling, & Scanlon, 2004; Vellutino, Scanlon, & Spearing, 1995). A study of Shankweiler et al. (1995) revealed that dyslexic children performed as good as their non-dyslexic peers on a task in which subjects had to decide whether a picture was a correct representation of a syntactically complex sentence. Vellutino et al. (1995) found no differences in semantic abilities between good and poor readers in the beginning stages of reading development, but did find differences between these two groups at later stages. These results suggest that semantic deficits are no primary cause of reading disabilities, but can arise as a consequence of it.

A large body of converging evidence now indicates that dyslexia stems from an underlying deficit in the phonological processing system (for reviews, see Beitchman & Young, 1997; Grigorenko, 2001; Mody, 2003; Pennington, 1999; Ramus, 2003; Snowling, 2000; Shaywitz, 1996). Psycholinguistic research repeatedly revealed a phonetic awareness deficit in dyslexia; that is, dyslexic children and adults are shown to have difficulties in detecting, segmenting and manipulating individual phones in words (Pennington, Van Orden, Smith, Green, & Haith, 1990; Siegel, 1993). However, a reciprocal relation exists between phonetic awareness and learning to read, and it can be argued that these awareness deficits are not so much a cause but a consequence of difficulties in learning to read. Nonetheless, longitudinal research demonstrated that poor readers already performed poorer than normal readers on phonetic awareness tasks before they learned to read (Elbro, 1996; Pennington, 1999). A study by Caravolas, Hulme and Snowling (2001) indicated that phonetic awareness is also a precursor of spelling development. Thus, phonetic awareness deficits can be considered to play a causal role in reading and spelling disabilities. The phonological deficit in dyslexia is, however, not restricted to phonetic awareness. Dyslexics are also shown to have difficulties in the perception of speech which is embedded in noise (Brady, Shankweiler & Mann, 1983). Another consistent feature of dyslexic subjects is their problems on verbal

memory tasks. Experiments demonstrated that poor readers have shorter verbal memory spans in tasks using digit span, letter strings, word strings and sentences (Ho, 2003; Snowling, 2000). Again, this memory span deficit appears persistent, being demonstrated in young children as precursor of reading deficits as well as in (compensated) adults with a history of reading problems (Paulesu et al., 1996; Rohl & Pratt, 1995).

Deficits are also revealed in the domain of speech production. Swam and Goswami (1997a, 1997b) conducted a series of picture naming experiments. Their results revealed a clear picture naming deficit of the dyslexic children relative to both chronological and reading age-matched controls, whereas their semantic knowledge was as well as that of the control children. Moreover, the dyslexic children displayed significantly greater percentage of phonological nonword errors. This pattern of results suggests a specific impairment in the activation of the phonological representations of picture names. In addition, Swan and Goswami (1997a) showed that the dyslexic's picture naming proficiency accounted for differences in performance on a phonetic awareness task, suggesting a dependency of phonetic segmentation skills on the quality of the phonological representation.

Faust, Dimitrovski and Shacht (2003) applied the tip-of-the-tongue (TOT) paradigm to dyslexia. TOT is assumed to reflect the situation in which the semantic representation of a concept is selected but a failure has arisen to properly activate the phonological representation, while semantic, syntactic and fragmentary phonological information of the item is available to the speaker (Levelt, Roelofs, & Meyer, 1999; Schwartz, 1999). Faust et al. (2003) demonstrated that dyslexic children exhibited substantially more TOT responses than normal readers in an object naming task. Moreover, in TOT situations, the dyslexic children were able to supply semantic and syntactic information that was similar to that of the normal readers, but were less able to provide (partial) phonological information. These findings confirm the assumption that dyslexia involves deficient mapping of or access to phonological representations.

In a clever experiment of Elbro, Borstrøm and Petersen (1998), children at kindergarten age were presented a hand-held puppet and were asked to help the puppet to pronounce words correctly. On behalf of the puppet, the experimenter named pictured objects at a very low level of distinctness (e.g., *codi* for *crocodile*). The child was then asked to pronounce the word very clearly for the (hard-hearing) puppet. The distinctness of their articulated words appeared to differentiate between poor and normal readers two years later. Assuming that unstable phonological representations cause greater difficulty in assembling accurately specified articulatory scores, this result indicates a causal relation between the quality of the phonological representation and reading development (Elbro et al., 1998).

These studies provide ample evidence for an impairment in the module of the language system which processes phonological information. However, recall that phonology is to be distinguished in both a lexical stage, i.e., the activation and competition of the word forms stored in the lexicon and a prelexical stage, i.e., active processes that operate on-line on intermediary phonetic/phonological representations in the course of speech perception. In general, the studies on phonological deficits in dyslexia did not differentiate between lexical and prelexical phonological processing (Ramus, 2001).

Recently, Blomert et al. (Blomert, Mitterer, & Paffen, 2004; Bonte & Blomert, 2004) examined the different processing stages of speech perception in dyslexia in a series of studies. In a carefully designed experiment, Blomert et al. (2004) examined the context sensitivity of dyslexic individuals on the auditory, phonetic and phonological level. The results revealed no evidence for insufficient compensation for context-dependent variation in any of the three levels nor did they reveal any categorization deficit. Nonetheless, Blomert et al. (2004) did found one difference between dyslexics and non-impaired readers, that is, dyslexic children were more strongly influenced by phonetically based context. This result might suggest an inefficiency in prelexical processing. On the basis of their results, Blomert et al. (2004) postulated that not the phonological representations per se but the time course aspects of the processes necessary to achieve lexcical access may be impaired in dyslexia.

Consequently, Bonte and Blomert (2004) investigated the on-line speech perception of dyslexics by means of event-related potential measures of implicit phonological processing. Using alliterating priming experiments, the ERP results revealed an anomaly in pre-lexical phonetic/phonological processing in dyslexics. In contrast, processing at a later lexical phonological level was shown to proceed normally (Bonte & Blomert, 2004). Moreover, the pattern of ERP results suggested that the anomalous pre-lexical processing in dyslexic children may be specifically related to the processing of word onsets. Findings of deviant prelexical processing of word onset information in dyslexia are of specific interest, since words onsets are considered to be of particular importance for lexical access in speech perception (Gow et al., 1996; McQueen, 2004). Taken together, these findings indicated that the core deficit of dyslexia is in the online computation of an intermediary representation during prelexical phonetic/phonological processing (Blomert et al., 2004; Bonte & Blomert, 2004).

In addition, Serniclaes, Van Heghe, Mousty, Carré, and Sprenger-Charolles (2004) postulated a deficit in the system of allophonic perception of speech. They revealed that dyslexic children maintain a higher sensitivity to phonemic distinctions that are not relevant for speech perception in their linguistic environment. These irrelevant phonemic distinctions are usually deactivated in early childhood and in their increased sensitivity to them, dyslexic children tend to resemble a profile of prelinguistic infants (Sernicales et al., 2004). This ‘residual’ sensitivity in dyslexic children to phonological features that are irrelevant for their native language, can be assumed to disrupt the efficiency of the prelexical phonological system.

Besides these psycholinguistic studies, there is a firm body of neuropsychological and genetic research on the etiology of dyslexia. The first evidence of abnormalities of brain structure in dyslexia came from a series of post-mortem studies by Geschwind and Galaburda (Galaburda, Sherman, Rosen, Aboitiz, & Geschwind, 1985). They revealed focal cortical malformations consisting of nests of ectopic neurons and glia in the first cortical layer, which alter the architecture of the affected areas. These ectopias clustered around the left Superior Temporal Gyrus and were also present in the inferior premotor and prefrontal cortex. They reflect an alteration of the neural migration to the cortex, which takes place roughly between 16 and 20 weeks of gestation (Galaburda, 1999b). A second finding was the presence of alterations in the pattern of cerebral asymmetry. In particular, the planum temporale (a

posterior region on the upper surface of the temporal lobe, which is part of Wernicke's area) failed to show the usual asymmetry in most dyslexics. Arguably, this more symmetric structure reflects distorted neural organization processes, possibly as a result of migration deficits. Geschwind and Behan (1983) showed an association between dyslexia and, among other things, gender, stuttering, left-handedness and immune diseases. On the basis of these findings and on the notion that testosterone has an effect on the neural migration to the cortex (especially in left hemisphere regions), Geschwind, Behan and Galaburda attributed the cortical alterations in dyslexia to the interaction between prenatal chemical conditions, possibly testosterone levels, and the maturation rate of the relevant brain areas (called the GBG hypothesis; Geschwind & Behan, 1983; Geschwind & Galaburda, 1987). To date, however, research has been unable to support this model in a consistent manner (Tonnessen, 1997).

Nonetheless, in support of Geschwind and Galaburda's post-mortem studies are findings of neuro-anatomical and neuro-physiological studies concerning dysfunctional brain structures in dyslexia. The most consistently reported sites exhibiting functional and structural disruptions in dyslexia are areas near the left posterior Superior Temporal Gyrus, including the planum temporale, although other sites such as left inferior frontal, left insular, cerebellar and thalamic areas are also reported to deviate in dyslexia (Grigorenko, 2001; Hynd & Hiemenz, 1997; Shaywitz et al., 1998). Interestingly, planum temporale activity (and activity in adjacent posterior perisylvian areas) is strongly associated with the computation of phonetic/ phonological features from the incoming speech signal in order to generate intermediary representations for lexical access, i.e., prelexical phonological processing (Griffiths & Warren, 2002; Jacquemot, Pallier, Le Bihan, Dehaene, & Dupoux, 2003; Jäncke, Wüstenberg, Scheich, & Heinze, 2002; Obleser, Eulitz, & Lahiri, 2004; for sign language, see also Pettito et al., 2000). Moreover, the planum temporale area appears to subserve the integration of lip movements and speech (Calvert et al., 1997) as well as that of letters and speech sounds (Nakada, Fuji, Yoneoka, & Kwee, 2001; Van Atteveld, Formisano, Goebel, & Blomert, 2004). Leonard et al. (2001) related left posterior perisylvian disruptions to phonological coding deficits. Taken together, these brain studies suggest a core deficit in the ventral pathway of (pre-lexical) phonological processing.

Based on evidence that dyslexia is familial and heritable (Grigorenko, 2001; Pennington, 1994), several studies investigated the genetic localization of dyslexia. Relatively common disorders as dyslexia are considered to be caused by a multiple-gene system. This system includes multiple genes, called quantitative trait loci (QTL), that make contributions of varying effect sizes to the variance of the trait and that are considered susceptibility loci (as opposed to a single, necessary disease locus) (Fisher & DeFries, 2002; Pennington, 1999; Plomin & Walker, 2003). In 1994, Cardon et al. reported evidence for linkage between dyslexia and a region on the short arm of chromosome 6, called 6p21.3; a finding that has been replicated by several research groups (for a review, see Fisher & DeFries, 2002). This linkage appeared to be closely related to phonological processing deficits (Fisher et al. 1999; Gayán, et al. 1999; Grigorenko et al., 2003, Turic et al., 2003). In support of the Geschwind and Galaburda theory, this region is in the vicinity of the major histocompatibility complex, which is essential to the immune system (Stromswold, 2001; The MHC sequencing

consortium, 1999). However, Gilger et al. (1998) failed to reveal a genetic correlation between dyslexia and immune disorders. Interesting, though, is that two other disorders that are related to the 'testosterone' hypothesis, namely autism (Burger & Warren, 1998) and congenital adrenal hyperplasia (girls born virile and with masculinized external genitalia due to exposure to elevated levels of prenatal testosterone; Hughes, 2002), are also being linked to region 6p21.3. Finally, Willcutt et al. (2002) related comorbidity between dyslexia and attention-deficit hyperactivity disorder to effects of a QTL on chromosome 6p21.3. In addition to chromosome 6, a linkage with dyslexia has been found for the long arm of chromosome 15 in several studies, as well as for the short arm of chromosome 18 in two separate genome-wide scans (Fisher & DeFries, 2002; Plomin & Walker, 2003; Taipale et al., 2003). Thus, it can be assumed that these QTLs are not genes for dyslexia, but genes that lead to a disruption in epigenesis and development of cytoarchitecture, which alters the neural circuit involved in phonological processing. These QTLs appear to be pleiotropic and can influence at least to some extent other systems, which are not causally related to the reading and spelling disabilities (Galaburda, 1999b; Gilger & Kaplan, 2001; Grigorenko, 2003b; Pennington, 1999). Arguably, on a functional level this effect is expressed in auditory processing deficits and motor deficits which have been found in a subset of dyslexics in some studies, but which appear to be unrelated to both the phonological deficit and the reading and spelling disabilities (Bretherton & Holmes, 2003; Raberger & Wimmer, 2003; Ramus, 2003). In sum, dyslexia is considered a genetically-based neurodevelopmental disorder. A multiple-gene system may result in an interruption of the process of neuronal migration, causing disruptions in the cytoarchitecture of the circuit typically devoted to phonological processing. Arguably, on a functional level, the sequelae of this 'fuzzy' neuronal circuit appear to be a language acquisition device that is unable to optimally fine-tune the phonological parameters. Consequently, it appears that the parameters are not fixed accurately enough and there remains too much variability in the phonological features. This may result in deviancies in the on-line construction of intermediary phonological representations to achieve lexical acces. This deficit is reflected in an instability of the phonological module, and disables dyslexics in both phonetic awareness and setting up a system of mappings between the letter strings of printed words and the sequences of phonological codes that underlie spoken words, hence in the acquisition of literacy skills.

Alternative explanatory models of dyslexia

The above mentioned phonological core deficit model is the predominant position in the explanation of dyslexia (Grigorenko, 2001; Pennington, 1999; Ramus, 2003). There are, however, several alternative hypotheses proposed. The two most prominent alternatives, dyslexia as an automatization/cerebellar deficit and dyslexia as an auditory temporal processing deficit, will be briefly discussed here (for a review, see Ramus, 2003).

Dyslexia as an automatization/cerebellar deficit

In 1990, Nicolson and Fawcett postulated a model in which dyslexia was interpreted as a general automatization deficit. It was hypothesized that difficulties in learning to read are a

symptom of a general impairment in acquiring skills, i.e., dyslexic children suffer from a deficit in the process of automatizing skills (Nicolson & Fawcett, 1990; 1995). This hypothesis was supported by experiments showing that dyslexic children performed poorly on a dual task where they had to balance whilst performing a secondary task, whereas they had no problems with balancing in a single task condition (Nicolson & Fawcett, 1990, 1995). In later stages, this model was expanded to a cerebellar dysfunction (Nicolson, Fawcett & Dean, 2001). The general automatization deficit is assumed to be a consequence of a cerebellar dysfunction. Phonological problems are considered to be a result of this automaticity/cerebellar deficit. An additional implication of this cerebellar dysfunction is the presence of motor deficits in dyslexics. Indeed, Nicolson et al. (2001) reported motor problems in their sample of dyslexic children.

The research findings on this automatization/cerebellar deficit hypothesis, however, are not unambiguously supportive. Yap and Van der Leij (1994) reported a replication of the balancing deficit in dyslexic children, but other studies failed to reveal automaticity impairments in dyslexic children (Van Daal & Van der Leij, 1999; Wimmer, Mayringer, & Landerl, 1998). In an attempt to explain this inconsistency between studies, Wimmer and co-workers (1998) suggested that balancing and motor deficits might be a reflection of comorbidity of dyslexia and ADHD. In support of this assumption, it was revealed that poor balancing was found among children with ADHD and children with both ADHD and dyslexia, but not among dyslexia-only children (Raberger & Wimmer, 2003; Wimmer, Mayringer, & Raberger, 1999). Likewise, Ramus, Pidgeon and Frith (2003) revealed that poor performance in motor tasks of a proportion of dyslexic children was, for the greater part, due to comorbidity with other developmental disorders. Moreover, Ramus et al. (2003) failed to reveal a time estimation deficit, even in those children who had a motor deficit, which is inconsistent with a disorder of cerebellar origin. Also they did not find a relationship between motor skills on the one hand and phonological processing and reading skills on the other. Another inconsistency with a cerebellar deficit, as noted by Zeffiro and Eden (2001), is the absence of clear manifestations of a classic cerebellar dysfunction (such as hypotonia, fatigability or disorders of voluntary movement) in dyslexics as well as the absence of reading problems and phonological deficits in patients with substantial cerebellar disease. Reports of normal implicit learning (Kelly, Griffiths, & Frith, 2002) and explicit learning (Benson, Lovett, & Kroeber, 1997) in dyslexics are also in contrast to the alleged automatization deficit.

At a theoretical level, this hypothesis has been criticized because its central concept, automaticity, is not clearly defined (Blomert, 2002). Moreover, at a symptom level, dyslexia is characterized by a specific reading and spelling deficit. It is unclear why a general cause, i.e. a general inability to automatize skills, only results in such specific (language-related) clinical symptoms (cf. Vellutino et al., 2004).

In sum, most of the research on this issue does not support a general automaticity/cerebellar dysfunction as a core deficit in dyslexia. Although it seems plausible that a proportion of dyslexic individuals exhibit motor deficits of cerebral or cerebellar origin (recall the pleiotropic genetic effects discussed above), these do not appear to be primary to their phonological processing or reading skills.

Dyslexia as an auditory temporal processing deficit

According to the auditory temporal processing hypothesis, the core problem in dyslexia is an auditory temporal processing deficit, which causes reading problems by impairing the phonological system (Farmer & Klein, 1995; Reed, 1989; Tallal, 1980; Tallal, Miller, Jenkins, & Merzenich, 1997). More specifically, problems in rapid auditory perception, especially the perception of transients, causes defective perception of information bearing elements in speech (especially, rapid spectral changes as in formant transitions at the onset of stop consonant-vowel syllables) and, consequently, impairs the phonological processing system. This hypothesis does therefore not dispute the phonological processing deficits in dyslexia, but claims that this deficit can be subsumed under a general deficit for processing rapidly presented auditory stimuli and, thus, places the core problem outside the language system.

The best known support for an auditory deficit comes from temporal order judgment and repetition tasks (Reed, 1989; Tallal, 1980). Reed (1989) presented reading disabled children a rapid auditory perception task that required temporal order judgments, respectively for brief high-low tones, for pairs of consonant-vowel syllables (/ba/-/da/) and for pairs of vowel stimuli. She found that the dyslexic children were impaired relative to controls as inter-stimulus intervals decreased (from 400 to 10 ms) for pairs of tones and pairs of consonant-vowel syllables. The dyslexic children were not impaired in the temporal order judgment of pairs of vowels. Since stop consonant-vowel syllables, but not vowels on their own, involve rapid spectral changes, it was concluded that these results support the assumptions of a rapid temporal processing deficit in dyslexia (Reed, 1989). Besides the support from temporal order judgment tasks, an auditory deficit has been repeatedly reported in studies using a variety of auditory tasks, such as discrimination of frequency or intensity, gap detection, detection of frequency and amplitude modulation (Farmer & Klein, 1995; Ramus, 2003).

However, the auditory processing deficit hypothesis has faced a number of problems. The assumption of a rapid or temporal auditory processing deficit implies that dyslexics have specific problems with short sounds and fast transitions. But some of the tasks (e.g., frequency discrimination or detection of frequency modulation) that are used as support do not require rapid auditory processing (Ramus, 2003). In addition, several studies indicated that the auditory processing deficits do not relate specifically to rapid processing deficits; that is, dyslexics did not display a poorer performance on short than on long inter-stimulus intervals, relative to non-dyslexics (Bretherton & Holmes, 2003; Chiappe, Stringer, Siegel, & Stanovich, 2002; France et al., 2002; Share, Jorm, MacLean, & Matthews, 2002; Waber et al., 2001). Moreover, most of the non-speech auditory tasks that are used appear to be no appropriate equivalent of the speech perception problems that are assumed to be a reflection of the general temporal processing deficit (Studdert-Kennedy, 2002). Mody, Studdert-Kennedy and Brady (1997) reported two experiments in which they aimed at using equivalent tasks for speech and non-speech sound processing. The results of the first experiment revealed that poor readers who had difficulties with the /ba/-/da/ temporal order judgment task performed equal to average readers when required to make temporal order judgments on syllables that were relatively easy to discriminate (e.g. /ba/-/sa/). This result indicated that they were able to discriminate under time pressure, but had problems with the similarity of

/ba/-/da/. The second experiment examined whether this similarity was auditory or phonetic, by using non-speech control stimuli, consisting of two sine waves with durations and frequency trajectories identical to those of the second and third formant that carried the /ba/-/da/ contrast. The results showed that, as opposed to the /ba/-/da/ performance, non-speech performance was unaffected by decreases in inter-stimulus interval. It was concluded that the difficulties with /ba/-/da/ were not due to an auditory deficit but to problems in discriminating and identifying phonetically similar syllables under time pressure, i.e., a phonological processing deficit (Mody et al., 1997). Additionally, Blomert and Mitterer (2004) revealed that the speech perception deficit as typically revealed with synthetic speech does not hold for natural speech. This result contradicts an auditory processing deficit hypothesis. Instead, it suggests that dyslexics are less able to apply their phonological categories built on natural speech consistently to the novel synthetic stimuli and, consequently, supports a phonological coding deficit model of dyslexia (Blomert & Mitterer, 2004).

Furthermore, recent studies indicated that there is no reliable relationship between performance on auditory temporal processing tasks and phonological processing in dyslexic individuals (Ramus, 2003; Snowling, 2001). For example, Bretherton and Holmes (2003) failed to reveal an association between tone ordering deficits and temporal order judgment of consonant-vocal syllables. Moreover, their results showed that average and poor tone order subgroups of dyslexic children performed similar on phonological awareness and reading tasks. In a longitudinal study, Share et al. (2002) assessed auditory temporal processing abilities in a sample of over 500 children at school entry, who were followed over subsequent years. The results showed that early temporal processing deficits did not predict later phonological processing problems or reading difficulties. Thus, several research attempts have been unable to provide a reliable link between problems in processing non-speech and speech sounds, and, therefore, failed to support the assumed mechanism by which an auditory deficit disrupts the perception of speech or phonemic awareness (Bretherton & Holmes, 2003; Ramus, 2003).

Finally, as shown in a meta-analysis of studies on auditory processing in dyslexia (Ramus, 2003), only a subset of dyslexics displayed an auditory processing deficit. Conversely, the results of Share et al. (2002) revealed that only 10% of the children with an auditory processing deficit exhibited reading difficulties.

In summary, although a subset of dyslexics display auditory processing deficits these do not appear to be restricted to rapid or temporal processing and have little influence on the development of the phonological processing system and reading skills (Bretherton & Holmes, 2003; Ramus, 2003). In other words, a substantial body of research seriously contradicts the assumptions of an auditory temporal processing deficit as a causal factor in dyslexia.

Treatment of dyslexia

In the light of the close relation between spoken and written language, as well as the evidence that dyslexia reflects a phonological processing deficit, methods that aim to treat dyslexic persons from a (psycho-)linguistic framework appear to be most promising. Indeed, positive results have been reported in studies evaluating phonologically-based or psycholinguistic

prevention and intervention methods in the last 10 years (Borstrøm & Elbro, 1997; Hatcher, 2000; Hatcher, Hulme, & Ellis, 1994; Korkman & Peltomaa, 1993; Lovett et al., 1994, 2000; Torgesen et al., 2001; Vellutino et al., 1996; Vellutino & Scanlon, 2002; Wise, Ring & Olson, 1999, 2000). The prevention of dyslexia is beyond the scope of this study, therefore, the reader who is interested in prevention methods is referred to a recent overview of the state of affairs by Torgesen (2002a) and to an extensive review by the Committee on the Prevention of Reading Difficulties in Young Children (Snow, Burns, & Griffin, 1998). Here, the focus is on the treatment of disabled readers and spellers.

The most effective treatment methods include training in phonetic awareness to provide a solid foundation for the acquisition of reading and spelling skills (Snowling, 1999). Furthermore, as Hatcher et al. (1994) revealed, phonetic awareness training is particularly effective when linked with systematic instruction in reading. Hatcher et al. (1994) reported a study in which three forms of training and a control condition were compared. The three training conditions were limited to phonology, reading, or reading with phonology. In the phonology training, tuition focused on phonological awareness tasks (e.g., segmenting words into phones), without relating these tasks to the written word. The reading training was modeled on the work of Clay (1985) and focused on reading books. The reading with phonology training included elements of both other training-methods. In addition, the participants conducted activities aimed at linking reading and phonology. These activities included practicing letter-sound associations and writing words while paying attention to letter-sound relationships. The study included a total of 125 seven-year-old children, who received individual training for 40 half-hour sessions spread over 20 weeks. The results showed that the reading with phonology treatment was most effective in improving reading accuracy and spelling. Their results demonstrated that in treating dyslexia it is important to form explicit links between reading activities and phonological knowledge.

One of the most successful intervention studies to date is the one of Torgesen et al. (2001). In this study, both short-term and long-term effects of two forms of training were evaluated. A total of 60 children received 67.5 hours of one-to-one instruction. One group of dyslexic children received the ‘Auditory Discrimination in Depth’ program (ADD), while the other group received the ‘Embedded Phonics’ program (EP). Both methods incorporated stimulation of phonemic awareness, explicit instruction in phonemic decoding skills, and applications of these skills to reading. The two programs differed, however, in their instructional emphasis. The ADD program trained phonemic awareness by associating the phonemes with the corresponding articulatory gestures. A large proportion of instructional time was dedicated to practicing to identify the number, order, and identity of sounds in words. In the EP program, a relatively smaller amount of focused instruction in phonics knowledge was provided; phonemic skills were trained within a context of larger amounts of monitored reading of text. Both programs produced large improvements in generalized reading skills that were maintained over a two-year follow-up period. The children’s average scores on reading accuracy attained the lower end of the normal range at the end of the follow-up period. Only their reading rate lagged behind (Torgesen et al., 2001).

A different approach to remediate reading disabilities has been developed by Merzenich, Tallal and coworkers (Merzenich et al., 1996; Tallal et al., 1996). Their

intervention program, named Fast ForWord, is based on two main assumptions. Dyslexia is assumed to be an auditory temporal processing deficit. The second assumption is based on animal studies on cortical plasticity of the auditory system, which have shown that the abilities to make fine distinctions about the temporal or spectral features of complex auditory stimuli can be altered by behavioral training (Recanzone, Schreiner, & Merzenich, 1993). It is, therefore, assumed that the disruption in the neural response of the auditory system in dyslexics can be reshaped by training, and by consequence, disabled language and reading skills can be ameliorated. To this end, Merzenich, Tallal and their colleagues developed remedial activities using acoustically modified speech and non-speech stimuli. Speech in this training was modified by slowing and amplifying the rapid frequency transitions in the speech signal (Tallal, Merzenich, Miller, & Jenkins, 1998).

Two pilot studies reported promising effects of this treatment program (Merzenich et al., 1996; Tallal et al., 1996). Later evaluation studies, however, failed to demonstrate positive effects of modified speech training on the reading skills of dyslexics (Agnew, Dorn, & Eden, 2004; Gillam, Frome Loeb, & Friel-Patti, 2001; Habib et al., 2002; Hook, Macaruso, & Jones, 2001; Verhoeven, 2003). For example, Habib et al. (2002) compared the effects of two sets of training exercises, which were similar except for the fact that one included modified speech training, while the other included natural speech training. The study failed to reveal an advantage for modified speech training. Verhoeven (2003) reported similar results. Thus, evidence substantiating the specific role of acoustically modified speech training in ameliorating reading difficulties is lacking at this stage (Ramus, 2003).

In The Netherlands, there has been a predominant tradition of treatment of dyslexia based on the neuropsychological framework of Bakker (1983, 1986). According to this so-called ‘balance model’, in the early stages of reading acquisition, children employ predominantly right-hemisphere functions, due to the emphasis on visuo-spatial features of printed words. As the reader matures, printed word recognition becomes automatic, providing allocation of attention to the linguistic properties of written language. At this stage, readers shift to left-hemisphere functions. The balance model predicts two types of reading disabilities. Children that fail to shift from right-hemispheric to left-hemispheric strategies, called P-type (perceptual) dyslexics, remain focused on the perceptual properties of texts, which leads to an accurate but relatively slow reading style. Children that rely prematurely on left-hemispheric strategies, called L-type (linguistic) dyslexics, are characterized by a fast but inaccurate reading style. On the basis of this model, a treatment was developed which involved stimulation of the functionally inactive hemisphere, the right hemisphere for L-type dyslexics and of the left-hemisphere for P-type dyslexics, in order to change the balance of hemispheric involvement in reading. Hemisphere-specific stimulation (HSS) directly stimulates the hemisphere through computerized presentation of words in either the left or right visual field. Hemisphere-alluding stimulation (HAS) engages each hemisphere by manipulating the nature of the reading task (Bakker, 1986).

In a series of studies, Spyer (1994) investigated the effects of hemisphere stimulation on the reading skills of P-type and Non-typed dyslexics. The results failed to show significant improvements in the reading skills of these dyslexics. In accordance with these results, a review of other studies evaluating the effects of hemisphere stimulation (Spyer, 1994) showed

that, in general, the results of these studies were not supportive of the efficacy of HSS. Dryer, Beale and Lambert (1999) reported an experiment in which they gave P-type and L-type dyslexics either the (Balance model) training that was designed for their subtype or a training designed for the opposite subtype. Their results failed to show differentiated effects between type-training congruent and incongruent conditions, which questions the validity of the Balance model as a basis for treatment. Furthermore, their results suggested that (marginal) gains obtained by Bakker's treatment program were due to other treatment contingencies and not to the specific nature of his remedial methods (Dryer et al, 1999).

Kappers (1997) and Van Daal and Reitsma (1999) evaluated the effects of a treatment method that combined Bakker's training with other remedial methods, such as auditory blending and grapheme-phoneme conversions. Dyslexic children received approximately a total of 60 hours of individual treatment, spread over a 15-months period. The results showed that, although the participants made progress on both word reading and text reading measures, their standing relative to average readers hardly changed during the course of treatment, that is, they did not close the gap in reading ability with normal readers (Kappers, 1997; Van Daal & Reitsma, 1999). Moreover, a one-year follow-up measurement revealed that after the termination of treatment, the rate of growth obtained in the treatment period decreased to a level in the vicinity of the pre-intervention rate (Kappers, 1997).

Another productive area of intervention research in The Netherlands concerns interventions focused on reading practice under time constraints by limiting the exposure duration of (pseudo-) words (De Jong, 2003). This practice is assumed to stimulate the use of multi-letter units in decoding words, which is considered an intermediate stage between letter-by-letter decoding and direct word recognition or 'sight word' reading (De Jong, 2003). Evaluation studies of these remedial technique yielded disappointing results; although significant effects are obtained on the decoding of the trained stimuli, studies failed to reveal a substantial transfer of effects (Das-Smaal, Klapwijk, & Van der Leij, 1996; Smeets & Van der Leij, 1995; Van der Leij, 1994; Yap, 1993).[2]

Issues to consider in research on the treatment of dyslexia

An overview of the relevant literature on the treatment of dyslexia provides a number of issues that deserve closer attention. First of all, a growing body of research indicates the importance of psycholinguistic principles for the treatment of dyslexia. These ingredients appear to be particularly effective when explicitly related to properties of written language and implemented in an intensive treatment program (Lovett, 1999; Lyon & Moats, 1997; Snowling, 1999; Swanson, 1999; Torgesen, 2002b). Most psycholinguistic treatments focus mainly on phonological principles and their relation to written language, which has been demonstrated to be effective. There are, however, indications that there can be an additional effect from teaching implications of the morphological structure of words on the orthography for the treatment of reading and spelling disabilities (Leong, 2000; Mahony, Singson, & Mann, 2000; Simons & Hoeks, 1987; Snowling, 2000).

As is often the case with clinical samples, sample sizes tend to be small in evaluation studies concerning the treatment of dyslexia. A meta-analysis of studies evaluating intervention for reading disabilities revealed that the total sample size of a study was on

average 28.23 (sd = 16.23) participants, only 10 out of 96 studies having a total sample size of 50 or more participants (Swanson, 1999). Since the majority of studies incorporated two or more conditions, the number of participants per condition can be considered to be small in many of these studies. These small sample sizes indicate a low a priori power and interfere with the replicability of the reported effects (Tversky & Kahneman, 1971), whereas replication of effects is considered one of the essential ingredients in supporting the efficacy of a treatment (Kazdin, 2003).

Another salient characteristic of the samples used in treatment studies is the age range. Practically all studies refer to elementary school children; there appears to be no substantial focus on the treatment of adolescents and adult dyslexics. Since dyslexia is a life-long disorder, there is a considerable number of adolescents and adults who are impeded in their functioning at school or work by their reading and spelling disabilities and who are in need of treatment (Schaap, 1986).

Although psycholinguistic treatment evaluations revealed positive effects, these treatment gains usually reflect short-term effects. Only a minority of studies examined long-term effects (Hatcher et al., 1994; Kappers, 1997; Torgesen et al., 2001; Wise et al., 1999), the most positive exception being the study of Torgesen et al. (2001), who reassessed their participants two years after the treatment had ceased. Since the goal of any treatment is to obtain long-lasting changes, this aspect should be one of the primary focuses of treatment evaluations.

Another point of attention concerns the transfer-of-learning. While results of treatment on phoneme awareness and non-word decoding skills are repeatedly reported in evaluation studies, only a relatively small number of studies revealed transfer of the learned concepts into generalized reading and spelling gains (Lovett, Barron, & Benson, 2003; Lyon & Moats, 1997; Moats & Foorman, 1997; Snowling, 1996), and just these areas are the problem domains for dyslexics. Research of Lovett et al. (Benson, Lovett, & Kroeber, 1997; Lovett et al., 2000) suggests that remediation which systematically trains strategies by which the dyslexic pupils are able to apply the learned (linguistic) concepts to untrained printed words is most promising in obtaining generalized effects.

Intervention studies demonstrated positive effects of treatment on reading accuracy; reading rate, however, appeared much less amenable to psycholinguistic treatment programs (Chard, Vaughn, & Tyler, 2002; Eden & Moats, 2002; Torgesen et al., 2001; Wolff & Katzir-Cohen, 2001). Torgesen, Rashotte and Alexander (2001) suggested that this discrepancy could be due to the fact that dyslexic children miss out a clear amount of reading practice compared to average readers, which is considered essential for the acceleration of reading rate, and that the duration of treatment is too short to close this gap. Others, however, have questioned whether present psycholinguistic treatment methods based on the assumption of dyslexia being caused by a phonological processing deficit are sufficiently capable of tackling the reading rate problem in dyslexia (Wolff & Katzir-Cohen, 2001). Consequently, there is a strong call for future research providing insight in the mechanisms that result in both reading accuracy and reading rate, i.e., fluent reading (Kame'enui & Simmons, 2001; Lyon & Moats, 1997; Torgesen, 2002a; Wolf, Miller, & Donnelly, 2000).

A related issue concerns the misbalance between the focus on reading and spelling in dyslexia treatment. In most intervention studies, there is only a minor or no attention on spelling skills (Berninger et al., 2000). Both reading and spelling deficits are characteristic symptoms of dyslexia (Hagtvet & Lyster, 2003; Lyon, 1995a; Snowling, 2000; Warnke, 1999). This appears to be a result of the fact that they are secondary language functions derived from spoken language and, consequently, are both dependent on knowledge about how the writing system encodes spoken language (Dietrich & Brady, 2001; Liberman, 1997; Perfetti, 2003). Reading and spelling are, thus, assumed to be strongly correlated and to develop concurrently (Shankweiler & Lundquist, 1992). Therefore, it seems reasonable to concentrate more on spelling skills in intervention and to attack both the reading and spelling deficits in an integrated treatment program.

Individual differences in dyslexic pupils' response to intervention are reported repeatedly: some make large profits, others appear far less amenable to intervention (Snowling, 2000; Torgesen, Wagner, & Rashotte, 1997a). Several studies investigated the predictive value of the seriousness of the phonological deficit on treatment success. The results on the impact of phonological deficits, however, appear to be far from being consistent (Hatcher & Hulme, 1999; Pogorzelski & Wheldall, 2002; Torgesen et al., 2001; Van Daal & Reitsma, 1999; Wise et al., 1999, 2000). Age-related differences in susceptibility to treatment have also been subject of investigation. Several authors have claimed that dyslexic children as they grow older become increasingly impervious to treatment (Baker et al., 1996; Cossu, 1999; Lyon, 1995b; Wentink & Verhoeven, 2001). In accordance with this assumption, Wise et al. (1999, 2000) observed that younger children showed stronger treatment gains than older children. Other studies indicated, however, that effectiveness of treatment does not necessarily decrease with increasing age. For example, Lovett and Steinbach (1997) reported equivalent gains of remediation for children in grades two to six.

An important issue concerning a treatment's external validity is the functionality of the literacy levels subsequent to treatment. In this light, it is surprising that progress in reading is often reported without relating the obtained levels to a functional level. While statistically significant results are provided, it remains unclear whether dyslexics are still performing at a below average level after treatment, or whether the treatment normalized reading into the average range (Jacobson & Truax, 1991; Torgesen, 2001). The sharp difference of these two outcomes in their impact on the functioning of the treated dyslexic stresses the importance to determine the extent to which the participants obtained a socially acceptable level of reading and spelling (Kendall, Marrs-Garcia, Nath, & Sheldrick, 1999).

Finally, a treatment's internal validity needs consideration. Most evaluation studies consist of a quantitative comparison of pre- and post-test, without considering the process by which effects are obtained (Lyon & Moats, 1988; 1997). Research within this context has clarified some issues concerning the treatment structure by comparing different treatment programs (Lovett et al, 2000; Wise et al., 1999, 2000). However, knowledge about the processes by which the treatment effects are attained remains limited (Harm, McCandliss, & Seidenberg, 2003; Lyon & Moats, 1997). In general, an important step to optimize the effectiveness of treatment is considered to be the identification of the change processes or mechanisms through which treatment achieves its effects and how the procedures relate to

these processes (Kazdin, 2001, 2003). Therefore, this step seems an essential one to take in the evaluation of any treatment.

Summary and outline for the thesis

It has been argued that the language module can be considered an innate and autonomous system. Several modules can be distinguished within this system, one of them, the phonological module, functions to interface peripheral sensorimotor systems. In contrast to spoken language, writing systems are human artifacts, aiming to transcribe spoken language. Consequently, reading and writing are essentially tied to the (spoken) language function system and in particular, dependent on the phonological module.

Dyslexia is characterized by a specific reading and spelling disability, and is assumed to be caused by a deficit in the module of the language system which processes phonological information. Since this part of the language system is the essential psychological function on which reading and spelling skills depend, it is reasonable to expect a specific disability in these skills to be a reflection of a dysfunction in the phonological system. The phonological deficit model of dyslexia fits, thus, comfortably with the general theories on the language system and literacy skills. At the same time, this model has been supported by a large body of converging evidence over the last twenty years, and is consequently considered the primary explanation for dyslexia. Nonetheless, alternative models of dyslexia have been proposed. However, these claims have a controversial status; they are not substantially supported by empirical data and are faced with both theoretical arguments and research findings that contradict their main assumptions (Ramus, 2003; Snowling, 2000; Vellutino et al., 2004).

In agreement with research on the etiology of dyslexia, phonologically-based or psycholinguistic treatment programs are designed for the remediation of the reading and spelling deficits of dyslexic children. Evaluation studies of these programs have revealed positive treatment outcomes. Still, further research is needed to substantiate these promising results. In the following chapters, a series of studies is presented which aimed at providing insight in the efficacy of a Dutch psycholinguistic treatment for dyslexia, called LEXY.

Chapter 2 provides the theoretical underpinnings of the LEXY treatment. In this chapter, a résumé is also presented of research conducted at the IWAL institute in order to provide a broader context of the development of the LEXY program.

In chapter 3, an evaluation of the treatment effects on the reading and spelling skills of dyslexics on both the short and long term is described. This study included children as well as adult dyslexics and evaluated treatment gains halfway the treatment, at the end of treatment, and one to four years after termination of the treatment.[3]

Chapter 4 focuses on a process-oriented evaluation of the treatment. In this study, it was aimed to show a time-course of effects that was specifically related to the timing of the treatment modules. On the one hand, by using this process-oriented evaluation design, information regarding the internal validity of the treatment can be provided. On the other hand, insights on the functional elements of treatment can be gained.

Chapter 5 reports a study aiming to replicate the treatment effects (on the short term) of the chapter 2 study. In order to examine the reliability of treatment effects, the treatment

response of two samples of dyslexic children were evaluated. The study focused on the question of whether dyslectics attained functional reading and spelling levels following treatment. A more specific focus was on the individual differences in the obtained literacy levels.

Chapter 6 has a more fundamental character. The purpose of this study was to examine whether two frequently reported causes of dyslexia, phonological processing problems and verbal memory impairments, represent a double-deficit or whether they are two expressions of the same deficit.

Subsequently, the study reported in chapter 7 was designed to investigate to what extent the effects of treatment vary as a function of the underlying core deficit causing the reading and spelling disabilities.

In chapter 8, a differentiated analysis of the development of reading skills during treatment is presented. The goal of this study was to provide a window on the processes by which the accuracy and rate of reading develop, during the treatment as well as in the subsequent years after termination of treatment.

Finally, chapter 9 covers the concluding remarks. The results of the presented studies are summarized and discussed in relation to the main issues in the evaluation of the treatment of dyslexia.

Notes

1. This is a matter of dispute, which however goes beyond the focus of attention here. Interested readers are referred to Di Sciullo and Williams (1987). Di Sciullo and Williams (1987) state 'The lexicon is like a prison - it contains only the lawless, and the only thing his inmates have in common is lawlessness'. They reserved the name listeme for the lexical unit.
2. In contrast to the clinical focus of the studies of Kappers (1997) and Van Daal and Reitsma (1999), these studies have, in general, a more experimental character.
3. Although the treated skills are a subject of primary education, we chose to use not only primary school children but adults as well in this chapter since the disorder is lifelong and the disabilities and their consequences will thus be long lasting. However, reading skills, such as tested by the Dutch EMT reading test (Brus & Voeten, 1973), are not normed for the adult population. For these older participants we used the norm at the end of primary education as the criterion for a normal level of reading proficiency, based on the following:
   1. As stated in Dutch law (Wet op het primair onderwijs [Law on primary education]; Besluit kerndoelen primair onderwijs [Decree core goals primary education]), technical reading is a skill that should be mastered at the end of primary education. A formal core goal of primary education is to provide students with a normal, functional level of technical reading and spelling skills. That is, at the end of their primary education, students have to possess a proficiency in these written communication skills according to the accepted rules and norms of our society and at a level in which they can function normally in society (see also Ministerie van OCW, 2002a; Sijtstra, Van der Schoot, & Hemker, 2002).
   2. Consequently, technical reading (as well as Dutch standard spelling) is no longer a subject of education in Dutch secondary education (e.g., Aarnoutse, 1991; Henneman & Kleijnen, 2002).
   3. Longitudinal research has revealed that reading skills develop with a slowing coefficient as a function of age, and that the curve of reading growth has leveled off at approximately the end of primary education

(e.g., McCardle, Scarborough, & Catts, 2001; Van der Leij, 2003; Verhoeven & Van Leeuwe, 2003). Thus, the degree of skill children have attained at the end of primary education is about the level of achievement on which they will rely for the rest of their lives (McCardle et al., 2001). Additionally, Van den Bos, Lutje Spelberg, Scheepsma, & De Vries (1999) conducted a cross-sectional research in which they used both representative samples of primary school children and a sample of children in the MAVO, HAVO and VWO levels of secondary school, i.e. the highest 60% of the population (Ministerie van OCW, 2002b) of secondary school children. They showed that at the end of their first year of secondary education the average level of word reading skill (EMT-test) was only one third of a standard deviation above the average of the general population at the end of primary education. When the fact that this secondary school sample includes only the highest 60% of the population is corrected for, this result provide support for the findings that reading development has leveled of at the end of Dutch primary education.
Thus, it is safe to conclude that the average level of reading skill at the end of primary education is an appropriate criterion for a normal, functional level of reading to test the attained levels of our older participants against.

Chapter 2

IWAL directions of research and LEXY treatment[1]

The IWAL-institute was founded by members of the department of psychology of the University of Amsterdam in 1983 in order to bring scientific knowledge of learning disabilities into practice and to advance scientific knowledge by the application of it in a clinical setting (IWAL, 1984). The institute is specialized in research, assessment and treatment in the field of dyslexia.

Directions of research

Before the subject of this thesis, the LEXY treatment, is discussed, a brief overview of the relevant directions of research at the IWAL institute is presented. Research at the IWAL has been motivated by research of Frank Vellutino (1979), who demonstrated that dyslexics have problems with the verbal factors in learning, memory and perception tasks. This assumption of dyslexia as a verbal deficiency guided the IWAL research program that adopted a psycholinguistic perspective on the components of our language system.[1] The central question of this program was whether dyslexia is to be considered a non-specific disorder of the language system or a specific disorder of one or more language components.

A lexical decision study has been conducted to examine the phonological processing capacities of dyslexic and non-dyslexic children (Gerretsen, 1989). Gerretsen (1989) examined whether a priming effect can be obtained when the prime and target share word-initial phonological information (e.g., nagel [nail] – natuur [nature]), as opposed to no overlap between prime and target (e.g., tube [tube] – natuur [nature]). In agreement with Slowiaczek and Pisoni (1986), the results revealed that the performance of non-dyslexic children did not differ between the no-overlap condition and the phonological overlap condition. In contrast, the dyslexic children revealed a significant difference between these conditions. More specifically, they responded significantly slower and made more errors in the phonological overlap condition than in the no-overlap condition. Thus, the results revealed no phonological priming effect for non-dyslexics, suggesting that, in normal conditions, phonological processing proceeds in an optimal, very fast way. For the dyslexic children, the results revealed a phonological priming effect, which was in the direction of an interference effect. Based on these results, it was concluded that in dyslexia the process of lexico-phonological access is deficient (Gerretsen, 1989).

A possible deficit in morphological processing was studied by using a lexical decision task (Jimmink, 1986). Subjects were presented with words assembled from a stem and a suffix. The task incorporated two conditions, nonwords due to incorrect word forming and real words due to correct word forming. For instance, the suffix *-heid* [-ness or -ty] was used. In Dutch, this suffix can be connected to an adjective, but is not allowed to be connected to a noun. Thus, this derivation rule allows *blij* + *heid* ⇒ *blijheid* [happiness], but not *stoel* + *heid* ⇒ *stoelheid* [chairness]. The subjects' task was to judge whether a word form was correct or not. The dyslexics' performance on this task was as accurate and as fast as that of non-

dyslexic children. Thus, no indications for a disorder in the morphological component of the language system were found (Jimmink, 1986).

A semantic priming study was then conducted to examine the semantic information processing of dyslexic individuals (Gerretsen, et al. 1990). In this study, subjects were presented with triplets of words and nonwords, in which the first two words were primes and the third word the target. In the priming condition, the word meanings were highly associated (e.g., *stoel* [chair] – *tafel* [table] – *bank* [couch]), whereas the words in the baseline condition were unrelated (*fles* [bottle] – *raam* [window] – *bank* [couch]). The results revealed a semantic priming effect, which was equal for dyslexics and non-dyslexics. Consequently, it was concluded that dyslexics process semantic information as efficient as non-dyslexics (Gerretsen et al., 1990).

Finally, the auditory discrimination of speech sounds was examined, although this sensory system is not considered to be a part of the language system. It is assumed, however, to be an external system to which the language system interfaces (cf. Chomsky, 1995) and, thus, of possible relevance for the functioning of this language system. In this study, word pairs (e.g., *tak* - *tok*) were presented auditory and subjects were asked to indicate whether these words were identical or not. The results revealed that the auditory discrimination of dyslexics was equal to that of non-dyslexics (Schaap, 1994; Schouws, 1988).

On the basis of the results emerging from the IWAL research program and the reading of the extant literature (Vellutino, 1987; Snowling, 1991), it was concluded that the core deficit in dyslexia is located within a specific component of the language system, i.e. the phonological processing of words (Schaap, 1997).

The LEXY treatment

Roots of the treatment

LEXY is developed from different perspectives. Firstly, it is based on psycholinguistic theories. In accordance with a growing body of converging evidence and corroborated in the research program of the IWAL, dyslexia is considered to stem from an underlying verbal deficit, and, more specifically, to be caused by a lexico-phonological processing deficit (Schaap, 1997). Accordingly, dyslexics are considered to be deficient in building up and consolidating a stable phonological representation in the mental lexicon. Furthermore, it is assumed that literacy skills are secondary language functions derived from spoken language and primary tied to the phonological module. Their dysfunctional phonological module, however, seems to prevent dyslexics from using the implicit structures of language in their reading and writing, by which the deciphering of each printed word becomes a problem on its own (Schaap, 1985). Therefore, it was aimed to construct a program that focuses the attention of the dyslexic explicitly on these linguistic structures for treating dyslexia (Schaap, 1983). A more extensive consideration of this psycholinguistic framework is presented in the previous chapter.

Another root of the treatment is an artificial intelligence project on the spelling of Dutch words. This project focused on the language units, the basic rules and the minimal heuristic knowledge to be implemented in a computer program in order to transform a phonic

word into a correct orthographic word form. An important aim was to clarify in which cases knowledge could be algorithmic and in which cases it had to be heuristic. Central to the computer program is an algorithm with an inferential structure (if a phone of class X is in position Y then perform operation Z) and a number of heuristics for those orthographic inconsistencies that could not be captured in the algorithm (Schaap, 1997; Schaap & Wielinga, 1979, 1982).

The main reason motivating this design is that spoken language and written language are two levels of expression that are correlated only to a certain degree in the Dutch language (the same is true for most other languages). There is no one-to-one relationship between speech sounds and letters or letter-groups, and phonological adjustments, such as assimilation, that take place during the process of speech production result in critical differences between the perceived, spoken word and its orthographic representation (e.g., the word |ζαδυκ| or |ζαγδυκ|, which is composed of the nouns |ζακ|and |δυκ|, is written as 'zakdoek').

This lack of a full correlation is largely due to the fact that the Dutch writing system includes a number of (phonological and morphological) principles that go counter to each other (see chapter 1, section 'Writing systems').

The complexity of the relation between the phonological and orthographic levels of expression required to postulate a level in between these two levels, which is more neutral in relation to the orthographic variation (cf. Chomsky, 1970; Pinker, 1999). By the use of this intermediate level, a number of spelling rules can be projected on the orthographic surface (Schaap & Wielinga, 1982; cf. Smith, 1978). Consequently, there is no direct relation between the phonological expression and the orthographic one {P < > O}, but an indirect, intermediated relation {P < > I < > O} (Schaap, 1996). On the basis of the principle of Chomsky's language theory (1975) stating that implicit language rules contain an inferential algorithmic structure, it appears that the projection rules are best presented by a set of inferential, algorithmic operations.

So far, the emphasis of LEXY has been on the linguistic adequacy of the program. It can be argued, however, that the program should contain an optimized adequacy of three parameters: a linguistic, a psychological and a didactic parameter. As stated by Schaap (1996), the elements, units and operations of a treatment of dyslexia have to be interpretable in linguistic theories, as well as in models of psychological information processing, and have to be didactically applicable. To optimize psychological and didactical adequacy, the above mentioned linguistic concepts are implemented in a treatment program adopting the model of learning activity of Gal'perin (1969) and Davydov (1990/1995), who elaborated on the work of Vygotsky (1934/1962) and Luria (1969). This framework, which is compatible with information processing models such as ACT-R (Anderson, 1993), provides one of the most practically applicable accounts of learning mechanisms by means of a stepwise process of internalization of an action. At the basis of this process is the orientation phase, which provides the learner with a psychological map of the action, incorporating systematic knowledge of the abstract elements and operations that are essential for the correct execution of an action as well as the recognition of these essential principles in a concrete-particular situation (Davydov, 1990/1995; Grigorenko, 1998; Van Parreren & Carpay, 1972). Thereafter, the action is learned using material or materialized objects, all steps of the action

are guided by overt speech. During the learning process, the materialized guidance will be taken away. Later on, the verbalization will be changed from overt speech to whispering and the number of explicit steps is slowly reduced, i.e. the action is abbreviated. In the end, the whispering disappears and transference of the action to the internal level takes place (Gal'perin, 1969; Grigorenko, 1998).

Within this learning framework, the occurrence of errors during learning is considered an indication that the systematic formation is not (yet) adequately implemented. Since there should first be an accurately implemented system of learning actions before the execution of this system can be optimized, the strategy of errorless learning is an important focus (Gal'perin, 1974/1989; Grigorenko, 1998).

It is also crucial that there is a full orientation base of knowledge of the system and recognition of the essential elements in the problem space and that an action is learned on the basis of its abstract algorithmic structure. Otherwise, specific objects will be memorized rather than forming a system of mental actions underlying the functional specificity of the skill, and consequently, there will be no full automatization or generalization of the action system (Davydov, 1990/1995; Gal'perin, 1974/1989; Grigorenko, 1998). As stated by Davydov (1990/1995), the characteristic of a learning task is that the student internalizes a general system of learning actions by which he can solve 'on the run' many concrete-particular tasks of a certain kind. Research findings in several skill domains give support for this framework of learning activity in learning new skills (Arievitch & Stetsenko, 2000; Berk, 1994; Haenen, 2001). For more elaborated reviews of this framework, the interested reader is referred to Arievitch and Stetsenko (2000) and Grigorenko (1998).

The LEXY treatment

These roots are implemented in a computer-based program, which focuses on learning the dyslexic pupils to recognize and use the phonological and morphological structure of Dutch words (Schaap, 1986a). The treatment teaches the dyslexics to act on what they hear. The syllabic structure of words is the focal point of the treatment. This is because the syllable is the smallest possible, but still naturally pronounceable, phonological structure. In accord with Levelt's theory on speech production (1989, 2001), it is assumed that the syllable emerges during prosodification, and is not a lexical element. In contrast to lexical representations, which are automatically molded into a phonetic plan and are inaccessible to conscious activities, syllabic scores are to some degree consciously accessible as internal speech (Levelt, 1989). Therefore, by taking the 'spoken' syllable as unit of processing, the attention of the dyslexic is drawn to a perceivable structure in contrast to a phoneme, which is an abstract entity. The use of syllables, rather than whole words or morphemes as central unit, allows dyslexics to better identify distinct speech sounds. At the same time, in Dutch the syllable is the phonological unit to which spelling rules apply (the same is true for many other languages). In the Dutch writing system the last phonic element of a syllable is essential to the dissociation between a spoken word form and its orthographic representation.

The correspondence between a phonic element and its standard graphical representation can be dissociated, depending on the phonological category to which the

terminal phonic element of a syllable belongs. In LEXY this is incorporated in its inferential algorithmic kernel, having the following structure:

IF p /# E Pi then O(p) → g E G.

When the terminal phonic element p of a syllable belongs to the i^{th} category of phonic elements Pi then the result of an operator O on p will be mapped onto a graphic element g that need not be the standard mapping. The basic principles of the Dutch written language can be realized within a learning system incorporating five types of operations as consequence of five types of terminal phonic elements: long vowels, short vowels, unvoiced consonants, sonoric vowels and unstressed morphemes (Schaap, 1997). For example, in Dutch, the voiced consonants /d/ and /b/ loose the property 'voice' in the terminal position, which is not reflected in their orthographic representation. Consequently, the operation says: if the last phone in a syllable is an unvoiced consonant then extend the word (operation) and if this results in a voiced consonant the voiced consonant graph should be written, otherwise the standard consonant. All essential terms in the algorithm have an explicit and exhaustive description in the program: the set of phones, the categories of phones, the mapping operations and the orthographic elements. This description is the central procedural structure of the program and has a full graphical representation on the computer screen; all elements of the description are also represented on a special keyboard (Schaap, 1997). In this way, the essential elements on both the phonological and the orthographic level of expression as well as the intermediary projection rules are presented to the pupil and, thereby, a full orientation base is provided in order to connect spoken and written language.

Some orthographic inconsistencies, however, cannot be accommodated by the algorithm. These are presented as heuristic knowledge. These heuristics include allographs, which have two standard graphical representations.

As LEXY is a computerized treatment program, it requires subjects to respond by typing the computer keyboard. To this end the keyboard of the computer is reconfigured (Schaap, 1986a). The keyboard does not have the usual qwerty-system of distinct letters. It consists of three key-categories. One part of the keyboard contains keys for each phone: for example /g/ (=consonant), /o/ (=short *vowel*), /oo/ (=long *vowel*), or /ieuw/ (=four-token sound). The phoneme system used corresponds to the system of Nooteboom and Cohen (1984). Phones were grouped on the keyboard according to the class of phones (for instance 'short vowels') to which they belong. Furthermore a group of schwa-containing morphemes (such as /ge/, /lijk/, /ig/, /en/) is added to the phoneme-system. One reason for this addition is the productivity of these bound morphemes (they can be more productive than certain vowels) in which they resemble phones. Another reason is the irregular writing of the schwa within these morphemes. Depending on the affix in which the schwa is used, it can be represented in the orthography by the letters *i*, *ij*, or *e*. This problem is solved in the program by treating them as a special class of phones, named morpheme-sounds. They are assigned to a specific part of the keyboard. Finally, the third part of the keyboard is the 'abstract token board'. It contains a series of icons to designate the categories of phones: 'short' vowels, 'long' vowels, (semi) diphthongs (which are subdivided in so-called two-token, three-token and four-token sounds), consonants and morpheme-sounds. For example, the key with the sign ◄ designates a consonant and the sign |||| designates a four-token speech segment. The abstract token

board also contains a series of icons that stand for different spelling rules, and icons for syllables with a full vocalic kernel and unstressed syllables. Thus, by using this redesigned keyboard, a physical representation of the essential ingredients for relating spoken and written language to each other is available to the dyslexic pupils (cf. Davydov, 1990/1995; Gal'perin, 1974/1989).

In concrete terms, treatment is provided on a one-to-one basis in a weekly 45-minute session. Besides these sessions at the institute, participants are required to practice at home three times a week for 15 minutes. Each session consists of several parts. A session starts by going through the homework. This takes about five minutes. Next, the LEXY instruction and training are discussed. During the instruction part, a new element is introduced and the rules of translation of the phonic into the orthographic form of a word are explained using a graphic algorithm (Schaap, 1992). Training consists of spelling and reading modules. In the spelling module, the participant is required to make the translation steps. First, the translation has to be made explicitly, step by step. Later on, a more implicit direct approach is practiced. In the reading module, words are projected individually on the computer screen in various ways; e.g., phone by phone (e.g., k/a/t (cat)), or syllable by syllable (e.g., ka/tten (cats)). During reading the whole word is projected faintly on the screen to allow anticipation (Schaap, 1992). The word components are highlighted at a pace, which is adjustable to the individual's reading speed. Instruction and training contain separate bodies of words, since the treatment is not a 'word trainer', but directed at general knowledge. A session ends by explaining the homework consignments. Homework consists of exercises on paper aiming at expanding training with the elements that have been subject of the session.

The treatment starts with a focus on the phonological structure of Dutch words. Later during treatment, operations are introduced to map the phonetic structure onto the correct orthographic word form. Next, attention is shifted to the implications of the morphological structure for orthography. Subsequently, the process of inflecting a verb is attended. For the orthographic representation of verbs both the phonetic and the morphologic structure are important. During the final part of the treatment, the focus is on loan words. The phonetic patterns of recurrent bound morphemes from Greek, Latin, English and French are taught. In addition, the focus of training is first on monosyllabic words containing simple phonetic patterns and, later, on more complex patterns and polysyllabic words (Schaap, 1992).

According to the principles of the theory of learning activity (cf. Gal'perin, 1974/1989), the program aims at achieving a certain mastery level for each element of the program. An element is considered mastered when the percentage of correctly performed items during training is at least 80%. Consequently, training proceeds to the next skill or to a combination of mastered skills, only after a particular skill has been mastered. This implies that participants do not pass through the program at a fixed pace.

Evaluations of LEXY

The effectiveness of the LEXY-treatment has been the subject of evaluation (Hoeks & Schaap, 1992; Van den Akker, Hoeks, & Mellenbergh, 1986). Van den Akker et al. (1986) evaluated the gains in reading and spelling skills obtained after six months of treatment. The study included 46 dyslexic participants ranging in age from about 7 to 41 years (mean was

about 15 years, modus 10 years). The results revealed clear improvements in spelling and accurate text reading, irrespective of age and IQ.

Hoeks and Schaap (1992) also examined the effects of the LEXY treatment after six months of training. Their study involved 99 dyslexic participants, who were on average about 14 years of age. Basically, the results replicated those of Van den Akker et al. (1986), showing substantial effects of treatment on both spelling and accurate text reading (Hoeks & Schaap, 1992). On average, the participants halved their number of errors for spelling and diminished the number of reading errors by more than half after a treatment period of six months. Both age and IQ were found to be unrelated to the efficacy of treatment.

In this thesis, the initial assessment of LEXY is the starting point of a more elaborated examination of this treatment program consisting of both outcome-oriented and process-oriented evaluation studies.

Notes

1. This research program has taken place partly in collaboration with the department of psychology of the University of Amsterdam and with the Max Planck Institut für Psycholinguistik, Nijmegen, The Netherlands.

Chapter 3

Long-term effects of a psycholinguistic treatment for dyslexia

Abstract

Short and long-term effects of a treatment for dyslexia are evaluated. The treatment is based on psycholinguistic theory and assumes that dyslexia is due to poor lexico-phonological processing of words. The treatment is computer-based and focuses on learning to recognise and to make use of the phonological and morphological structure of Dutch words. The results of the treatment were clear improvements in reading words, reading text and spelling. Effect sizes of standardised treatment gains were large (Cohen's $d > .80$ for all variables). Following the treatment, participants attained an average level of text-reading and spelling. The attained level of reading words and reading text was found to be stable over a four-year follow-up period. Spelling showed a slight decline one year after the treatment, but remained stable thereafter.[2]

Introduction

Developmental dyslexia is a reading and spelling disorder, which is related to deficits in phonological processing (Lyon, 1995a; McDougall, Hulme, Ellis, & Monk, 1994; Pennington, 1991; Shaywitz, 1996; Siegel, 1993; Snowling, Goulandris, & Defty, 1996; Swan & Goswami, 1997a, 1997b; Stanovich, 1988; Vellutino, 1987; see for review Beitchman & Young, 1997). Evidence from different perspectives suggests that the relationship between phonological processing deficits and printed-word recognition is causal, and partly biological (Lyon, 1995a; Torgesen, Wagner, & Rashotte, 1994; Wise, Ring, & Olson 1999).

A study by Shankweiler et al. (1995) shows that phonological awareness constitutes the strongest single correlate of reading success, and is far superior to measures of general intelligence in distinguishing dyslexic from normal readers. The most striking finding from this study is that other problems within the language domain, like morphological difficulties, stem from the same weakness in phonological processing that underlies reading disability. Syntactic knowledge did not distinguish reading-disabled children from normal children.

Psycholinguistic research provides evidence that an unstable or under-specified phonological representation in the mental lexicon is a core deficit in dyslexia (Elbro, Borstrøm, & Petersen, 1998; Goswami, 2000; Snowling, Nation, Moxham, Gallagher, & Frith, 1997; Swan & Goswami, 1997a, 1997b). This suggests that dyslexics have problems in constructing a stable phonological representation of words in the mental lexicon. It appears that the activation of lexical items by the abstract sound code is not specific enough (Gerretsen, 1989). Since the letters of a writing system represent the phonetic constituents of words, they present problems for those with dyslexia in the processing and production of written words, that is, reading and spelling (Byrne & Liberman, 1999; Mattingly, 1972).

On the basis of these findings, a treatment focusing on phonological processing deficits seems to be the most promising (Snowling, 1996). An increasing number of studies report

positive effects of treatment of phonological deficits with phoneme analysis and phoneme blending as core aspects (Alexander, Andersen, Heilman, Voeller, & Torgesen, 1991; Hatcher, 2000; Lovett et al., 1994; Torgesen, et al., 1994; Wise, et al., 1999).

The study by Lovett and colleagues (1994) shows sizeable effects of two word identification programs: a direct instruction program of phonological analysis and blending, and a strategy-training program, which is a more metacognitive-oriented treatment of word identification. Both programs increased real-word reading, but the direct instruction also improved nonword reading.

Most studies evaluate the short-term effectiveness of treatment, without considering long-term effects (Lyon & Moats, 1997). This is surprising since the goal of any given treatment is to bring about a long-lasting improvement. A small number of long-term studies have been published recently (Olson, Wise, Ring, & Johnson, 1997; Wise, et al., 1999; Torgesen et al., 2001). The study of Wise et al. (1999) focused on three versions of phonological training. First, a version in which participants explicitly learned how to relate articulatory gestures to sound and spelling-sound patterns; second, a condition in which participants learned explicitly to manipulate sounds in syllables with speech and print, and finally, a condition combining the two. The study showed persistent gains in word-recognition skills for all training conditions ten months after the training.

The objective of the present evaluation study is to establish long-term effects of a treatment for dyslexia, which in essence tries to improve the way those with dyslexia manage their phonological problem. The present study addresses three questions. First, will those with dyslexia (children and adults) read and spell better by learning to master the sound patterns of words? Second, if they succeed in mastering the sound structure of Dutch words during the treatment, will their command of that structure persist over subsequent years and give rise to a stable improvement in spelling and reading? Contrary to a usual comparison of the treatment group with a control group, in this study dyslexics are compared with their norm group. To assess the efficacy of a treatment properly, it is not sufficient to establish merely significant improvements in reading and spelling. It is also necessary to establish that a minimal socially acceptable level of reading and spelling (i.e. a functional level of reading and spelling) has been achieved. So, the third question in this study concerns the comparison of the mastery level of the dyslexics at the end of the treatment with the level of normal readers and spellers. The treatment is judged to be successful if the treated dyslexics attain an average level that is comparable to that of normal readers.

All participants in this study received a computer-aided and human-tutored treatment of dyslexia, called LEXY. The LEXY treatment is based on a psycholinguistic theory, which holds dyslexia to be caused by a deficit in the lexico-phonological processing of words (Schaap, 1997).

Content and Structure of the Treatment

The LEXY treatment, developed and used over 15 years, is computer based and focuses on learning to recognise and use the phonological and morphological structure of Dutch words (Schaap, 1986a, 1997). More specifically, the focus of LEXY is on the language units, the

basic rules and the minimal heuristic knowledge needed to be implemented in a computer program in order to transform a phonic word into a correct orthographical word form. The sound structure of words is the basis of the treatment. The program focuses at the smallest possible, but still naturally pronounceable, phonological structure, i.e. the syllable. By taking the ‘spoken’ syllable as the unit of processing, the participant finds it easier to identify distinct speech sounds. Lovett and her co-workers (1994) approach the problem of word decoding in the same way by means of their ‘word attacking skills’ program. In Dutch, as in many other languages, the correspondence between a phonic element and its standard graphical representation can be dissociated, depending on the phonological category to which the terminal phonic element of a syllable belongs. This aspect is implemented in LEXY as an inferential algorithm. This algorithm is presented as a set of production rules, which can be seen as operations on five types of terminal phonic elements: ‘long’ vowels, ‘short’ vowels, unvoiced consonants, sonoric vowels and unstressed morphemes (Schaap, 1997). The algorithm is defined in general terms: "If the last speech sound <S> of the syllable is a member of the class <C>, then perform operation <O>". Every concept in this rule is defined explicitly; the existing speech sounds, the classes to which these sounds belong, and the operations that are applicable to a given sound. By stating every rule into the same strict and short format, the rules are easy to acquire even for very young participants. The algorithm, however, cannot accommodate some orthographic inconsistencies. These are presented as heuristic knowledge.

The keyboard of the computer was redesigned. The keyboard does not have the usual qwerty-system of distinct letters. It consists of four key-categories. One part of the keyboard, the so-called abstract sound board, contains abstract tokens to designate speech segments: either a consonant, a short vowel, a long vowel, a diphthong, a two tokens speech sound, a three or a four tokens speech segment. For example a consonant is designated by the key with the sign of '#' (= consonant) and the sign ' ▭ ' designates a long vowel. Another part of the keyboard contains the concrete sound keys: for example /g/ (= consonant), /o/ (= short vowel), /oo/ (= long vowel), /ui/ (= two tokens vowel). The third part of the keyboard contains the productive word parts (the so-called bound morphemes) such as /ge/, /lijk/, /ig/, /en/. These are treated as distinct sound units. They form a sound category in themselves because they all have the “schwa” in common. The last part of the keyboard contains icons, which stand for different operations. With these four parts of the keyboard one can construct words in such a way, that the participant will keep his or her attention exclusively focused on the sound structure, and not on the distinct letters of the written form of the word.

The LEXY treatment is an integral reading and spelling programme that is highly structured. Treatment was provided in a 45-minute session, which took place once a week. Besides the sessions at the institute, participants where required to practise at home three times a week for 15 minutes. A treatment session was divided in several parts. Each session started by going through the homework. Next, LEXY instruction and training were discussed. During the instruction a new element was introduced, and the rules of translation of the phonic into orthographic form of the word were explained using a graphical algorithm. Training consisted of spelling and reading modules. During the spelling module, the participant was required to make the translation steps. First, the translation had to be made

explicitly, step by step. Later on, a more implicit direct approach was practised. During reading training, words were projected individually on the computer screen in various ways; e.g., phone by phone (e.g., k/a/t (c/a/t)), onset-kernel-coda (e.g., kl/a/p (sl/a/p)), or syllable by syllable (e.g., ka/tten (ki/tten)).The words used for reading practice represented the element introduced in the instruction. During reading the whole word was projected faintly on the screen to allow anticipation (Schaap, 1997). The word components were highlighted at a pace which was adjustable to the individual's reading speed. Instruction and training contained separate bodies of words, since the treatment was not a 'wordtrainer', but directed at general knowledge. A session ended by explaining the homework consignments. Homework consisted of exercises on paper with the aim of expanding training with the elements that were the subject of the session. The treatment was composed of six modules.

The first module focuses on learning to distinguish the Dutch speech sounds. During this first part of the treatment, emphasis is on mastering and learning to recognise the speech sounds in monosyllabic words: short vowels, long vowels, consonants and the speech sounds with two, three and four tokens. Hearing the speech sounds is followed by associating the speech sounds with the class of phonic elements, to which it belongs, and with the letter (cluster) corresponding to it. LEXY presents a word and then asks the participant to repeat the sound pattern of the word and next to replicate that sound structure on the sound board, first by pressing the abstract keys, followed by pushing the concrete keys. In this way, the participant is constantly forced to listen to what is heard: namely sound patterns, composed of speech sounds that must be learned to be heard.

In the second module, attention was shifted to situations where the correspondence between a phonic element and its standard graphical representation is dissociated. Operations were introduced to map the phonic word onto the correct orthographic word form for monosyllabic words. Focus is still on monosyllabic words. In this module, LEXY starts with single words, and proceeds with simple sentences.

The third module extends the knowledge of the first modules, but focuses the attention on polysyllabic words. Participants were instructed to decompose words into their distinct syllables. In Dutch, typically, stressed and unstressed syllables are to be distinguished. Operations were presented to map the phonic word onto the correct orthographic word form for polysyllabic words. For example, if a short vowel ends a syllable, the following syllable starts with two consonant graphs. So, the rule is " If the last sound of the syllable is an element of the class of short vowels, then it must be followed by two consonant graphs". In this case, when the right keys are pressed, then the computer will change the single consonant into a double one. For example, the Dutch word 'kapper' (= hairdresser), is broken down into the parts /ka/ and /per/. Combining these two parts yields the word "kaper" (hijacker), which has a long vowel. This is different from hairdresser, so one has to double the consonant /p/ to get /kapper/. In Dutch, one is confronted with the linguistic aspect of bound morphemes. Without dividing the bound morpheme into still smaller elements, LEXY teaches the dyslexic to hear the bound morpheme as a whole, a part of the word with an invariable sound pattern.

Module four focuses on the morpheme structure of words and on compound words. In contrast to English, in Dutch one can compose compound words by assembling words and word parts. Also, pupils learn to recognise the most common affixes in spelling or reading

tasks. The fifth module concentrates on the Dutch verb. For the orthographic representation of verbs both the phonetic and the morphologic structure are important. During the final part of the treatment, attention is given to loanwords. The phonetic patterns of recurrent bound morphemes from Greek, Latin, English and French are taught.

The treatment focuses at a mastery level for each element, which means that the duration of the treatment varies. The total treatment takes about one year. The focus of the LEXY programme is to achieve a functional level of literacy: i.e. a level at which the participants can function at school, and later in their professions and in society in general. It is not a designed to cure dyslexia, but to try to turn people with dyslexia into phonological experts, which appears to be the most promising way to handle their problems.

Method

Participants

The treatment sample in this partly retrospective study consisted of those referred to the IWAL Institute for Dyslexia in Amsterdam, The Netherlands. Referrals originated from multiple sources, including parents, schoolteachers and psychological and educational services. To be selected for the present study participants had to be at least one standard deviation below average in reading or spelling attainment at the start of treatment. They had to have an IQ score of at least 85, normal, or corrected to normal, vision and normal hearing. They had to be free of any diagnosed sensory or neurological problems. Their reading and/or spelling retardation was not attributable to economic or educational factors.

The core deficit of the participants treated at the IWAL-institute involved phonological processing. Analysis of persons referred to the IWAL showed that 87% of the participants between 10 and 15 years who had reading and spelling problems also had a phonological processing deficit, and that 89% of those who started the treatment had problems with phonological processing of words.

The study was planned to include 100 participants. Some over-sampling was carried out to accommodate expected 'non-response'. A total of 157 potential participants were selected, of whom 57 could not be tested. Of these 57 participants, the majority (35) could not be traced, due to a change of address in the interval between the termination of their treatment and the follow-up. Three of the other 22 persons stated that they were not willing to engage in the follow-up because of dissatisfaction with their treatment and 19 indicated that they were satisfied with the treatment but were not able to participate (most of them because of time constraints). Since these non-participants could have a potential bias on the follow-up results, we tested whether their gains at the end of the treatment differed from those of the participants. This analysis showed that the gains in reading and spelling did not differ significantly between the two groups (t-tests; all $p > 0.1$).

As explained below, it proved impossible to distribute the 100 participants evenly over the follow-up measurement occasions. Participant characteristics are summarised in Table 1. At the time of pretesting the full sample had a mean z-score ($M = 0$ and $sd = 1$ in the general population) of –1.65 ($sd = 0.96$) for reading words, a mean z-score of -0.98 ($sd = 1.27$) for reading text and a mean z-score of –2.74 ($sd = 2.39$) for spelling. In the full sample, IQ ranged

from 90 to 129. At the start of treatment, the youngest participant was nearly 7 years old and the oldest slightly over 41 years old. At the follow-up the youngest participant was about 9.5 years and the oldest about 45 years old. The sample consisted for 36% of participants who were 9 years or younger at the start of treatment, 35% were 10-12 years, 12% were 13-18 years old and 17% were 19 years and older. The social-economic status of the sample was tested by comparing the incomes of the participants with the average income of the Dutch population (Central Bureau of Statistics, 1995). No significant differences were found between the participants and the general population (t-test; $t = -1.05$, $p = 0.92$). There was no significant difference between the follow-up groups as to reading, spelling, age, sex, IQ, or number of treatment sessions.

Table 3.1. Participant Characteristics

	N	gender ratio	age (years) *M* (*sd*)	age (years) Median	IQ *M* (*sd*)	number of sessions *M* (*sd*)
total	100	78M/22F	13.7 (7.6)	10.9	109 (9.7)	49.0 (16.5)
follow-up group 1	29	25M/4F	11.8 (5.5)	10.2	111 (9.0)	53.5 (14.7)
follow-up group 2	23	18M/5F	15.8 (9.4)	11.8	110 (10.5)	44.5 (15.8)
follow-up group 3	22	19M/3F	14.1 (8.5)	11.4	111 (10.3)	49.3 (20.7)
follow-up group 4	26	16M/10F	13.6 (7.5)	10.8	108 (9.8)	47.7 (14.6)

Procedure

Reading and spelling performances of each participant were assessed four times: at the start of treatment (m1), after 26 weeks of treatment (m2), at the end of treatment (m3) and at the follow-up measurement occasion (m4). The study uses a cross-sequential, or overlapping longitudinal design. The longitudinal aspect stems from the fact that every participant was assessed at four occasions. The cross-sectional aspect of the design stems from the fact that long-term effects of treatment (m4) were assessed by using four different follow-up groups (participants were tested 1, 2, 3 or 4 years after the termination of their treatment). Measurements 1, 2 and 3 were carried out at the IWAL Institute prior to the actual study. Follow-up measurements (m4) were carried out during the investigation. The individual sessions took about 40 minutes to complete. The following skills were assessed: reading words, reading text and spelling.

Measures

The phonological measures included a phoneme synthesis test, which required participants to recognise words from separately presented speech sounds, and a phoneme segmentation test, which required participants to pronounce the speech sounds in words separately. A homophone test was used, in which participants had to find different meanings from the same word form. Also, a Dutch version of the subtest auditory closure from the Illinois Test of Psycholinguistic Abilities (ITPA) was used. Two phonological memory tests were included; i.e. a digit span test and an auditory interference test, which required participants to repeat in the same or reversed group order two groups of three words which were phonologically related.

Intelligence was assessed using parts of various intelligence tests. Hearing loss, visual impairment and neurological problems, if present, were reported in an anamnesis. Problems with peripheral auditory perception were tested with an auditory discrimination test. Visual processing problems were tested with a time-limited test for the discrimination of figural details.

Reading and Spelling Tests

Reading words was assessed by the One-minute-test (Brus & Voeten, 1973), consisting of a chart with 116 non-related words increasing in length. The total number of correctly read words within one minute determines the score.

Text reading was assessed by the 'Livingstone' text (Schaap, 1986b). This text consists of 64 lines which participants are required to read. The words represent the problems in the Dutch written language. The number of reading errors determines the participants' test score.

Spelling skills were assessed using the IWAL standard dictation (Harel, 1981). The IWAL standard dictation consists of 19 sentences. The words used in the sentences can be considered to be familiar to all elementary-school children, as well as a representative sample of the problems in the Dutch spelling (Harel, 1981).

All of these tests are sufficiently reliable (range r_{tt} 0.90 - 0.98). During treatment, words and sentences that are part of the tests were avoided.

Although the One-minute-test, the Livingstone-text and the IWAL standard dictation were used in a standard fashion, due to factors relating to the every day IWAL practice it occasionally occurred that for the measurement of reading text or spelling other tests were used. Different tests have thus sometimes been used at different moments of time for the same person. To guarantee intrapersonal comparability of results, the data of the different tests for these persons were transformed to a standard score, so their scores can be used in the index, which is explained in the next section.

At the time of follow-up measurements (m4) all participants took the three standard tests. At the same time the participants completed a questionnaire (see appendix). In this questionnaire participants are asked about their reading habits: how often they read and for what periods of time. Questions are also asked about the performance of the participants in reading and spelling at the time of questionnaire completion and about treatment satisfaction.

Preliminaries to Data Analysis

The Dependent Measure

In order to evaluate treatment effect, simple statements about 'significant differences' are not very useful. As we evaluate the treatment essentially with respect to its remediation effect, it makes sense to formulate a *remedial index* for each of the three tests:

$$r_{ixt} = \frac{{}_{i}x_{t} - {}_{i}x_{0}}{{}_{i}x_{nt} - {}_{i}x_{0}}$$

in which $_{i}x_{t}$ = the score of participant *i* on test *x* at time *t*
$_{i}x_{0}$ = the score of participant *i* on test *x* at the start of the treatment
$_{i}x_{nt}$ = the norm for test *x* corresponding to the age of participant *i* at time *t*

The remedial index of person *i*, at time *t*, for test *x* is the ratio of two distances: 1) the one it would have covered ideally, from its first deficient score to the general norm at the time of measurement. This is expressed in the denominator; and 2) the one it covered actually in that time interval. This is expressed in the numerator. One would wish all participants to score about '1' (ie. they are all 'normal' after remediation). An index of about '0' would indicate there had been no remediation effect whatsoever. Most participants were expected to be somewhere between these extremes. Theoretically it would be possible to have an index < 0 (the participant deteriorated) or > 1 (the participant scores above the average norm now). Note that the time *t* in the index refers to the moment of measurement (for instance: after 4 years) and is identical in numerator and denominator.[3]

Assumptions of the Statistical Tests
As each group includes more than 20 participants and the number of participants per group is about equal, we can be brief about assumptions behind the Anovas and *t*-tests that we plan to apply: our tests are robust (Stevens, 1992; Winer, Brown, & Michels 1991). As each score was established in an individual investigation, and preliminary tests show no significant differences between groups as to age, sex, IQ and number of sessions, there seems to be no ground to suspect a contamination by 'intraclass correlation'.

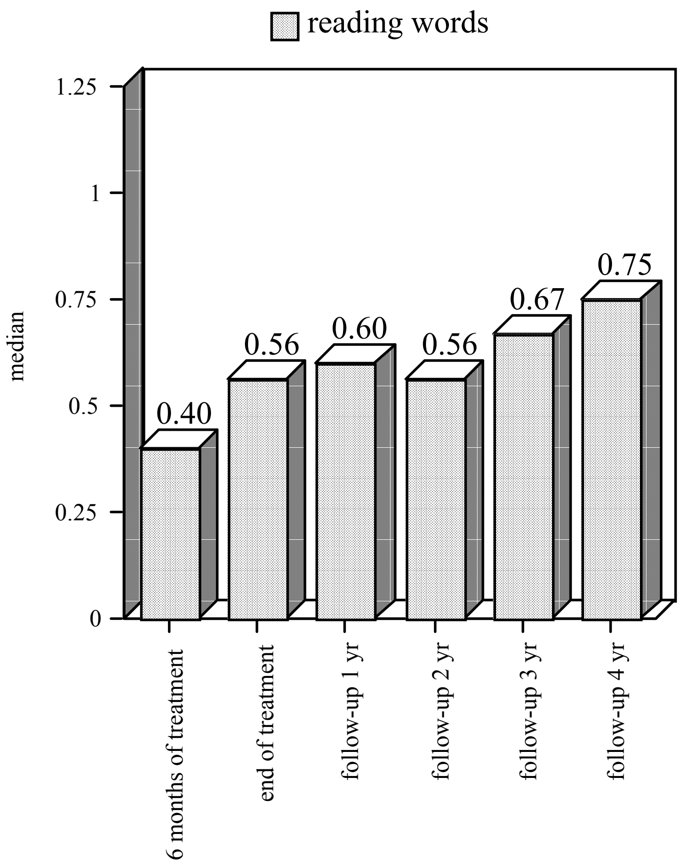
We used three dependent variables that are psychologically related. They are supposed to stem from a common root: dyslexia. To investigate whether there is dependency in a technical sense, we computed the Pearson correlation coefficient between the three variables. We did so separately for the measurement-between, the measurement-after and the follow-up measurement. There are, consequently, (3 x 3 =) 9 coefficients. Of these, 8 range from -0.02 to 0.17 and only one (reading text *x* reading words at the follow-up) reaches $p < 0.01$ significance with a value of 0.30. This indicates that there is no reason to abandon our original plan to analyse the three dependent variables separately.

Results

Reading words. Figure 1 shows the medians of the remedial indices at the times of measurement. Surprisingly, these show a tendency to increment at the follow-up measurements. The remedial index at the start of treatment was 0 by definition. Therefore, we tested the progress made by the participants after six months of treatment by a right one-tailed t-test. Results indicated a significant improvement on reading words ($t = 8.82$, $p < 0.01$; effect-size $d = 1.62$). The participants' levels of word reading after six months of treatment, at the end of treatment and 1, 2, 3, and 4 years after treatment were compared in an Anova with one between-subject factor: follow-up groups (1, 2, 3 or 4 years after treatment) and one within-subjects factor: times of measurement (after six months of treatment, at the end of

treatment and follow-up). Results revealed no main effect for groups, $F(3,96) = 0.54$, $p = 0.65$, but a significant one for moment of measurement, $F(2,192) = 16.14$, $p < 0.01$.

Figure 3.1. Medians of the Remedial Indices for Reading Words



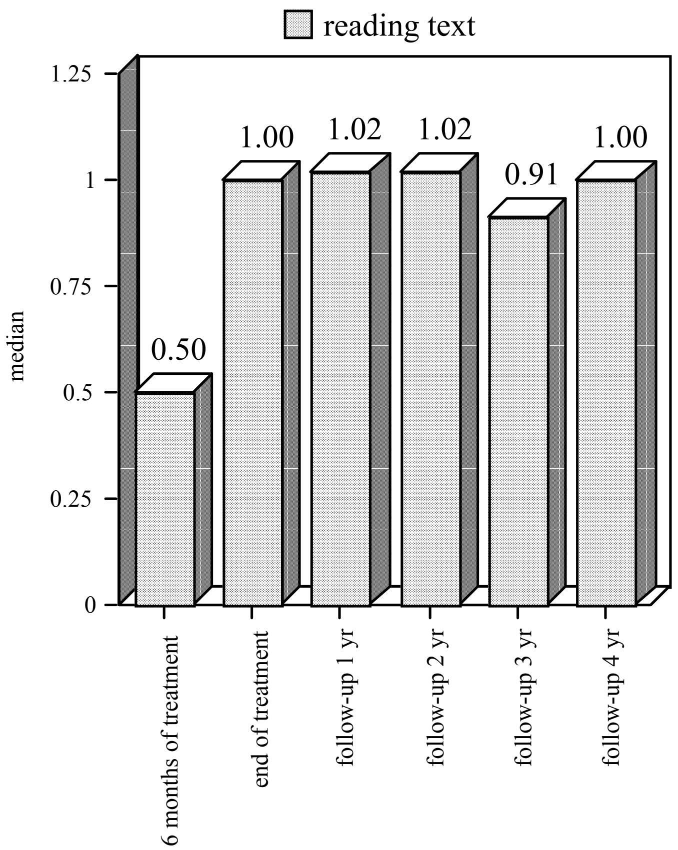
There was no significant interaction, $F(6,192) = 1.02$, $p = 0.42$. The significant effect was profiled by a test for linear contrast, which showed, together with Figure 1, that word reading was significantly improved at the end of treatment ($p < 0.01$; effect-size $d = 0.54$), and that the participants' word reading levels at the follow-up measurements were not inferior to the levels at the end of treatment ($p = 0.02$). The remedial index of a 'normal' reader was 1 by definition. Therefore, we compared the attained level at the end of treatment to the normal level of word reading by a left one-tailed *t*-test. Results revealed that the participants differed significantly from the normal level at the end of treatment, $t = -2{,}98$, $p < 0.01$. Frequency distributions of the remedial indices are shown in Table 2.

Results for word reading showed that the treatment gives a clear continuous positive effect, which persists after the treatment. However, the effect was not substantial enough to render the participants comparable to 'normal' subjects.

Table 3.2. Frequency Distributions in Percentages (Cumulative Percentages) of the Remedial Indices for Reading Words

remedial □index:	6 months of treatment		end of treatment		1 year after treatment		2 years after treatment		3 years after treatment		4 years after treatment	
>1	10	(10)	17	(17)	20.7	(20.7)	21.7	(21.7)	27.3	(27.3)	19.2	(19.2)
0.8-1	6	(16)	8	(25)	10.3	(31.0)	4.3	(26.1)	13.6	(40.9)	23.1	(42.3)
0.6-0.8	13	(29)	20	(45)	20.7	(51.7)	17.4	(43.5)	22.7	(63.6)	38.5	(80.8)
0.4-0.6	22	(51)	28	(73)	27.6	(79.3)	34.8	(78.3)	18.2	(81.8)	15.4	(96.2)
0.2-0.4	28	(79)	17	(90)	20.7	(100)	4.3	(82.6)	9.1	(0.9)	3.8	(100)
0-0.2	18	(97)	7	(97)	0	(100)	13.0	(95.7)	4.5	(95.5)	0	(100)
<0	3	(100)	3	(100)	0	(100)	4.3	(100)	4.5	(100)	0	(100)

Figure 3.2. Medians of the Remedial Indices for Reading Text

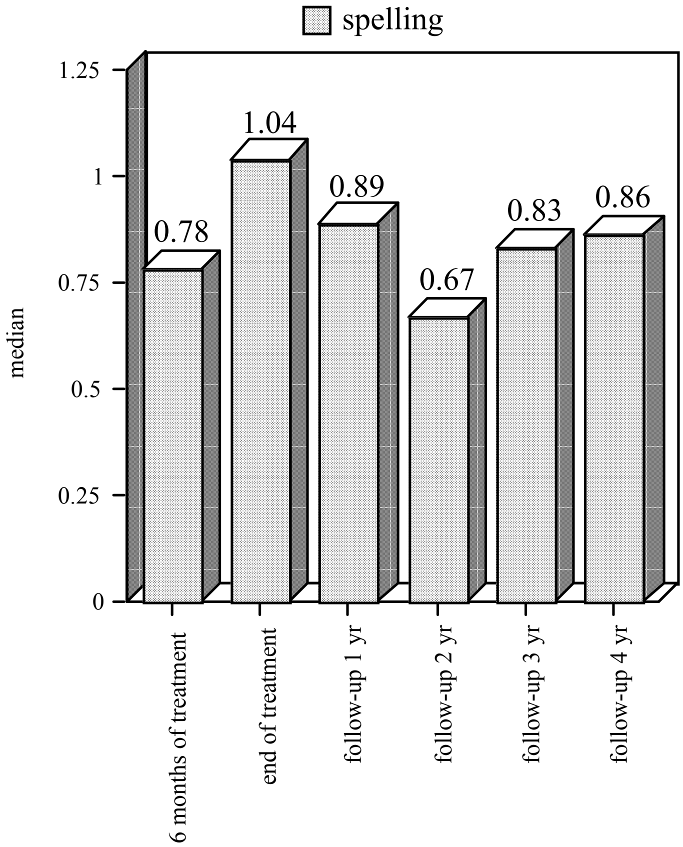


Reading text. Figure 2 shows the median remedial indices. As can be seen from this figure, participants made a sizeable improvement in reading test. The improvement after six months of treatment was analysed by a one-tailed *t*-test. The test revealed a significant effect of treatment after six months, $t = 3.24$, $p < 0.01$; effect-size $d = 0.88$. Reading text levels after six months of treatment, at the end of treatment and at the follow-up measurements were compared by an Anova (times of measurement by follow-up groups). The results of this comparison revealed no main effect for groups, between subjects, $F(3,96) = 1.37$, $p = 0.26$. The main effect for moment of measurement was significant, within subject, $F(2,192) = 9.91$, $p < 0.01$. No significant interaction was present, $F(6,192) = 0.34$, $p = 0.92$. Linear contrasts revealed a significant difference between levels attained at six months of treatment and those at the end of treatment, $p < 0.01$; effect-size $d = 0.66$, but no significant differences between levels at the end of treatment and at the follow-up measurements ($p = 0.54$). A one-tailed *t*-test showed no significant differences between the normal level of text reading and the attained level at the end of treatment. The frequency distributions of the remedial indices are presented in Table 3. As for reading text, the results indicate that the treatment had a clear continuous effect, which held over the years, and that the effect was sufficiently large to regard the participants as being no longer disabled by their dyslexia when reading text.

Table 3.3. Frequency Distributions in Percentages (Cumulative Percentages) of the Remedial Indices for Reading Text

remedial index:	6 months of treatment		end of treatment		1 year after treatment		2 years after treatment		3 years after treatment		4 years after treatment	
>1	31	(31)	56	(56)	62.1	(62.1)	60.9	(60.9)	45.5	(45.5)	76.9	(76.9)
0.8-1	7	(38)	6	(62)	10.3	(72.4)	13.0	(73.9)	18.2	(63.6)	3.8	(80.8)
0.6-0.8	9	(47)	7	(69)	20.7	(93.1)	8.7	(82.6)	13.6	(77.3)	7.7	(88.5)
0.4-0.6	4	(51)	6	(75)	0	(93.1)	4.3	(87.0)	9.1	(86.4)	0	(88.5)
0.2-0.4	20	(71)	11	(86)	3.4	(96.6)	8.7	(95.7)	4.5	(90.9)	3.8	(92.3)
0-0.2	21	(92)	10	(96)	0	(96.6)	0	(95.7)	4.5	(95.5)	0	(92.3)
<0	8	(100)	4	(100)	3.4	(100)	4.3	(100)	4.5	(100)	7.7	(100)

Figure 3.3. Medians of the Remedial Indices for Spelling



Spelling. The median remedial indices are presented in Figure 3. Inspection of Figure 3 suggests that participants' spelling attainment clearly improved during treatment, but slightly declined after treatment. The participants improved significantly after six months of treatment, as demonstrated by a one-tailed *t*-test ($t = 9.52$, $p < 0.01$; effect-size $d = 0.95$). An Anova (times of measurement by follow-up groups) revealed no main effect for groups (between subjects, $F(3,96) = 0.28$, $p = 0.84$), but a significant effect of moment of measurement (within-subject, $F(2,192) = 14.13$, $p \sim 0.00$). There was no significant interaction, $F(6,192) = 1.89$, $p = 0.09$. Linear contrasts indicated - together with Figure 3 - a significant increase in spelling attainment in the interval between six months of treatment and the end of treatment ($p < 0.01$; effect-size $d = 2.15$), but also a significant decline after treatment ($p < 0.01$). The isolated value of the median at the end of treatment, the maximum of all values reported, is highlighted by the value of the contrast between measurement after six months and follow-up measurement: $p = 0.34$. A one-tailed *t*-test indicated that the participants attained a normal level of spelling at the end of treatment (no significant effect). Frequency distributions of the remedial indices are shown in Table 4.

Results for spelling indicated continuous effect of treatment on spelling. Participants, however, did not maintain their level reached at the end of treatment, but fell back to about the level they had after six months of treatment. Nonetheless, they were still comparable to non-dyslexics in their spelling at the end of treatment.

Table 3.4. Frequency Distributions in Percentages (Cumulative Percentages) of the Remedial Indices for Spelling

remedial index:	6 months of treatment		end of treatment		1 year after treatment		2 years after treatment		3 years after treatment		4 years after treatment	
>1	30	(30)	65	(65)	24.1	(24.1)	21.7	(21.7)	40.9	(40.9)	30.8	(30.8)
0.8-1	18	(48)	22	(87)	37.9	(62.1)	21.7	(43.5)	9.1	(50.0)	30.8	(61.5)
0.6-0.8	22	(70)	8	(95)	20.7	(82.8)	17.4	(60.9)	9.1	(59.1)	19.2	(80.8)
0.4-0.6	10	(80)	0	(95)	6.9	(89.7)	4.3	(65.2)	18.2	(77.3)	3.8	(84.6)
0.2-0.4	10	(90)	2	(97)	10.3	(100)	13.0	(78.3)	9.1	(86.4)	0	(84.6)
0-0.2	6	(96)	1	(98)	0	(100)	13.0	(91.3)	4.5	(90.9)	7.7	(92.3)
<0	4	(100)	2	(100)	0	(100)	8.7	(100)	9.1	(100)	7.7	(100)

Secondary analyses

Background variables. To gain insight into the nature of the treatment effect, we examined the remedial index in relation to some other characteristics of the participants. Effects of age, IQ, seriousness of the phonological deficit, and social-economic status on treatment gains were analysed by correlation coefficients (Kendall's tau). In each case we looked at the indices at the end of treatment, as well as at the follow-up values for all three dependent variables.

The age range of the participants is wide. Therefore, it is important to assess the influence of age on the treatment effects. As can be seen in Table 5, the overall level of correlation was low. The highest correlation was 0.250 for reading text at the end of the treatment. This value points at about 6% of common variance, which was at the follow-up decreasing to near zero. So, we can safely conclude that the effects of treatment are independent of age.

Results revealed a significant correlation, $r = 0.197$, $p < 0.05$, between IQ and spelling at the end of treatment. However, it was the only significant correlation. The other values ranged from -0.011 to 0.054.

It stands to reason to explore the relation between the effect of treatment and the seriousness of the deficit prior to the treatment. The degree of the latter was operationalised by the number of phonological tests[4] on which the participant scored below the mean in the pretesting. Hence it ranges from 0 to 6. Correlations ranged from -0.245 to 0.011. Two of the correlations were significant, both at reading text: at the end of treatment, r = -0.209 (p < 0.01) and at follow-up r = -0.245 (p < 0.01). Whatever the background of this result, one must conclude that the correlation between effect of treatment and seriousness of deficit at the start of treatment is far from substantial.

Also, the social-economic status was related to the effects of treatment. In The Netherlands, health care insurance is a proper way to operationalise social-economic status. People with a lower status have a 'sickness fund insurance' and those with higher status have a private health insurance. Social-economic status was also operationalised by income. Results showed no significant relations between treatment effects and social-economic status (correlations ranged from -0.172 to 0.157 for type of health care insurance, and from -0.098 to 0.078 for income).

Table 1.5. Correlations Between Age and Treatment Effect

	end of treatment	follow-up
Reading Words	0.047	-0.096
Reading Text	-0.250*	-0.068
Spelling	0.081	0.079

* p < .01

Two separate explorations. Scrutinising the remedial indices and identifying participants with values < 0.2, showed no overlap for the three outcome measures. In the questionnaire, some items referred to daily habits of reading. These items were included in order to be able to relate a potential deterioration at follow-up to these habits. As the former did not take place, there was little point in exploring these answers. A large majority of the

participants (about 90%) gave positive reactions to the other questions: i.e. better reading and spelling following treatment, few or no problems with reading and spelling in daily life, satisfaction with the treatment, treatment made daily life easier.

Discussion

The present study addressed three questions, concerning the LEXY treatment of dyslexia:

1. Is the treatment effective? Do dyslexics (children and adults) display significant improvements in reading and spelling following the treatment?
2. Are the effects of the treatment long lasting?
3. Are the effects of the treatment substantial and clinically relevant? Establishing effects of the treatment by means of statistical test is a necessary but not sufficient condition of the treatment's success. Ultimately, a treatment should result in appreciable, clinically relevant improvements.

The first question can be answered positively. By teaching the participants to make use of the phonological and morphological information in spoken and written words, the LEXY treatment resulted in improvements in reading and spelling. The outcomes were steady increases in performance at reading words, reading text and spelling after six months of treatment. These increases ranged from nearly halving the distance between the scores of the participants and the norm for reading words to a reduction of this distance for more than three quarters for spelling. At the end of treatment the performance levels showed further improvement. An important aspect is that the results of this investigation are not just an improvement on the words that were practised during the treatment. Rather the results show a clear generalisation of effect. The words in the tests differ from those used in the treatment, and are representative of the Dutch written language.

The answer to the second question is provided by results that show that the beneficial effects of the LEXY treatment are persistent. Participants displayed stable improvements in reading over a period of one to four years after the treatment. Their improvements in spelling declined slightly after the first year but stabilised at that level over the following years.

As to the last question, the improvements were clinically relevant as the participants achieved an average level of reading text and spelling. This result is unusual in the field of treating dyslexia (Torgesen et al., 2001). Reading words did not reach the normal level, although a large effect size shows that the treatment gain is substantial. At the end of treatment the distance between the dyslexic's scores at reading words and the norm is reduced with more than 50%. In addition, as the questionnaire reveals, a large majority of the participants also experienced substantial improvement following treatment in their reading and spelling.

However, some participants do *not* profit from the LEXY treatment on some variables (remediation indices < 0.2), although they were very few in number and every participant did profit from the treatment on at least one variable.

The other two results that cast some shadow are the slight decline of spelling after the treatment and the below-normal reading of words at the end of treatment. These results can be explained by putting the three dependent variables on some 'scholastic training - full life experience' continuum.

Every literate person in Dutch society is to a substantial degree involved in reading text; on the other hand, there are quite a few jobs, and situations in general, in which spelling is hardly required. In this way spelling and reading text can be seen as poles of a continuum, with reading text being at the 'experience' side. Viewing this way it is unsurprising that spelling, being the 'rule-learning instruction kernel' of the treatment, shows symptoms of over-learning at the end of treatment, which are corrected after the treatment. Results show that the partial relapse after termination of treatment can be considered as a one time only event and not as a steady decline.

All these comments do not apply to the task of reading words; on the contrary, one could postulate some 'under-learning' that would account for the fact that the effect is not 'substantial' enough and that more time is needed to bring reading words into the normal range.

A question is how the current study fits in to the broader picture of treatment evaluations. In terms of transfer of treatment effects, both Snowling (1996) and Lyon and Moats (1997) mention in their evaluation reviews, many intervention studies fail to find effects of transfer, or worse, do not look for such effects. Lyon and Moats (1997) suggest that the amount of time invested in the explicit integration of phonological skills in reading tasks is a crucial factor in determining the amount of transfer. The current study was designed to find transfer of effects by assessing reading and spelling skills with words that differ from the words used in the treatment. As mentioned above, a generalisation of effect was found with respect to both reading and spelling. Since the LEXY treatment has a strong focus on operations by which the learned phonological concepts can be translated to the orthography, the results provide some evidence for the Lyon and Moats hypothesis.

Some researchers have argued that there are developmental, age-related boundaries beyond which dyslexic children cannot be successfully remediated with phonological training (Wagner, Torgesen, & Rashotte, 1994). However, Lovett and Steinbach (1997) showed that effectiveness of treatment does not necessarily decrease with increasing age. They reported equivalent gains of remediation for children in Grades 2, 3, 4 and Grades 5, 6. The current study extends the findings of Lovett and Steinbach (1997) by showing that adolescents and adults profit as much as elementary-school children from treatment.

As mentioned in the introduction, the majority of intervention studies report only short-term effects. It is thus unclear whether reported gains observed in these studies persist over time (Lyon & Moats, 1997). Since the current study does report follow-up effects, it has some important implications. By showing clear long-term improvements in reading and spelling, it provides further support for the proposition that focusing on the phonic structures of words is a promising way to approach the reading and spelling problems of the dyslexic.

A point of consideration is the absence of a control group in a formal sense in the present study. It was chosen not to use a control group of non-impaired persons because of the fundamental difference between the two groups; that is, the dyslexic group are characterised

by a function deficit (phonological processing deficit), whereas those free of dyslexia have an intact underlying function. Since dyslexia seems to reflect a developmental deviance (Stanovich, Siegel, & Gottardo, 1997), the non-impaired readers do not serve as a suitable control for the progress made by the dyslexic group during the treatment period. In this sense, the normal reading development of dyslexics is a more informative control condition; there is clear evidence that the reading deficit of dyslexics is stable over the years (Foorman, et al., 1997; Jacobson, 1999; Juel, 1988; Stanovich, 1986). The goal of this study was to test whether participants, starting with a reading and spelling deficit, can obtain a more or less normal level of reading and spelling skills after the treatment with the LEXY-program. Therefore, it appeared to be an adequate design to test the progress of each participant against a criterion, which is based on the average of a large normative sample. Population norms can hereby be considered as a control condition (Torgesen et al., 2001).

Another option could be the use of a control group of dyslexics. For this option, we were faced with both ethical and practical difficulties. A control condition with dyslexics, who were not treated or treated with a programme, which was *a priori* expected to be non-effective, would be ethically questionable. Comparing LEXY with another treatment that was potentially effective, would be ethical. It also would have been informative, since it could provide further information on the effective aspects of the programme. Unfortunately, this option encountered practical impediments. However, in another study a process-oriented evaluation of the treatment has been carried out to provide a window on the dynamics of change. In this study a configuration of effects was related to the time course of the treatment components. The participants showed a cascade of improvements that corresponded to the presentation order of treatment components (Tijms, in press).

Another point of concern relates to the problem of self-selection of participants. The sample of the present study can be considered as a cohort randomly drawn from the IWAL-population. Arguably, it is not a random sample from the population of Dutch dyslexics. Most of the participants were referred to the Institute, and therefore not self-selected in a strict sense. Our results provided no indications for a bias in the demographic sample. The incomes of the sample were comparable with the average of the Dutch population. Furthermore, within the sample, treatment effects were not related the social-economic status of the participant. This result is consistent with results of a study on the reading and spelling attainment in Dutch elementary schools (Sijtstra, 1997). This study revealed no relationship between the social-economic status of students and their word reading and spelling performances at the end of elementary education.

Analogues can be drawn between Dutch and English. Both the orthographies are based on the same principles with the alphabetical principle being the standard. In English, significant changes in pronunciation around 1400 were responsible for serious disruptions of the level of grapheme-phoneme concordance that existed before the change and were not corrected afterwards. In Dutch, this did not happen to any great degree; in this respect Dutch spelling is more transparent than English. The conservative tendencies in the spelling of Greek and Latin (learned) words have had a longer live in English than in Dutch. In both languages many French words have been incorporated, in the development of English as part of the core of the language and as such also an integral part of the orthography. In eighteenth

century many French words were introduced in Dutch in their original spelling, complicating Dutch orthography. From the second half of the twentieth century English words, most of them in their original spelling, became part of Dutch vocabulary. A strong popular wish for a spelling reform of loan-words at the end of the last century ended in a confusing result. A rational linguistic principle of spelling is morphological constancy: the wish to show in the spelling the common root of words. Because this principle breaks the grapheme-phoneme relation there is a need for 'repair'. In both English and Dutch, this principle and the repair are very productive. English examples: *read* (present tense) – *read* (past tense); *nation* – *nation*al; *bomb* - *bomb*ard; repair of the grapho-phonic relation is: (*hope*) *hope*d – (*hop*) *hopp*ed, here the shortness of the vowel is repaired by doubling the consonant. Here are some Dutch examples: *paard* - *paard*en (horse-horses) the letter d is written in paard analogous to paarden, although the pronunciation of the last consonant is /t/; repair: (hoop) hopen – (hop) hoppen (the words have the same meaning as in English). Also in Dutch the repair in order to preserve the shortness of the preceding vowel is by doubling the consonant (in general: the short vowel in an open syllable should always be followed by two consonant graphs). In Dutch, other than in English, both aspects of the morphological principle are systematically applied on orthographic level.

Preliminary findings of the Greek version of LEXY have shown improvements in the spelling skills of 12 dyslexic children. The participants reached a normal level of spelling single words after two to three months of (weekly) treatment (Psomaka Hoette, Michopoulou, Fotopoulou, & Anthi, 1999). These findings support the notion that the LEXY method may be a useful treatment in other language areas as well. Notwithstanding the above arguments, further research is needed on the treatment effect. On the other hand, our results support the usefulness of psycholinguistic models as the fundamental basis of treatment for dyslexia.

Notes

1. This chapter is published in *Journal of Research in Reading, 26,* 121-140 with Jan Hoeks, Marja Paulussen-Hoogeboom and Ton Smolenaars as co-authors.
2. A preliminary report of the data was presented at the World congress on dyslexia, September 1997, Thessaloniki, Greece.
3. As the participant at the beginning of treatment does not need be below his or her norm on *all* variables, in a few cases the denominator becomes zero or negative. Paradoxically, then, this subject should need no treatment at all (on this aptitude). In order to avoid this the norm in question was doubled in order to make the denominator positive again. This has the desirable effect of not inflating the remediation index. On the contrary, by raising the norm it becomes 'unnaturally' low.
4. Note that these are not part of the dependent variables and so do not enter the remediation index, thereby avoiding a contamination of the issue. As the remediation index by definition specifies the amount of remediation relative to the amount needed to overcome the disabling effects of dyslexia, one would not expect substantial relations here. The more so in view of the fact that treatment time is variable: 'until-success'.

Appendix. Questionnaire about the reading habits and treatment satisfaction

How many days a week do you read:	never	1-2 days	3-4 days	5-6 days	every day
newspapers	-	-	-	-	-
magazines	-	-	-	-	-
books	-	-	-	-	-
letters/leaflets	-	-	-	-	-

How long do you approximately read each time:	less than 5 minutes	5 to 15 minutes	15 to 30 minutes	longer than 30 minutes
newspapers	-	-	-	-
magazines	-	-	-	-
books	-	-	-	-
letters/leaflets	-	-	-	-

How is your reading in comparison to the time before the treatment?
- much better
- somewhat better
- no difference
- somewhat worse
- much worse

How is your spelling in comparison to the time before the treatment?
- much better
- somewhat better
- no difference
- somewhat worse
- much worse

Are you having difficulties with reading in your everyday life?
- a lot of difficulties
- a few difficulties
- no difficulties

Are you having difficulties with spelling in your everyday life?
- a lot of difficulties
- a few difficulties
- no difficulties

Are you satisfied with the treatment?
- yes
- don't know
- no

Did the treatment simplify your everyday life?

- no
- don’t know
- yes

Chapter 4

A process-oriented evaluation of a computerised treatment for dyslexia[1]

Abstract

One hundred thirty-one 10- to 14-year-old Dutch children with reading and spelling difficulties received a treatment for dyslexia. The treatment was computer-based and focused on learning to recognise and use the phonological and morphological structure of Dutch words. The treatment consisted of several modules, each addressing specific links between phonological concepts and the writing system. A process-oriented evaluation of this treatment showed a time course of effects that was specifically related to the timing of treatment components. The children showed a cascade of improvements that corresponded to the presentation order of the treatment modules. These findings indicate that the computerised treatment based on inferential algorithms provides an effective tool in the remediation of dyslexia.

Introduction

Writing systems are human inventions, developed as a response to language and aiming at graphic representation of spoken language (Liberman, 1997). In alphabetical writing systems the graphs transcribe the (morpho)phonological representations in the mental lexicon (Mann, 1998; Pinker, 1999). These representations can be considered as sequences of phonemes which preserve the basic units of meaning (Mann, 1998). In the process linking phonological representations to a phonetic plan for connected speech, the language user is assumed to employ a series of phonological rules (Levelt, 1989, 2001). These rules are critical for the differences between the spoken word and its orthographic representation. The phonological rules are triggered by a class of phonemes that share one or more features (e.g. voicing). This suggests that phonological rules are not directed at the phonemes as such, but on the features from which they are composed (Pinker, 1994). This process constitutes the phonetic module (Liberman, 1997; Pinker, 1999). It is supposed that the phonetic module is essential for reading and spelling (Dietrich & Brady, 2001; Liberman, 1997). The basic task of learning to read and spell appears to be that children must learn how the writing system encodes their language (Perfetti, 1999b).

Developmental dyslexia is characterised by a persistent difficulty in the acquisition of reading and spelling skills (Dietrich & Brady, 2001; Lyon, 1995a; Pennington, 1991; Snowling, 2000). Since Vellutino's (1979) crucial review of dyslexia, it has become increasingly evident that dyslexia stems from an underlying deficit in the phonological processing system (Beitchman & Young, 1997; Crain & Shankweiler, 1991; Leonard et al., 2001; Lovett, 1997; Lyon, 1995a; Shaywitz, 1996; Siegel, 1993; Vellutino, Scanlon, & Spearing, 1995). Dyslexic individuals have been shown to have difficulty in segmenting and manipulating phones[2] in words, subtle difficulties in speech perception and production, limitations in performance of phonics-based memory, and problems with rapid retrieval of

phonological information from long-term memory (Elbro, Borstrøm, & Petersen, 1998; Mody, Studdert-Kennedy, & Brady, 1997; Pennington, Van Orden, Smith, Green, & Haith, 1990; Wagner, Torgesen, & Rashotte, 1994). Psycholinguistic research indicates that an unstable or underspecified phonological representation in the mental lexicon is a core deficit in dyslexia (Elbro et al., 1998; Goswami, 2000; Snowling, 2001; Swan & Goswami, 1997a, 1997b). This suggests that dyslexics possess a dysfunctional phonological system. As a result dyslexics seem to be unable to use the implicit phonological structures in their reading and spelling.

On the basis of the above, phonologically based interventions seem most promising in the treatment of reading and spelling problems of dyslexics. An increasing number of evaluation studies report beneficial effects of training phonology on reading performance (Hatcher, 2000; Lovett et al., 2000; Pogorzelski & Wheldall, 2002; Snowling & Nation, 1997; Swanson, 1999; Torgesen et al., 2001; Wise, Ring, & Olson, 1999, 2000). Most evaluation studies consist of a quantitative comparison of pre- and post-test, without considering the process by which effects are obtained (Lyon & Moats, 1988; 1997). Research within this context has clarified some issues concerning the treatment structure by comparing different treatment programs (Lovett et al, 2000; Wise et al., 1999, 2000).

One important finding is that tuition of phonological awareness is a necessary, but not a sufficient, component of intervention for generalised improvements in reading and spelling. Explicit instruction relating the phonic elements to their orthographic representation appears necessary (Hatcher, Hulme, & Ellis, 1994; Snowling & Nation, 1997). For example, in the study of Hatcher et al. (1994), three forms of training were compared, which were limited to phonology, reading, or reading with phonology. In the phonology training, tuition focused on phonological concepts (e.g., segmenting words into phones), without relating these concepts to the written word. The reading training was modelled on the work of Clay (1985) and focussed on reading books. The reading with phonology training included elements of both other training-methods. In addition, the participants conducted activities aimed at linking reading and phonology. These activities included practising letter-sound associations and writing words while paying attention to letter-sound relationships. The results showed that the reading with phonology treatment was most effective. Hatcher et al. (1994) concluded that in treating dyslexia it is important to form explicit links between reading activities and phonological knowledge.

Though comparison of the effectiveness of different treatments may provide important information on treatment features, the process by which the treatment effects are attained remains largely unclear. In a review of the pertinent literature, Lyon and Moats (1997) conclude that limitations remain with respect to the knowledge of why specific treatment programs are effective and that “we have yet to solidify and refine our knowledge” (cf. Lyon & Moats, 1997, p. 580).

The objective of the present study was to establish a procedural evaluation of a Dutch psycholinguistic treatment for dyslexia, coined LEXY. The effectiveness of the LEXY-treatment has been the subject of evaluation before (Hoeks & Schaap, 1992; Van den Akker, Hoeks, & Mellenbergh, 1986; Tijms, Hoeks, Paulussen-Hoogeboom, & Smolenaars, 2003). The studies of Van den Akker et al. (1986) and of Hoeks and Schaap (1992) revealed clear

improvements in spelling and accurate text reading after six months of treatment. Tijms et al. (2003) evaluated the short and long-term effects of treatment. This study replicated the positive treatment effects but, more importantly, indicated that the improvements in word and text reading were stable over a 4-year follow-up period. Spelling showed a slight decline one year after the treatment, but remained stable thereafter.

The primary purpose of the present study was to examine the relation between the timing of treatment effects and the presentation order of treatment modules. Four modules are distinguished in LEXY, each addressing specific elements of the writing system. It is anticipated that the timing of an effect is closely tied to the corresponding treatment module. Revealing the link between the order of the treatment modules and their successive effects throughout the LEXY treatment will provide a detailed window on the dynamics of change. The present study had a longitudinal set-up, therefore each subject served as its own control, so that a control group of non-dyslexics was unnecessary and a control group of dyslexics unethical.

The Treatment

LEXY is based on the assumption that dyslexia is caused by problems in the building up and consolidation of a stable phonological representation in the mental lexicon (for a description of the program, see also Tijms et al., 2003). The focus of LEXY is on the language units, the basic rules and the minimal heuristic knowledge needed to be implemented in a computer program in order to transform a spoken word into a correct orthographical word form. Central to the computer program is an algorithm with an inferential structure (if a phone of class X is in position Y then perform operation Z) and a number of heuristics for those orthographical inconsistencies that could not be captured in the algorithm (Schaap, 1997).

LEXY is inspired also by remedial considerations. In view of the dyslexic's problems with verbal information processing, the modality of instruction is graphic rather than verbal. During instruction all new actions are guided by a graphic representation of the action. Subjects have to articulate all their actions in order to induce appropriate internalisation of the action. Recent research findings support the importance of inner speech in learning new skills (Berk, 1994). Additionally, LEXY is highly structured and its demands are within the information processing capabilities of the subject.

The treatment starts with a focus on the phonetic structure of Dutch words. Later in the treatment operations are introduced to map the phonetic structure onto the correct orthographic word form. Next, attention is shifted to the implications of the morphological structure for orthography. This aspect differs from most interventions focussing on phonemic skills. Recently, the importance of morphemic knowledge in the development of reading and spelling skills has been emphasised (Leong, 2000; Mahony, Singson, & Mann, 2000; Mann, 2000). Thus, Snowling (2000) recommends that intervention methods should include morphemic knowledge. Also, the focus of training is first on monosyllabic words containing simple phonetic patterns and, later, on more complex patterns and polysyllabic words. Throughout, training proceeds to the next skill or to a combination of mastered skills, only after a particular skill has been mastered.

The syllabic structure of words is the focal point of the treatment. This is because the syllable is the smallest possible, but still naturally pronounceable, phonological structure. It is assumed that the syllable is not a lexical element, but emerges during prosodification, and is to some degree consciously accessible as internal speech (Levelt, 1989, 2001; Schiller, 1997). Therefore, by taking the ‘spoken’ syllable as unit of processing, the attention of the dyslexic is drawn to a perceivable structure in contrast to a phoneme, which is an abstract entity. Usage of the syllable allows dyslexics to better identify distinct speech-sounds than the use of whole words or morphemes as central unit. At the same time, in Dutch (as well as many other languages) the syllable is the phonological unit to which spelling rules apply. In the Dutch writing system the last phonic element of a syllable is essential to the dissociation between a spoken word form and its orthographic representation.

The correspondence between a phonic element and its standard graphic representation can be dissociated, depending on the phonological category to which the terminal phonic element of a syllable belongs. This aspect is implemented in LEXY as an inferential algorithm. This algorithm is presented as a set of production rules which can be seen as operations on five types of terminal phonic elements: ‘long’ vowels, ‘short’ vowels, unvoiced consonants, sonoric vowels and unstressed morphemes (Schaap, 1997). The algorithm is defined in general terms: "If the last phone <P> of the syllable is a member of the class <C>, then perform operation <O>". Each concept in this rule is defined explicitly; the existing speech-sounds, the classes to which these sounds belong, and the operations that are applicable to a given class of sounds. Some orthographic inconsistencies, however, can not be accommodated by the algorithm. These are presented as heuristic knowledge.

LEXY is a computerised treatment program requiring subjects to respond by typing the computer keyboard. To this end the keyboard of the computer is reconfigured. The keyboard does not have the usual qwerty-system of distinct letters, but consists of keys for each phone. It also contains an ‘abstract keyboard’, consisting of a series of icons to designate the categories of phones, a series of icons that stand for different spelling rules, and icons for stressed and unstressed syllables (Tijms et al., 2003).

Goal of the Study

Numerous evaluations of treatments for dyslexia have been conducted. A limitation of these evaluations is that the overall treatment effect is evaluated, without consideration of the process by which this effect is obtained. The present study evaluates the process by which treatment effects of a treatment for dyslexia is attained. Although this treatment is for reading and spelling difficulties and has previously been shown effective for both reading and spelling (Tijms et al., 2003), the present process-oriented evaluation is focussing on spelling only. The current focus on spelling is based on previous studies showing that spelling provides a valid index of orthographic knowledge that is essential for both reading and spelling (e.g., Perfetti, 1992, 1999b). Moreover, in contrast to spelling, reading is a covert process that does not adapt itself to a process-oriented analysis (cf. Shankweiler & Lundquist, 1992). The present treatment is divided into four modules, each addressing specific elements of the writing system. It is predicted that the treatment has a substantial overall-effect and, most importantly, that the timing of an effect is closely tied to the corresponding treatment module.

Method

Participants

The treatment sample in this study comprised 131 children, who were referred to the IWAL-institute.[3] The children were referred to IWAL because they were falling behind at school with respect to reading and spelling. The referrals originated from any one of a number of sources, including schoolteachers, parents and psychological and educational services.

The sample was a cohort of clients diagnosed at the IWAL-institute between 1990 and 1998. Participants selected from this cohort ranged from the sixth grade of elementary school through the second grade of secondary school (which equals an age range from about 10 to 14 years). To be included in this study, participants had to be at least one standard deviation below average in their reading or spelling abilities. In addition, they had to display problems in the phonological processing of words. This seemed to be an appropriate additional selection criterion, in view of the evidence indicating that phonological processing problems constitute the core deficit in dyslexia (Lovett, Borden, DeLuca, Lacerenza, Benson, & Brackstone, 1994; Torgesen, Wagner, & Rashotte, 1997b).

Table 4.1. Characteristics of Participants

n		131	
Age (years)		11.9	(1.5)
IQ		109.3	(10.2)
Number of treatment sessions		45.5	(14.3)
Gender ratio (male : female)		2.6 : 1	
School grade	elementary school	grade 6:	26%
		grade 7:	24%
		grade 8:	23%
	secondary school	grade 1:	19%
		grade 2:	8%
Word Reading Rate ZS		-1.51	(0.93)
Text Reading Accuracy ZS		-1.04	(1.65)
Text Reading Rate ZS		-2.57	(2.56)
Spelling ZS		-3.04	(2.37)
Phoneme Synthesis ZS		-0.32	(0.84)
Phoneme Analysis ZS		-0.34	(1.25)
Auditory Closure ZS		-0.82	(0.89)
Homophones ZS		-0.04	(0.89)
Phonological Memory – Digit Span ZS		-0.62	(0.76)
Phonological Memory – Interference ZS		-0.44	(1.19)

Note. Standard deviations in parentheses. ZS= z-score

Exclusion criteria were an IQ-score one standard deviation or more below average, problems with auditory discrimination of speech-sounds, problems with visual discrimination of

figures, or broad neurological problems. Thirteen children dropped out during the first half of the treatment for various reasons (e.g., motivation or moving to some other town). They were excluded from the sample. Since this exclusion could have influenced the evaluation outcomes, their reading and spelling performances were compared to the performances of the sample. Kolmogorov-Smirnov tests demonstrated that neither the levels of reading and spelling at the start of treatment (spelling: $p = .93$; word reading: $p = 1.00$; text reading accuracy: $p = 1.00$; text reading rate: $p = 1.00$) nor the treatment gains after three months of treatment (spelling: $p = .10$; word reading: $p = .34$) differed significantly between the two groups. Descriptive characteristics of the participants are summarised in Table 1.

Selection Measures

Problems with reading and/or spelling and phonological processing problems were characteristic of the individuals in the sample. Tests that were used for selection are summarised below. For all measures, reliability coefficients are presented in parentheses.

Reading and Spelling Tests

Word Reading Rate. Reading skills were assessed by the EMT (One-Minute-Test; Brus & Voeten, 1973), a time-limited test comprising one- to five-syllable unrelated words. The number of correctly read words within one minute determined the score ($r = .89$ to .93, test-retest).

Text Reading Accuracy and *Text Reading Rate* were assessed by the 'Livingstone' text (Schaap, 1986). This text consists of 64 lines which subjects are required to read. Subjects are instructed to read the text both fast and accurately. The text represents the various problems in the Dutch written language. The number of reading errors and the time taken for completion provide the outcome measures (Accuracy: $r = .93$ to .94, Rate: $r = .97$ to .99, test-retest).

Spelling. Spelling skills were assessed using the IWAL-Standard Dictation (Harel & Schaap, 1981). This dictation contains 19 sentences. The words are familiar to all elementary-school children. Based on the classification systems of Bakker (1965) and Van der Wissel (1963), for each of the common problems of the Dutch writing system several words were incorporated in the dictation (Harel & Schaap, 1981). Scoring is based upon the number of spelling-errors ($r = .90$, test-retest).

Phonological Tests

The literature on dyslexia distinguishes various language functions in which phonological processing plays a central role (Wagner & Torgesen, 1987; Liberman, 1997). Accordingly, a number of phonological tests was administered to assess different manifestations of the phonological processing deficit.

Phoneme Synthesis. The subtest Auditory Synthesis of the Language Test for Children (TVK; Van Bon, 1982) was used to examine the ability to synthesise phones into a word. This test is analogous to the Blending Words subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999).The Auditory Synthesis test consists of 29 items presented using a tape-recorder. Each word is presented phone by phone.

Participants are asked to say the word that results when phones are blended. Scoring is based upon the number of correct responses (*r* = .89, internal consistency).

Phoneme Analysis. The IWAL-Auditory Analysis was used to assess the subject's ability to segment words into phones. This test is similar to CTOPP subtest Segmenting Words (Wagner et al., 1999). The Auditory Analysis consists of 25 orally presented items. The items are monosyllabic words. Participants had to say each word phone by phone. The number of correct responses represents the score on the task (*r* = .85, internal consistency).

Auditory Closure. A Dutch version of the Illinois Test of Psycholinguistic Abilities (ITPA) subtest Auditory Closure was used (TvK-Word Recognition; Van Bon, 1982). Participants were presented with words in which one or more phonemes are deleted and replaced by a short silence. Participants are required to say the word. This test includes 29 items. Scoring is based upon the number of correct responses (*r* = .74, internal consistency).

Homophones. A homophone test (Hoeks, 1985) was used to measure the ability to link two different meanings to the same word form. This test is similar to Guilfords' Seeing Different Meanings (Guilford, 1971). Each of 22 items of the homophone test consists of four pictures presented on a white card. All of the four pictures represent a different meaning, but two of them can be linked to the same word form. Participants were asked which two pictures could be connected to the same word. Scoring was based upon the number of correct recognised pairs of homophones (*r* = .77, internal consistency).

Short-term Phonological Memory. Two short-term phonological memory tests were used. The first was a Dutch version of the Digit Span subtest of the WISC (WISC-RN; Van Haasen et al., 1985). The number of digits that a participant could repeat in correct or reversed serial order immediately after hearing them represents the score on this test. Scoring criteria are given in the test manual (*r* = .78 to .85, internal consistency). The second test is the IWAL-Auditory Interference test, in which two lists of three words are used to produce inter-list interference. The test is composed of 6 items. Each item consists of two groups of three monosyllabic words, which are presented orally. After presentation of the two groups, participants are asked to repeat the first group and after that to repeat the second group, or to repeat the second group and after that the first group. Scoring is based upon the number of words repeated correctly (*r* = .67 to .72, internal consistency).

Procedure

Treatment was provided on a one-to-one basis in a 45-minute session, which took place once a week. Besides these sessions at the institute, participants were required to practice at home three times a week for 15 minutes per time.

A treatment-session was divided in several parts. Each session started by going through the homework. Next LEXY instruction and training were discussed. During the instruction a new element was introduced, and the rules of translation of the phonic into orthographic form of the word were explained using a graphic algorithm (Schaap, 1997; see appendix A for an example of the algorithm). Training consisted of spelling and reading modules. During the spelling module, the participant was required to make the translation steps. First, the translation had to be made explicitly, step by step. Later on, a more implicit direct approach was practised. During reading training, words were projected individually on

the computer screen in various ways; e.g., phone by phone (e.g., k/a/t (English: c/a/t)), onset-kernel-coda (e.g., kl/a/p (sl/a/p)), or syllable by syllable (e.g., ka/tten (ki/tten)). During reading the whole word was projected faintly on the screen to allow anticipation (Schaap, 1997). The word components were highlighted at a pace, which was adjustable to the individual's reading speed. Instruction and training contained separate bodies of words, since the treatment was not a 'wordtrainer', but directed at general knowledge. A session ended by explaining the homework consignments. Homework consisted of exercises on paper with the aim to expand training with the elements that were subject of the session.

The program aimed at achieving a mastery level for each element of the program. This implies that participants did not pass through the program at a fixed pace. An element was considered to be mastered when the percentage of correctly performed items during training was at least 80%.

Module-specific Elements

Module 1. During module 1, only monosyllabic words were used. In the first part of this module, focus was on the phonetic structure of Dutch words. Training of speech-sounds took place on both a concrete level and an abstract level. At the concrete level, practice focused on the different speech-sounds. For instance, pronouncing or typing the word /schreeuw/ (cry) as /s/ /ch/ /r/ /eeuw/. Abstract practice focused on the abstract phonetic structure of words. For instance, sounding out or typing /schreeuw/ as [◄] (consonant) [◄] [◄] [IIII] (four-token sound).

Speech-sounds known as allographs have two standard graphic representations. Dutch allographs are ei/ij and au(w)/ou(w). These two types of allographs were introduced here by a story that included the most common words containing one of the two representations. Although the participants read this story here for the first time, it would recur throughout the treatment.

The second part of module 1 dealt with operations to map the phonetic structure onto the correct orthographic word form. Three rules were introduced. The first rule was related to long vowels. The rule, coined one-token rule, presents that if a long vowel ends a syllable, it is written only with a single graph instead of the standard two graphs.

The second rule concerned the voiced consonants, which devoice in Dutch if they end a syllable. In case of the plosive voiced consonants, /d/ and /b/, this change in pronunciation is not expressed in the spelling. In the program, this phenomenon was dealt with by the lengthening rule. If the last phone in a syllable is an /t/ or an /p/ then extend the word and if this results in a voiced consonant (/d/ or /b/) then the voiced consonant graph should be written, otherwise the standard consonant.

The third rule related to three different phoneme-aspects. The first two aspects concerned pairs of phonemes that sound alike, i.e., /ou/ (/au/) versus /ouw/ (/auw/), and /g/ versus /ch/. The third element concerned the phone /ng/, which is changed to /nk/ when followed by /t/. This change is not expressed in the spelling, but the /ng/ can be traced by pronouncing the word in its stem form. All three aspects were represented by the shortening rule, which states in case of /g/: if the last phone in a syllable in its shortest form is an /g/ then write *–g*, otherwise write *–ch-*.

Module 2. Polysyllabic words were presented in this treatment for the first time and the module instructed the participants to decompose words into their distinct syllables. Stressed and unstressed syllables are distinguished. The first theme of this module concerned the schwa. Depending on the affix in which the schwa is used, it can be represented in the orthography by the letters *i*, *ij*, or *e*. These affixes can be recognised since they are the last (or only) part of an unstressed syllable. Schwa-containing morphemes were presented as indivisible quasi-phones, coined “morpheme-sounds”. The keyboard included a special category for these morpheme-sounds. One reason for this addition is the productivity of these bound morphemes (they can be more productive than certain vowels) in which they resemble phones. Another reason is the irregular writing of the schwa within these morphemes. This resulted in the morpheme-rule, which states: “if the last phone of an unstressed syllable is a morpheme-sound then write down this morpheme-sound in its written form”.

The second theme of this module related to long vowels at the end of the syllable, and the one-token rule applied to polysyllabic words. Furthermore, the related phenomenon of short vowels at the end of the syllable was introduced. Since a long vowel written with only one graph can lead to confusion with a short vowel for the reader, a distinction between the two vowels is created in the Dutch writing system by placing two consonants after a short vowel. The change in case of a short vowel as the terminal phonic element of a syllable was captured in the two-token rule. If the last phone in a syllable is a short vowel then two consonants should follow.

Module 3. In the third module, emphasis was shifted from the phonetic to the morphologic structure of words. Participants learned to recognise stem and bound morphemes. They also learned how bound morphemes are attached to a stem. In Dutch, two types of bound morphemes can be distinguished. In one type, the orthography depends on the syllabic structure. Participants first learned this category. They were taught that words with a bound morpheme in this category have to be divided into syllables, as in the foregoing modules. Thereafter, attention was shifted to the other type of bound morphemes. In this type, the orthography is dependent on the morphemic structure. Participants learned that words with one of these bound morphemes are divided into their morphemic structure. The most common affixes were presented, such as diminutives (a specific class of bound morphemes in Dutch). *Module 4*. The process of inflecting a verb was the focus of the fourth module. In the orthographic representation of verbs both the phonetic structure and the morphologic structure are important. Special attention was paid on the past tense and participle. Participants were taught that (regular) past-tense suffixes of a verb are created by adding –*de(n)* or *–te(n)* (depending on the voicing of the final phone of the verb stem) at the verb stem. A participle has a prefix (*ge-*), the verb stem, and a suffix *–d*, *-t* or *–n*. Since /d/ devoices *–d* and *–t* suffixes sound the same. Participants learned to form the verb in the past tense, and, if this results in a voiced consonant (/d/) then *–d* should be written, otherwise *–t.*

Design

This retrospective study incorporates a longitudinal design. Participants were assessed at the start of the treatment and after every module until the end of their treatment. At every evaluation, a spelling test was used to assess various types of errors. There are two versions of

this spelling test. Scores on the second version were converted into first version scores. Potential differences between versions were examined by comparing the two versions on each evaluation. Chi-square tests indicated that meaningful differences between the two versions were absent (all $p > .05$).

Evaluation of Treatment Effect

To assess the effect of treatment, a spelling-test was administered. The participants' errors on this test were classified into eleven categories. These categories represent the most common problems of the Dutch writing system and resemble classification-systems of Van der Wissel (1963), Bakker (1965) and Henneman (2000). Seven of these categories can be linked to a particular aspect of the writing system on which the program explicitly focused in one of the modules. These were labelled first order categories because a failure to obtain a change in the expected direction on such a category would present a serious challenge to the claim of an orderly pattern of improvements. The remaining four categories refer to aspects on which the program had a more implicit focus, or which are shared by several modules. These were labelled second order categories.

Multiple forms were used for the spelling test to avoid effects due to practice.

First Order Categories

Here we describe briefly the errors associated with the first order categories.

Letter-sound errors (module 1): A phone is not written in its standard graphic representation. For instance, the phone /eeuw/ in 'l*eeuw*' (lion) is written as 'l*euw*'.

Lengthening errors (module 1): Interchange of *-d* and *-t* or *-b* and *-p* at the end of a syllable, e.g. erroneous or non-usage of the 'lengthening-rule'. For instance, 'baar*t*' is written instead of 'baar*d*' (beard).

Shortening errors (module 1): Interchange of *-ng* and *-nk*, *-g* and *–ch*, or *–ouw* and *–ou* at the end of a syllable, e.g. erroneous or non-usage of the 'shortening-rule'. For instance, 'zi*nkt*' is written instead of 'zi*ngt*' (sings).

1-2 Token rule errors (module 2): Erroneous or non-usage of the '1-token rule' or '2-token rule' in polysyllabic words. This occurs either when a long vowel at the end of a syllable is written with two tokens, or a short vowel is followed by only one consonant-token, or a long vowel is erroneously followed by two consonant-tokens. For instance, ba*k*en is written instead of ba*kk*en (to bake).

Morpheme-sound errors (module 2): A schwa containing bound morpheme is not written in its standard graphic representation. For instance, *gu*noeg instead of *ge*noeg (enough).

Morphological errors (module 3): Errors concerning the morphemic structure of a word, such as diminutives. For instance, ster*tje* instead of sterr*etje* (little star).

Verbs (module 4): Erroneous inflections of verbs. For instance, 'zij vin*d*' instead of 'zij vin*dt*' (she finds).

Second Order Categories

The errors associated with the second order categories are described briefly here.

Phonological errors (module 1). This category refers to phonetic writing, for instance, as a consequence of assimilation. Module 1 focused implicitly on this category since accurate phonetic analysis is a central theme here. An example of assimilation is the word 'schrok' (frightened), in which the phoneme /s/ is followed by two velar sounds (/ch/ and /r/) that can assimilate in pronunciation. This may result in writing 'schok' instead of 'schrok'.

Allograph errors (module 1). Interchange of two graphic representations for the same phoneme or for phonemes whose pronunciations are alike (e.g. *f/v/w* and *s/z*). For instance, *f*er instead of *v*er (far).

Letter errors (module 1). Addition, omission, or replacement of a letter without a demonstrable reason (e.g. a reason relating it to one of the other categories). For instance, ka*m* instead of ka*t* (cat).

Word errors. Addition, omission or replacement of a word. Since treatment is generally directed at subword levels (phonological and morphological), no particular module can be linked to this category.

All words used in the tests are not part of the corpus of words used in the treatment. This ensures that the treatment effect is generalised, not simply due to word-learning. These categories and the parts of the treatment to which they are related, lead to a predicted pattern of changes that is shown in Table 2.

Table 4.2. Predicted Pattern of Changes

	Module			
Category	1	2	3	4
Letter-sound	X			
Lengthening	X			
Shortening	X			
1-2token rule		X		
Morpheme sounds		X		
Morphological			X	
Verbs				X
Phonological	X			
Allograph	X			
Letter	X			
Word				

Note. An X indicates the module at which an error category is predicted to display the largest change.

Results

The results are presented in three separate sections: (1) Overall treatment gain, (2) Temporal dynamics of effects, and (3) Individual differences.

Overall Treatment Gain

Pre- and posttest scores for spelling are presented in Table 3. As can be seen from this table, participants made a sizeable improvement in spelling skills. The general treatment effect for spelling was analysed by comparison of Z-scored pretest and posttest levels. Z-scores were used to correct for age-related changes. Changes in standard scores indicate the extent to which the participants changed positions within the distribution of spelling ability of a large (non-impaired) age-norm group (Torgesen et al., 2001). Wilcoxon matched pairs signed ranks test ($Z = -9.855$; $p < .001$) indicated that the gain in spelling during treatment was highly significant. The effect size ($d = 1.49$) of this gain was large (Cohen, 1988). At the end of the treatment, spelling was comparable to the general population mean, as demonstrated by a one-sample Wilcoxon test ($Z = 2.63$; $p = 1.00$).

Table 4.3. Means and Standard Deviations for Raw and standardized Pretest and Posttest Scores for Spelling

Spelling	Pre		Post	
RS[a]	33.17	(21.16)	8.88	(5.19)
ZS	-3.04	(2.37)	0.09	(0.64)

Note. Standard deviations in parentheses. RS = raw score. ZS is z-score, the average z-score for normative samples is 0 with a standard deviation of 1. [a] Total number of errors.

Temporal Dynamics of Effects

Individual scores were transformed into a binary score by means of a median split. The median value of the number of errors made within a particular error category at the start of treatment was used as a cut-off criterion. With the use of this median value, frequency data were created allowing for distribution-free tests of hypotheses concerning main effects and interactions (Wilson, 1956). In Table 4 the proportion of scores equal to or above the median value was presented for each error category as a function of the treatment modules. Due to all-day practice, after the first module only monosyllabic words were tested. The rational was that the first module contained solely monosyllabic words. Since some categories were only (or for a large part) represented in polysyllabic words, these were not tested at this time. Two asterisks mark the categories not tested after module 1. Inspection of Table 4 suggests an interaction between error category and module as predicted.

The presence of the interaction between module and error category was tested by submitting these classes to logit modelling. This analysis fits the relationship between a response variable and a set of categorical regressor variables (Vermunt, 1996). Two models were fitted to the classes, the model with and the model without the interaction. The missing data for some categories after module 1 were treated as structural zeros in the analysis (Vermunt, 1996). Goodness of fit test showed that only the model including the interaction fitted (no interaction: $G^2(35) = 183.63$, $p < .01$; interaction: $G^2(0) = .00$). Effect size ($w = .18$) for the fitted model compared to the model without interaction-effect is moderate. In comparison to the model of no change (model of independence), the effect size ($w = .47$) of the fitted model is large (Cohen, 1988).

Table 4.4. Proportion of Scores Equal to or Above the Median Value in Each Error Category as a Function of Treatment

	start of treatment	Module 1	module 2	module 3	module 4
Letter-sound	.53	.99	.94	.98	.99
Lengthening	.59	.99	.94	.96	.99
Shortening	.65	.94	.88	.94	.97
1-2Token rule	.50	**	.90	.99	1.00
Morpheme sound	.60	**	.83	.93	.94
Morphological	.52	**	.49	.71	.77
Verb	.56	**	.56	.66	.85
Phonological	.53	.98	.82	.91	.99
Allograph	.60	.98	.90	.96	.98
Letter	.57	.91	.92	.95	1.00
Word	.58	**	.85	.90	.97
n	129	129	84	94	117

Note. Participants were sometimes tested at a time when the next module was already started. These scores were excluded from analysis. This fact, together with drop out of participants who did not finish the treatment, resulted in a varying number of scores per measurement occasion.

Follow-up tests were conducted to examine whether the time course of effects displayed the predicted pattern. To this end, a decomposition of the model was conducted. Firstly, we tested within each error category whether there was significant change during treatment. As can be seen in Table 5, goodness of fit tests rejected the time independence for all error categories (all $p < .001$). This indicated that there was an effect of treatment within each error category. Secondly, contrasts between evaluation times were conducted within each error category, to determine the module which resulted in the largest change. These contrasts are presented in Table 6, together with a parameter indexing the proportion of explained association: $\frac{G^2{}_{contrast}}{G^2{}_{total}} \text{x}100$. This parameter provided an index of the proportion of change obtained at a specific time (within a certain error category). All contrasts within an error-category refer to the same portion (all df = 1) of the G^2_{total}, therefore they can be compared directly.

Inspection of Table 6 shows that, as predicted, progress was most clearly seen for error categories Letter-sound, Lengthening and Shortening at the end of the first module. Within the error categories related to the second module (1-2 Token rule and Morpheme sounds), participants showed the largest change at the end of this module. As expected, most improvement in Morphological errors (module3) and in Verb errors (module 4) was observed during module 3 and module 4, respectively. Within the error categories, which were indirectly related to module one (Phonological, Allograph, and Letter errors), participants showed the largest change towards the end of this first module. Finally, with respect to category word errors, not related to any module in particular, participants showed their major change at the end of the second module.

Table 4.5. Goodness-of-Fit Tests for Model of Independence

Module	Category	Goodness-of-fit (sign.)
1	Letter-sound	$G^2(4) = 157.52$ ($p < 0.0046$)
1	Lengthening	$G^2(4) = 127.39$ ($p < 0.0046$)
1	Shortening	$G^2(4) = 63.89$ ($p < 0.0046$)
2	1-2Token rule	$G^2(3) = 139.90$ ($p < 0.0046$)
2	Morpheme sounds	$G^2(3) = 56.09$ ($p < 0.0046$)
3	Morphological	$G^2(3) = 26.82$ ($p < 0.0046$)
4	Verbs	$G^2(3) = 32.15$ ($p < 0.0046$)
1	Phonological	$G^2(4) = 137.18$ ($p < 0.0046$)
1	Allograph	$G^2(4) = 111.56$ ($p < 0.0046$)
1	Letter	$G^2(4) = 106.12$ ($p < 0.0046$)
-	Word	$G^2(3) = 56.09$ ($p < 0.0046$)

Table 4.6. Contrasts

	Category	Contrast	$G^2(1)$ (p)	% explained $G^2_{Fi\text{-}tot}$
First order categories	Letter-sound module 1	**M1-M2**	92.303 (0.0000)	58.6%
		M2-M3	5.042 (0.025)	3.2%
		M3-M4	1.756 (0.18)	1.1%
		M4-M5	0.603 (0.44)	0.4%
	Lengthening module 1	**M1-M2**	78.303 (0.0000)	61.5%
		M2-M3	5.042 (0.025)	4.0%
		M3-M4	0.266 (0.61)	0.2%
		M4-M5	2.706 (0.10)	2.1%
	Shortening module 1	**M1-M2**	35.208 (0.0000)	55.1%
		M2-M3	2.084 (0.15)	3.3%
		M3-M4	1.660 (0.20)	2.6%
		M4-M5	1.008 (0.32)	1.6%
	1-2Token rule module 2	**M1-M3**	40.861 (0.0000)	29.2%
		M3-M4	7.349 (0.01)	5.3%
		M4-M5	1.623 (0.20)	1.2%
	Morpheme sounds module 2	**M1-M3**	13.232 (0.0003)	23.6%
		M3-M4	3.661 (0.06)	6.5%
		M4-M5	0.179 (0.67)	0.3%

Table 4.6. Contrasts - continued

	Category	Contrast	$G^2(1)$ (p)	% explained $G^2_{Fi\text{-}tot}$
	Morphological	M1-M3	0.199 (0.65)	0.7%
	module 3	**M3-M4**	9.449 (0.0021)	35.2%
		M4-M5	0.870 (0.35)	3.2%
	Verbs	M1-M3	0.0004 (0.98)	0.0%
	module 4	M3-M4	1.871 (0.17)	5.8%
		M4-M5	11.151 (0.0008)	34.7%
Second order	Phonological	**M1-M2**	87.735 (0.0000)	64.0%
categories	module 1	M2-M3	19.096 (0.0000)	13.9%
		M3-M4	3.471 (0.063)	2.5%
		M4-M5	8.158 (0.043)	5.9%
	Allograph	**M1-M2**	70.132 (0.0000)	62.9%
	module 1	M2-M3	7.227 (0.007)	6.5%
		M3-M4	1.979 (0.160)	1.8%
		M4-M5	1.224 (0.269)	1.1%
	Letter	**M1-M2**	42.195 (0.0000)	39.8%
	module 1	M2-M3	0.003 (0.960)	0.0%
		M3-M4	0.641 (0.423)	0.6%
		M4-M5	8.237 (0.004)	7.8%
	Word	M1-M3	16.592 (0.0000)	25.0%
	module -	M3-M4	1.427 (0.232)	2.2%
		M4-M5	3.434 (0.064)	2.5%

Note. Contrasts expected to account for the largest part of the association are printed bold

Analyses of Individual Differences

To gain insight in factors that might influence the efficacy of treatment, we related the pattern of changes to grade level and seriousness of the phonological deficit.

Grade Level

The influence of grade level on the interaction-effect of category and module was analysed, by testing whether grade level was independent of all other variables (module, category and median value). If this model would fit, this indicates that grade level has no influence on the effects of treatment (Wickens, 1989). Goodness-of-fit test (G^2 (297) = 317.99, p = .19) showed that the model fitted, so that the patterning of effects can not be attributed to grade level.

Seriousness of the Phonological Deficit
The phonological deficit was defined as a composite of all five phonological tests. It was tested whether the seriousness of the phonological deficit was independent of all other variables. Goodness-of-fit test (G^2 (198) = 112.41, p = 1.00) showed that the patterning of effects was not related to the level of phonological deficiency.

It could be argued that a potential relation between the phonological deficit and the efficacy of treatment was resolved by the variability in duration of treatment. To test this possibility, the seriousness of the phonological deficit was related to the duration of each treatment module. A One-way Analysis of Variance tested the effect of phonological deficit on duration. The results revealed no significant effects ($F_{(1,129)} = 2.05$, $p = .15$ for module 1; $F_{(1,129)} = .02$, $p = .90$ for module 2; $F_{(1,128)} = 2.25$, $p = .14$ for module 3; $F_{(1,117)} = .44$, $p = .51$ for module 4), indicating that duration of treatment was not dependent on the seriousness of the phonological deficit.

Discussion

One important finding from this study was the size of the improvements in spelling achievement made by the participants. The program produced large standardised gains in spelling. Following treatment, participants attained an average level of spelling. These are generalised improvements, since the study was designed to find generalisations of effects by assessing spelling skills with words that differ from the words used in the treatment. This finding confirms beneficial effects for both reading and spelling, previously obtained using this treatment (Tijms et al., 2003).

It is interesting to compare the overall spelling-gain obtained in this study with those reported in other studies. Although the emphasis is on reading skills in most treatment studies, a number of studies have evaluated spelling skills (Wise et al., 1999, 2000; Lovett et al., 1994, 2000; Torgesen et al., 2001; Hatcher, 2000). Several studies report standardised gains in spelling, but in none of these studies the spelling level was comparable to the general population mean following treatment.

Though the size of the overall treatment-effect was relatively impressive, the main objective of this study was to carry out a procedural evaluation of the treatment. Concerning this objective, the most striking finding was that the time course of treatment effects accurately matched the predicted temporal ordering. The timing of each effect was closely tied to the corresponding treatment module. The treatment starts with a focus on the phonetic structure of words and, corresponding to the prediction, at the end of the first module participants had made most progress on related aspects of the writing system. After teaching the phonetic structure, attention is shifted to situations where the correspondence between a phonic element and its standard graphic representation is dissociated. For this, operations are introduced to map the phonetic structure onto the correct orthographic word form. As predicted, the largest effect on operations related to monosyllabic words was attained at the end of module 1, and on operations related to polysyllabic words at the end of module 2. At the end of the second module, morpheme-related errors were still being made. Participants made most progress on this aspect following the next module, which specifically addresses

the causes of morphological errors. The last module concerned verbs. It was only after this module that effect on this aspect was present.

On the one hand, these findings provide important support for the validity of the LEXY-treatment. They demonstrate that the effects of the LEXY-program are treatment-specific. The findings indicate that these effects cannot be attributed to non-specific factors (e.g., time in treatment, maturation, other instruction) as these factors would have produced general effects unrelated to the timing of specific treatment modules.

On the other hand, several implications can be derived for the set up of a treatment for dyslexia from this finding. The first implication refers to the problem of transfer. The transfer of the trained skills to reading and spelling has been shown to be a crucial factor in treating dyslexia. There are indications that explicit instruction in both phonological awareness and sound-symbol correspondences is important in ensuring this transfer (Hatcher, Hulme, & Ellis, 1994; Snowling & Nation, 1997). The present study confirmed these indications. It showed that increasing dyslexics' awareness of the phoneme system and teaching them phones with their standard graphic representation results in improvements in their spelling skills. However, these improvements were restricted to those domains of the writing system that are related to the attended phonological aspects.

This leads to the second implication. Knowledge of the phoneme system seems to be insufficient for a dyslexic to handle situations, in which the correspondence between a phonic element and its standard graphic representation is dissociated. The results indicated that explicit instruction concerning the phonological rules, underlying the differences between the spoken word and its orthographic representation, is important to obtain further improvements. This result relates to the study of Benson, Lovett and Kroeber (1997), which focused on the ability of dyslexics to use rule-based learning. They showed that dyslexics were as capable as non-dyslexics to learn from rules with a inferential structure, when the underlying concepts derived from a knowledge base that they already understand. The results from this study are consistent with the present findings showing that by the use of the inferential algorithm, linking phonological concepts to the writing system, dyslexics appear to be able to convert their acquired phonetic knowledge into better literacy skills.

The third implication refers to the influence of morphological elements on the orthography. After the presentation of the phonetic structure of words and of operations, by which the learned phonological concepts can be translated to the orthography, problems related to morphological concepts still exist. This implies that specific attention to the morphological structure of words is necessary. Snowling (2000) noted that treatment of reading disabilities should place a focus on training relationships between morphological structures and orthographic representations, next to training the mappings between orthography and phonology. The findings of the present study support Snowling's notion.

The analysis of the influence of individual differences on the effects of treatment indicated that the seriousness of the phonological deficit had no influence on the effectiveness of the treatment. This finding seems surprising, since phonological processing problems constitute the core deficit in dyslexia. However, this result has also been observed in other studies. Both Pogorzelski and Wheldall (2002) and Torgesen et al. (2001) found no influence of various phonological abilities on treatment effect. In a study of Torgesen et al. (1999),

rapid naming was related to gains in reading words, whereas phonological memory and phonological awareness showed no relation. In contrast, Wise et al. (1999, 2000) reported a relation between phonological awareness and treatment effect, with rapid naming having no consistent relation with the effectiveness of treatment. Van Daal and Reitsma (1999) analysed the influence of rhyming on treatment efficacy, but found no relation.

The current pattern of results did not reveal a relation between the effectiveness of treatment and the seriousness of the phonological deficit. Since phonological processing deficits were used in this study as a selection criterion of the treatment sample, the restriction in variation may have contributed to the absence of an influence of the phonological deficit on the treatment effects. Moreover, on four of the six phonological tasks, the distribution of scores tailed off to the left, indicating ceiling effects. Another explanation of the absence of relation is that in treatment with intensive phonological training, the level of initial phonological skills is less important, since such treatment is designed to overcome these phonological weaknesses (cf. Hatcher & Hulme, 1999).

A point of debate is the influence of age on the efficacy of treatment. In studies of Wise et al. (1999, 2000), younger children showed stronger treatment gains than older children. This led the authors to suggest that remediation may be more effective if it is started earlier. Other researchers have also argued that the longer children with dyslexia go without intervention, the lower the rate of success (Lyon, 1995b). However, Lovett and Steinbach (1997) showed that effectiveness of treatment does not necessarily decrease with increasing age. They reported equivalent gains of remediation for children in grades 2, 3, 4 and grades 5, 6. Also, Torgesen et al. (2001) found no relation between age and treatment effect. The present study concurs with the findings of Lovett and Steinbach (1997) and Torgesen (2001), in that it shows no influence of grade level on the effectiveness of treatment. This indicates that older children are as capable as younger children to benefit from treatment.

In summary, the results of the present study support the assumption that the effectiveness of the LEXY-treatment is related to its theoretical basis. Being based on psycholinguistic models, it emphasises the importance of these models as the fundament for treating dyslexia. Furthermore, the study provided support for the importance of psycholinguistic models from a new perspective: not by comparison of treatment effects of different programs, but by mapping out the sequences of changes during treatment.

Notes

1. This chapter is in press in the journal *Educational Psychology*.
2. A phone is a perceptual class of speech sounds with a singular linguistic function. The terms phonic and phone are used to express the perceptual character of speech sounds, phonemes being abstract linguistic entities within a phonetic or phonological theory.
3. The IWAL-institute was founded by members of the department of psychology of the University of Amsterdam in 1983 in order to bring scientific knowledge of dyslexia into practice. It is specialized in research, assessment and treatment in the field of dyslexia.

Chapter 5

A computerised treatment of dyslexia: Benefits from treating lexico-phonological processing problems[1]

Abstract

Two hundred sixty-seven 10- to 14-year-old Dutch children with dyslexia were randomly assigned to one of two samples that received a treatment for reading and spelling difficulties. The treatment was computer-based and focused on learning to recognise and use the phonological and morphological structure of Dutch words. The inferential algorithmic basis of the program ensured that the instruction was highly structured. The present study examined the reliability of the effects of the treatment, and provided an evaluation of the attained levels of reading and spelling by relating them to normal levels. Both samples revealed large, generalised treatment effects on reading accuracy, reading rate, and spelling skills. Following the treatment, participants attained an average level of reading accuracy and spelling. The attained level of reading rate was comparable to the lower bound of the average range.

Introduction

Developmental dyslexia refers to a complex, biologically rooted behavioural condition that results from an impairment of reading-related processes and that is manifested in a persistent difficulty in the acquisition of the written form of language under the condition of adequate education and a normal developmental environment (Grigorenko, 2001). Written language is a relatively recent human invention, developed as a response to spoken language and aimed at graphic representation of spoken language (Liberman, 1997; Pennington, 1999). In alphabetical writing systems the graphs transcribe phonetic elements of language (Byrne & Liberman, 1999; Frost, 1998). Accordingly, the phonological processing system is supposed to be essential for reading and spelling (Perfetti, 1999a; Pennington, 1999).

A large body of converging evidence indicates that dyslexia stems from an underlying deficit in the phonological processing system (Beitchman & Young, 1997; Crain & Shankweiler, 1991; Leonard et al., 2001; Lovett, 1997; Shaywitz, 1996; Shaywitz et al., 1998; Vellutino, Scanlon, & Spearing, 1995). Dyslexic individuals are characterised by difficulty in segmenting and manipulating phones in words, subtle difficulties in speech perception and production, limitations in performance of phonics-based memory, and problems with rapid retrieval of phonological information from long-term memory (Elbro, Borstrøm, & Petersen, 1998; Mody, Studdert-Kennedy, & Brady, 1997; Pennington et al., 1990; Wagner, Torgesen, & Rashotte, 1994). Psycholinguistic research indicates that an unstable or underspecified phonological

representation in the mental lexicon is a core deficit in dyslexia (Elbro et al., 1998; Goswami, 2000; Snowling, 2001; Swan & Goswami, 1997). This suggests that dyslexics possess a dysfunctional phonological system. As a result dyslexics seem to be unable to use the implicit phonological structures in their reading and writing.

There is evidence to suggest that the reading and spelling difficulties are long lasting (Foorman, Francis, Shaywitz, Shaywitz, & Fletcher, 1997; Jacobson, 1999). For many dyslexic individuals the phonological processing problems appear to persist over the life span (Elbro, Nielsen & Petersen, 1994; Foorman, et al., 1997). The persistent reading and spelling difficulties have serious implications for the social functioning of individuals with dyslexia. Dyslexia is found to be associated with, among other things, the attendance of special schools, and lower achieved academic levels and lower self-esteem (Beitchman & Young, 1997; Pennington, 1991; Warnke, 1999). The persistence of the disorder has led some researchers to conclude that there are biological constraints, preventing intervention from having long-lasting effects (Cossu, 1999; Lyon, 1995b; Foorman et al., 1997). On the other hand, the persistent and potentially harmful consequences of this disorder provides a challenge to intervention strategies. Phonologically based interventions seem most promising in the treatment of reading and spelling problems of dyslexics. An increasing number of evaluation studies report beneficial effects of training the phoneme structure of words (Hatcher, 2000; Hatcher, Hulme & Ellis, 1994; Lovett, et al., 2000; Moats & Foorman, 1997; National Reading Panel, 2000; Snowling & Nation, 1997; Torgesen, et al., 2001; Wise, Ring, & Olson, 1999, 2000). Though the positive results of these interventions are encouraging, there are still some weaknesses in the accumulated evidence. Positive results of treatment on phoneme awareness and non-word decoding skills are repeatedly reported in evaluation studies, but only a few studies revealed transfer of the learned concepts into generalised reading and spelling gains (Lyon & Moats, 1997; Lovett et al., 2000; Snowling, 1996), and just these areas are the problem domains for dyslexics.

Another problem is related to the size of the samples. Swanson (1999) conducted a meta-analysis of studies evaluating intervention for reading disabilities. This meta-analysis revealed that the total sample size of a study was on average 28.23 (sd = 16.23) participants, only 10 out of 96 studies having a total sample size of 50 or more participants. Since the majority of studies incorporated two or more conditions, the number of participants per condition was small in many of these studies. These small sample sizes indicate a low a priori power and interfere with the replicability of the reported effects (cf. Tversky & Kahneman, 1971).

Furthermore, progress in reading is often reported without relating the obtained reading level to the normal level. It remains unclear in these cases whether dyslexics are still performing at an below average level after treatment, or whether the treatment normalised reading into the average range. Both outcomes may produce statistically significant results, but they differ sharply in their impact on the functioning of the treated dyslexic. Thus, for treatment evaluation, it is not sufficient to merely establish

significant improvements in reading and spelling. Rather, it is necessary to determine the extent to which the participants reduced their lag in reading and spelling rate. It is also necessary to determine the extent to which the participants obtained a socially acceptable level of reading and spelling (i.e., a functional level of reading and spelling).

A positive exception is the study of Torgesen et al. (2001). In this study, two forms of training were evaluated. Both methods incorporated instruction in phonemic awareness and phonemic decoding skills. A total of 60 children received 67.5 hours of one-to-one instruction. Both programs produced large improvements in generalised reading skills that were maintained over a 2-year follow-up period. The children's average scores on reading accuracy attained the average range at the end of the follow-up period. Only their reading rate lagged behind (Torgesen et al., 2001).

The objective of the present study was to examine the effectiveness of a Dutch treatment for dyslexia, called LEXY. LEXY is based on psycholinguistic theory, in which dyslexia is hypothesised to be caused by a lexico-phonological processing deficit (Schaap, 1997; Tijms, Hoeks, Paulussen-Hoogeboom, & Smolenaars, 2003). Accordingly, dyslexics are considered to be deficient in constructing and consolidating an accurate phonological representation in the mental lexicon. The treatment is computer-based and focuses on learning to recognise and use the phonological and morphological structure of Dutch words. More specifically, the focus of LEXY is on the language units, the basic rules, and the minimal heuristic knowledge needed to be implemented in a computer program in order to transform a phonic[2] word into a correct orthographic word form. Central to the computer program is an algorithm with an inferential structure (i.e., if a phone of class X is in position Y then perform operation Z; see appendix A for an example of the algorithm), and a number of heuristics for those orthographic inconsistencies that can not be accommodated by the algorithm (Tijms et al., 2003).

LEXY is also based on remedial considerations. In view of the dyslexic's problems with verbal information processing, the modality of instruction is graphic rather than verbal. During instruction all new actions are guided by a graphic representation of the action. Subjects have to articulate all their actions in order to induce appropriate internalisation of the action. Research findings support the importance of inner speech in learning new skills (Berk, 1994). Additionally, LEXY is highly structured and its demands upon the subject are kept within the information processing capabilities of the dyslexic subject.

The syllabic structure of words is the focal point of the treatment. This is because the syllable is the smallest possible, but still naturally pronounceable, phonological structure. It is assumed that the syllable is not a lexical element, but emerges during prosodification, and is to some degree consciously accessible as internal speech (Levelt, 1989; Schiller, 1997). By taking the syllable as unit of processing, the attention of the dyslexic is drawn to a perceivable structure in contrast to a phoneme, which is an abstract entity. The use of syllables, rather than whole words or morphemes,

allows dyslexics to better identify distinct speech sounds. At the same time, the syllable is the phonological unit to which Dutch spelling rules apply (the same is true for many other languages). In the Dutch writing system the last phonic element of a syllable is essential to the dissociation between a spoken word form and its orthographic representation.

The correspondence between a phonic element and its standard graphic representation can be dissociated, depending on the phonological category to which the terminal phonic element of a syllable belongs. This aspect is implemented in LEXY as an inferential algorithm. This algorithm is presented as a set of production rules, which can be seen as operations on five types of terminal phonic elements: 'long' vowels, 'short' vowels, unvoiced consonants, sonoric vowels, and unstressed morphemes (Schaap, 1997). The spelling rule is defined in general terms as follows: "If the last phone <P> of the syllable is a member of the class <C>, then perform operation <O>". Each concept in this rule is defined explicitly; the set of speech sounds, the classes to which these sounds belong, and the operations that are applicable to a given sound. Some orthographic inconsistencies, however, can not be accommodated by the algorithm. These are presented as heuristic knowledge.

The dysfunctional language system, which characterises dyslexia, seems to prevent dyslexics from using the implicit structures of language in their reading and writing. By making the phonological and morphological structure explicit, the LEXY program tries to clarify the knowledge necessary to determine the algorithmic or heuristic group to which a given word belongs.

The effectiveness of the LEXY-treatment has been reported in previous studies (Tijms et al., 2003; Tijms, in press). Tijms et al. (2003) evaluated the short and long-term effects of treatment. This study revealed positive treatment effects on word reading rate, text reading accuracy and spelling. More importantly, this study indicated that the improvements in word and text reading were stable over a 4-year follow-up period. Spelling showed a slight decline one year after the treatment, but remained stable thereafter. Tijms (in press) conducted a process-oriented evaluation of the treatment to provide a window on the dynamics of change. A configuration of effects was related to the time course of the treatment components. The participants showed a cascade of improvements that corresponded to the presentation order of treatment components. This result indicated that the effects of the LEXY-program are treatment-specific.

The present study focussed on two important aspects regarding the efficacy of this treatment program. Most importantly, the question of whether dyslexics attained normal reading and spelling levels following treatment was addressed. Regarding this question, the aim of the present study was to provide a detailed analysis of the attained literacy levels. In addition, the reliability of the treatment effects were investigated. To this end, the treatment gains on reading and spelling abilities were analysed in two large samples of dyslexic children.

Instead of using controls, norm-referenced scores were used to examine the attained levels of reading and spelling. These norm-referenced scores are standard scores, with a mean of 100 and a standard deviation of 15, which represent a participant's relative position within the norm group (Van Daal & Reitsma, 1999). This comparison to norm-referenced scores together with the longitudinal design of the study eliminates the need of a normal control group (Torgesen et al., 2001; Van Daal & Reitsma, 1999).

Although phonological processing problems are generally acknowledged as the core deficit in dyslexia, only few studies selected the participants on the basis of phonological deficits. Usually, selection is based primarily on the presence of reading difficulties. It is very likely that this strategy has resulted in heterogeneous treatment samples. Obviously, the heterogeneity within samples complicates the generalisation of results to a specific population. Furthermore, results may be difficult to replicate. Phonological deficits should be included as an additional selection criterion for obtaining a homogeneous sample, which facilitates both generalisation and replication (Lovett, Borden, DeLuca, Lacerenza, Benson, & Brackstone, 1994; Torgesen et al., 1999). Thus, in the present study, participants were explicitly selected on the basis of phonologically based reading and spelling deficits.

Method

Participants

The treatment sample in this study comprised children, who were referred to the IWAL-institute[3] because they were falling behind at school with respect to reading and writing. The referrals came from a variety of sources, including schoolteachers, parents, and psychological and educational services.

Participants were selected in the range from the sixth grade of elementary school through the second grade of secondary school. This selection included children ranging in age from about 10 to 14 years. To be included in the study, participants had to be at least one standard deviation below average in their reading or spelling abilities. In addition, they should be deficient in the phonological processing of words. Exclusion criteria were an IQ-score of one standard deviation or more below average, problems with auditory discrimination of speech sounds, problems with visual discrimination of figures, or broad neurological problems. Twenty-six children dropped out during the first half of the treatment for various reasons (e.g., lack of motivation or they moved elsewhere). They were excluded from the sample. A comparison of drop outs versus participants indicated that neither the levels of reading and spelling at the start of treatment nor the treatment gains after three months of treatment differed significantly (Kolmogorov-Smirnov tests, all p's > 0.1). Participants were randomly assigned to one of two groups to assess the reliability of treatment effects. The first treatment group included 131 participants, the second 136 participants. Descriptive characteristics of these participants are summarised in Table 1. Kolmogorov-Smirnov tests failed to

reveal any significant difference between the two treatment groups on age, IQ, number of sessions, reading, spelling, and phonological abilities (all *p*'s > 0.1).

Table 5.1. Characteristics of Participants

		Treatment Group 1		Treatment Group 2	
N		131		136	
Age (years)		11.9	(1.5)	11.7	(1.4)
IQ		109.3	(10.2)	107.8	(10.5)
Number of treatment sessions		45.5	(14.3)	48.0	(16.1)
Gender ratio (male : female)		2.6 : 1		2.3 : 1	
School grade	Elementary school	grade 6:	26%	grade 6:	26%
		grade 7:	24%	grade 7:	29%
		grade 8:	23%	grade 8:	25%
	Secondary school	grade 1:	19%	grade 1:	12%
		grade 2:	8%	grade 2:	9%
Word reading rate SS		77.37	(14.00)	75.78	(14.75)
Spelling SS		54.37	(35.62)	58.86	(35.01)
Phoneme Synthesis SS		95.13	(12.55)	95.22	(12.68)
Phoneme Analysis SS		94.40	(18.80)	91.12	(23.21)
Auditory Closure SS		87.70	(13.39)	90.22	(13.44)
Homophones SS		99.34	(13.42)	98.39	(12.33)
Phonological Memory – Digit Span SS		90.69	(11.38)	92.40	(11.93)
Phonological Memory – Interference SS		93.39	(17.82)	94.84	(13.98)

Note. Standard deviations in parentheses. SS = standard score (mean = 100; standard deviation = 15).

Selection Measures

Tests that were used for selection are summarised below. The tests included reading and spelling tests and a series of tests for assessing phonological deficits. Reliability coefficients of all measures are presented in parentheses.

Reading and Spelling Tests

Word reading rate. Reading skills were assessed by the One-Minute-Test (Brus & Voeten, 1973), a time-limited test in which the number of correctly read unrelated words within one minute determined the score (*r* = .89 to .93, test-retest).

Spelling. Spelling skills were assessed using the IWAL-Standard Dictation (Harel & Schaap, 1981). This dictation contains 19 sentences. The words making up the sentences are familiar to all elementary-school children. Moreover, the collection of words is a representative sample of the various spelling problems in Dutch (Harel & Schaap, 1981). Scoring is based upon the number of spelling-errors (*r* = .90, test-retest).

Phonological Tests

A number of phonological tests was administered to assess different manifestations of the phonological processing deficit.

Phoneme Synthesis. The subtest Auditory Synthesis of the Language Test for Children (TVK; Van Bon, 1982) was used to examine the ability to synthesise phones into a word. This test is analogous to the Blending Words subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen, & Rashotte, 1999). The Auditory Synthesis test consists of 29 items presented using a tape-recorder. Each word is presented phone by phone. Participants are asked to say the word that results when phones are blended. Scoring is based upon the number of correct responses (r = .89, internal consistency).

Phoneme Analysis. The IWAL-Auditory Analysis test was used to assess the subject's ability to segment words into phones. This test is similar to CTOPP subtest Segmenting Words (Wagner et al., 1999). The Auditory Analysis test consists of 25 orally presented items. The items are monosyllabic words. Participants have to say each word phone by phone. The number of correct responses represents the score on the task (r = .85, internal consistency).

Auditory Closure. A Dutch version of the Illinois Test of Psycholinguistic Abilities (ITPA) subtest Auditory Closure was used (TvK-Word Recognition; Van Bon, 1982). Participants are presented with words in which one or more phonemes are deleted and replaced by a short silence. Participants are required to say the word. This test includes 29 items. Scoring is based upon the number of correct responses (r = .74, internal consistency).

Homophones. A homophone test (Hoeks, 1985) was used to measure the ability to link two different meanings of the same word form. This test is similar to Guilford's Seeing Different Meanings (Guilford, 1971). Each of 22 items of the homophone test consists of four pictures presented on a white card. All of the four pictures represent a different meaning, but two of them can be linked to the same word form. Participants are asked which of two pictures could be connected to the same word. Scoring is based upon the number of correct recognised pairs of homophones (r = .77, internal consistency).

Short-term Phonological Memory. Two short-term phonological memory tests were used. The first was a Dutch version of the Digit Span subtest of the WISC (WISC-RN; Van Haasen et al., 1985). The number of digits that a participant is able to repeat in correct or reversed serial order immediately after hearing them represents the score on this test. Scoring criteria are given in the test manual (r = .78 to .85, internal consistency).

The second test was the IWAL-Auditory Interference test, in which two lists of three words are used to produce inter-list interference. The test comprises 6 items. Each item consists of two groups of three monosyllabic words which are presented orally. After presentation of the two groups, participants are asked to repeat the first group and

after that to repeat the second group, or to repeat the second group and after that the first group. Scoring is based upon the number of words repeated correctly (r = .67 to .72, internal consistency).

Design

The current retrospective study consisted of a pretest-intervention-posttest design. Four outcome measures were taken from all of the participants before and after their treatment: (1) word reading rate, (2) text reading accuracy, (3) text reading rate, and (4) spelling. Two of the outcome measures, word reading rate and spelling, were used in selecting the participants. These measures were described above. The other two, text reading accuracy and text reading rate, were assessed by the 'Livingstone' text (Schaap, 1986). This text consists of 64 lines that subjects are required to read. Subjects are instructed to read the text both fast and accurately. The text represents the various problems in the Dutch written language. The number of reading errors and the time taken for completion provide the outcome measures (accuracy: r = .93 to .94, rate: r = .97 to .99, test-retest). Multiple forms were used for all outcome measures to avoid effects due to practice.

Procedure

LEXY is a computerised treatment program that requires subjects to respond by typing the computer keyboard. To this end the keyboard of the computer is reconfigured. The keyboard does not have the usual qwerty-system of distinct letters, but consists of keys for each phone. It also contains an 'abstract keyboard', consisting of a series of icons to designate the categories of phones, a series of icons that stand for different spelling rules, and icons for stressed and unstressed syllables (Tijms et al., 2003).

Treatment was provided on a one-to-one basis in a weekly 45-minute session. Besides these sessions at the institute, participants were required to practice at home three times a week for 15 minutes.

Each session consisted of several parts. A session started by going through the homework. This took about five minutes. Next the LEXY instruction and training were discussed. During the instruction a new element was introduced, and the rules of translation of the phonic into orthographic form of the word were explained using a graphic algorithm (Schaap, 1997; see appendix A). Training consisted of spelling and reading modules. In the spelling module, the participant was required to make the translation steps. First, the translation had to be made explicitly, step by step. Later on, a more implicit direct approach was practised. In the reading module, words were projected individually on the computer screen in various ways; e.g., phone by phone (e.g., k/a/t (cat)), onset-kernel-coda (e.g., str/i/p (strip)), or syllable by syllable (e.g., ka/tten (cats)). During reading the whole word was projected faintly on the screen to allow anticipation (Schaap, 1997). The word components were highlighted at a pace, which was adjustable to the individual's reading speed. Instruction and training

contained separate bodies of words, since the treatment was not a 'word trainer', but directed at general knowledge. A session ended by explaining the homework consignments. Homework consisted of exercises on paper aiming at expanding training with the elements that had been subject of the session.

The treatment started with a focus on the phonological structure of Dutch words. Later on, operations were introduced to map the phonic word onto the correct orthographic word form. Next, attention was shifted to the implications of the morphological structure for orthography. This aspect differs from most interventions focussing on phonemic skills. Recently, the importance of morphemic knowledge in the development of reading and spelling skills has been emphasised (Leong, 2000; Mahony, Singson, & Mann, 2000; Mann, 2000). Thus, Snowling (2000) recommended that intervention methods should include morphemic knowledge. Subsequently, the process of inflecting a verb was attended. For the orthographic representation of verbs both the phonetic and the morphologic structure are important. During the final part of the treatment, the focus was on loan words. The phonetic patterns of recurrent bound morphemes from Greek, Latin, English and French were taught.

Initially, training was directed to monosyllabic words containing simple phonetic patterns. Subsequently, the focus shifted to more complex patterns and poly-syllabic words. Throughout, training proceeded to the next skill or to a combination of skills only after a particular skill had been mastered.

The program aimed at achieving a certain mastery level for each element of the program. An element was considered to be mastered when the percentage of correctly performed items during training was at least 80%. This implies that participants did not pass through the program at a fixed pace. The corpus of words used in the treatment are not part of the words used in the tests. This ensures that treatment effects are generalised, not simply due to word-learning. A more detailed review of the treatment can be found in Tijms et al. (2003).

Results

Attained Reading and Spelling Levels

Although the goal of the study was to examine the attained levels of reading and spelling, the participants' progress during their treatment was first assessed. The raw and standard scores at pretest and posttest are presented in Table 2. As can be seen from this table, all reading and spelling levels improved from pretest to posttest, indicating that the treatment had a widespread and positive effect. Following treatment, the number of text reading errors is reduced by 50%, and the number of spelling errors is reduced by 80%. Reading rate increased by more than 25% for text reading, and by approximately 30% for word reading. Comparison of the raw scores[4] at the pretest and posttest using Wilcoxon matched pairs tests indicated that these improvements were satisitically significant. The results revealed that the participants of treatment group 1 made highly significant improvements on all outcome measures: word reading rate ($Z = -9.67$, $p <$

0.001), text reading accuracy ($Z = -9.47$, $p < 0.001$), text reading rate ($Z = -8.87$, $p < 0.001$), and spelling ($Z = -9.86$, $p < 0.001$). The results of treatment group 2 are basically similar: word reading rate ($Z = -9.97$, $p < 0.001$), text reading accuracy ($Z = -9.77$, $p < 0.001$), text reading rate ($Z = -9.70$, $p < 0.001$), and spelling ($Z = -10.01$, $p < 0.001$).

To determine whether participants would obtain normal reading and spelling levels, the attained levels were compared to the average of the normative sample; i.e., a standard score of 100. As can be seen from the standard post-test scores in Table 2, both treatment samples appear to have attained a normal level for spelling and text reading accuracy, but not for word reading rate and text reading rate. Following treatment, the distance between the scores of the participants and the norm with respect to the two reading rate measures was reduced by half. The comparisons were subjected to one-sided Wilcoxon signed rank tests. These tests revealed that both treatment groups attained an average level for text reading accuracy (group 1: $Z = 6.64$, $p > .05$; group 2: $Z = 6.57$, $p > .05$) and for spelling (group 1: $Z = 2.63$, $p > .05$; group 2: $Z = 0.85$, $p > .05$). But with respect to word reading rate (group 1: $Z = -7.63$, $p < .01$, group 2: $Z = -7.87$, $p < .01$) and text reading rate (group 1: $Z = -7.20$, $p < .01$; group 2: $Z = -7.25$, $p < .01$), the participants differed significantly from the average level.

Following Torgesen et al. (2001), progress was evaluated against a second norm; that is a standard score of 90 (from a distribution with 100 as the mean and 15 as sd), representing the lower bound of the average range. A Wilcoxon signed rank test, using a score of 90 as criterion, showed that the first treatment group did not differ significantly for reading word rate ($Z = -1.91$, $p > .05$). Text reading rate, however, did differ significantly ($Z = -2.09$, $p < .05$). In contrast, the second treatment group did not differ significantly for reading word rate ($Z = -1.24$, $p > .05$), or for text reading rate ($Z = -.75$, $p > .05$).

Mann-Whitney tests were conducted to compare the treatment effects between treatment groups. The tests failed to reveal any significant differences between the two groups in the obtained reading and spelling levels (word reading rate: $Z = -.05$, $p = .96$; text reading accuracy: $Z = -.24$, $p = .81$; text reading rate: $Z = -.72$, $p = .47$; spelling: $Z = -.67$, $p = .50$).

Table 3 presents the distribution of the attained reading and spelling skills. These results reveal similar proportions in both treatment groups. Most of the participants attained a level equal to, or above, the general population mean for text reading accuracy and spelling. Moreover, half of the participants were within the average range for both reading-rate measures.

Table 5.2. Pretest and Posttest Scores for Reading and Spelling Measures

		Treatment Group 1				Treatment Group 2			
Measure		Pre		Post		Pre		Post	
Word reading rate[a]	RS	52.34	(14.31)	66.77	(12.33)	50.64	(12.99)	66.59	(12.98)
	SS	77.37	(14.00)	88.15	(13.65)	75.78	(14.75)	87.85	(14.59)
Text reading accuracy[b]	RS	42.98	(25.28)	18.54	(9.35)	44.88	(24.39)	19.29	(11.86)
	SS	84.35	(24.73)	105.98	(9.87)	82.17	(23.83)	105.18	(12.51)
Text reading rate[c]	RS	568.47	(218.42)	421.75	(105.89)	572.14	(255.38)	413.28	(102.97)
	SS	61.38	(38.44)	84.58	(19.93)	60.56	(44.15)	86.23	(20.16)
Spelling[b]	RS	39.84	(24.35)	8.41	(4.86)	47.10	(30.70)	9.50	(6.80)
	SS	54.37	(35.62)	101.09	(9.60)	58.86	(35.01)	99.31	(11.85)

Note. Standard deviations in parentheses. [a] Number of words correctly read within 1 minute. [b] Number of errors. [c] Time in seconds. RS = raw score; SS = standard score.

Table 5.3. Percentages of Attained Reading and Spelling Levels

	Treatment Group 1				Treatment Group 2			
Level	word reading rate	text reading accuracy	Text reading rate	spelling	word reading rate	text reading accuracy	text reading rate	spelling
Posttest SS ≥ SS=100 level	20%	79%	23%	66%	18%	80%	22%	61%
Posttest SS ≥ SS=90 level	48%	94%	48%	87%	52%	93%	50%	83%
Posttest SS ≥ Pretest SS	91%	99%	90%	100%	93%	99%	92%	98%

Note. SS = standard score

Individual Differences

A final set of analyses focussed on treatment gains vis-à-vis the individuals' initial diagnostic profiles. The relevant features of the individual profile were the extent of the phonological deficit, initial reading and spelling level, age, and IQ. The influence of these profile features on the treatment gain was assessed using multiple regression analyses (MM-estimation; Yohai, Stahel & Zamar, 1991). Since the two treatment groups revealed similar improvements, they were pooled (total *n* = 267). The results of these analyses are presented in Table 4. As can be seen in the table, the extent of the phonological deficit did not systematically affect treatment gain. There were only two significant effects; one on word reading rate and the other on spelling. By contrast, there were clear effects of the initial levels of reading and spelling. The results revealed for each reading and spelling measure that the pretest level was significantly related to the treatment gain on the relevant measure. The relations were all negative, indicating that individuals with larger deficits made greater progress.

Finally, a significant negative relation was observed between age and gains for word reading rate, indicating that the word reading rate of older participants benefited more from treatment than the rates of younger individuals. Age did not significantly affect improvements seen for any of the other outcome measures. IQ was significantly related to the gains on text reading rate, but not to any of the other outcome measures.

Table 5.4. Simultaneous Regression Analyses of Predictor Variables on Treatment Gains

	Dependent Variable			
Predictor variable	word reading rate	text reading accuracy	Text reading rate	spelling
Age	1.26*	.46	-.82	.29
IQ	.11	.08	.23*	.13
Phoneme Synthesis	1.22	1.10	1.08	.12
Phoneme Analysis	.13	-.32	.66	-1.13*
Auditory Closure	.76	1.20	.37	.84
Homophones	-2.06*	-.71	-1.90	.88
Digit Span	.75	-.02	2.03	1.47
Interference	.75	-.46	.49	-.98
Initial Level	-3.49*	-12.91*	-8.87*	-13.64*
Robust R^2	.19	.55	.43	.67

Note. Values are regression coefficients. $*p < 0.5$

Discussion

The aim of present study was to evaluate the effectiveness of a computerised treatment that focussed on teaching to recognise and use the phonological and morphological structure of Dutch words. In the present study, we were able to replicate the positive effects of this treatment program reported in a previous study (Tijms et al., 2003). Using two large treatment samples, the present study showed sizeable effects of treatment on both reading and spelling

abilities of dyslexics. The two treatment groups showed a highly similar pattern of results, supporting the reliability of the treatment effects.

Following treatment, the participants attained a level of spelling that was comparable to the average level general population. Approximately 85% of the participants attained a level of spelling above the lower bound of the average range. The results revealed a similar progress with respect to text reading accuracy. In addition, sizeable improvements were observed for both word reading and text reading rate. Contrary to spelling and reading accuracy, however, the participants did not attain the average level of the general population. Their levels were comparable to the lower bound of the average range; only half of the participants attained a level of reading rate within the average range and the other half fell short of this level.

Another important feature of the current treatment was that its effects generalised to uninstructed words of varying complexity. This indicates that the participants were able to generalise the learned phonological and morphological concepts, and so attain overal better reading and spelling skills. This is a particularly promising result, since transfer-of-learning appears to be a major hurdle for many treatment methods (cf. Lovett et al., 2000).

It is interesting to compare the treatment effects obtained in this study with those reported in other studies. Standardised gains in word reading accuracy have been reported by several intervention studies (Hatcher, 2000; Lovett et al., 1994, 2000; Torgesen et al., 2001; Wise, Ring & Olson, 1999, 2000). One of the most successful studies has been reported by Torgesen et al. (2001). In this study, about half of the participants obtained a level of text reading accuracy within the average range, i.e., the mean standardised reading level was comparable to the lower bound of the average range. Other studies, however, revealed considerably less progress. In particular, reading rate has been less susceptible to intervention than reading accuracy (Torgesen et al., 2001; Lovett et al., 2000; Lyon & Moats, 1997; Van der Leij & Van Daal, 1999). This pattern of results led some researchers to conclude that phonologically-based intervention methods are less suitable for improving reading fluency of dyslexics (Wolf & Katzir-Cohen, 2001). A Dutch study published by Van Daal and Reitsma (1999) showed that, although the participants made progress on both word reading and text reading measures, their standing relative to average readers did not change during the course of treatment.

Although in most studies the emphasis is on reading skills, a limited number of studies evaluated spelling skills (Wise et al., 1999, 2000; Lovett et al., 1994, 2000; Torgesen et al., 2001; Hatcher, 2000). Those studies typically report gains in spelling, but none of these studies demonstrated that the attained spelling level was within the average range.

The results of the current study did not reveal a relation between individual differences in phonological deficit and treatment gain. At first glance, this finding seems surprising, since phonological processing problems constitute the core deficit in dyslexia. The current finding is compatible, however, with results of previous studies that failed to show a consistent impact of phonological measures on the dyslexic’s responses to treatment (Hatcher & Hulme, 1999; Torgesen et al., 1999, 2001; Van Daal & Reitsma, 1999; Wise et al., 1999, 2000). Hatcher and Hulme (1999) explained the recurrent lack of relation between the extent of the phonological deficit and treatment response by suggesting that in treatments consisting of

intensive phonological training the level of initial phonological skills is less important, because those treatments are designed to overcome these phonological weaknesses (cf. Hatcher & Hulme, 1999). However, restriction of range of initial levels of phonological processing provides a simpler explanation of the absence of a relation between the effectiveness of treatment and the seriousness of the phonological deficit. Since phonological processing deficits were used in this study as a selection criterion of the treatment sample, the restriction in variation may account for the lack of association.

In addition, in the current study, age was found to be unrelated to the efficacy of treatment. Wise et al. (1999, 2000) observed that younger children showed stronger treatment gains than older children. This led the authors to suggest that remediation may be more effective for younger participants. Along similar lines, others have argued that the longer dyslexic children go without intervention, the lower the rate of success (Lyon, 1995b). Other studies indicated, however, that effectiveness of treatment does not necessarily decrease with increasing age. For example, Lovett and Steinbach (1997) reported equivalent gains for children in grades two to six. Similarly, Torgesen et al. (2001) failed to observe a relation between age and treatment effect. The present findings are consistent with these studies, showing the effectiveness of treatment is not age-dependent. On the positive side, this finding implicates that older children, as younger children, may benefit equally from treatment.

Finally, the effectiveness of treatment was not related to IQ. This finding is in agreement with previous reports (Hatcher & Hulme, 1999; Torgesen et al., 1999; Van Daal & Reitsma, 1999). It should be noted, however, that the present study included participants with IQ-scores of at least 85. Hatcher (2000) observed that low IQ (IQ scores between 55 and 75) reduced the susceptibility to treatment. In contrast, the current evaluation revealed that participants with the lowest initial reading and spelling levels tended to gain the most from treatment. This finding indicates that those children who are most in need for treatment benefit most from it.

In conclusion, the present study provided strong support for the claim that reading and spelling disabilities of children with a phonological processing disorder are amenable to treatment. This conclusion provides a challenge to existing notions that the biological constraints in dyslexia make reading and spelling marginally susceptible for intervention (Cossu, 1999). Arguably, in spite of the phonological processing disorder in dyslexia, the language system of dyslexics allows them to communicate spoken language in a normal way. It is merely the contrived, written form of communication that poses problems for them. The orthographic transcription of spoken language is very deterministic, contrary to the spoken language itself, which allows for variability in pronunciation. Inaccurate phonological representations prevent the efficient processing of information related to this strictly determined graphic representations. Basically, the LEXY treatment provides the dyslexic with a system, relating morphophonological features to the orthographic representation of the phonemes. It would appear that the treatment supports the phonetic module and facilitates access to the lexicon. As shown in the present study, this support may advance the reading and spelling abilities of dyslexics to a functional level.

Notes

1. This chapter is in press in the journal *Dyslexia* with Jan Hoeks as co-author.
2. A phone is a perceptual class of speech sounds with a singular linguistic function. The terms phonic and phone are used to express the perceptual character of speech sounds, phonemes being abstract linguistic entities within a phonetic or phonological theory.
3. The IWAL-institute was founded by members of the department of psychology of the University of Amsterdam in 1983 in order to bring scientific knowledge of dyslexia into practice. It is specialised in research, assessment and treatment in the field of dyslexia.
4. In the age range of the sample of the present study, the normal curve of literacy development levels off (Foorman et al., 1997). Therefore, to avoid suggesting artificially high treatment gains relative to the normal growth, raw scores were analysed instead of standardised gains.

Chapter 6

Verbal memory and phonological processing in dyslexia[1]

Abstract

This study examines whether two frequently reported causes of dyslexia, phonological processing problems and verbal memory impairments, represent a double-deficit or whether they are two expressions of the same deficit. Two-hundred-and-sixty-seven Dutch children aged 10- to 14 with dyslexia completed a list-learning task and several phonological tasks, together with a number of reading and spelling tests. The results indicate that phonological deficits and verbal memory impairments in dyslexia stem from the same root, which seemingly reflects an inaccurate encoding of the phonological characteristics of verbal information. This phonological encoding deficit is a negative predictor for both the reading and spelling skills of dyslexic children.

Introduction

Developmental dyslexia refers to a biologically rooted reading anomaly under the conditions of adequate education and a normal developmental environment (Grigorenko, 2001). Two frequently reported causes of dyslexia are phonological processing problems and verbal memory impairments. Since language processes seem to deploy different memory functions, it is an interesting question whether the phonological and the verbal memory deficits in dyslexia represent a so-called double-deficit or whether they are two expressions of the same underlying disorder. The main goal of the present study was to answer this question.

A milestone in the field of dyslexia has been the seminal work of Vellutino (1979), revealing that those with dyslexia have systematically difficulties on tasks incorporating a verbal component, whereas they perform at the same level with non-dyslexics on comparable tasks without a verbal component. These results led to the conclusion that the cause of dyslexia is within the verbal learning and memory domain.

Over the last two decades various linguistic components (such as syntax, semantics, morphology, phonology) have been analysed to reveal the part of the language process that is dysfunctional. A large body of converging evidence now indicates that dyslexia stems from an underlying deficit in the phonological processing system (Beitchman & Young, 1997; Lyon, 1995a; Mody, 2003; Shaywitz, 1998; Snowling, Nation, Moxham, Gallagher & Frith 1997). One of the most robust findings is an explicit phonemic awareness deficit; that is, dyslexic children have difficulty in consciously detecting, segmenting and manipulating individual speech-sounds in words (Beitchman & Young, 1997). This deficit is assumed to be a causal factor in reading and spelling difficulties. However, the relationship between phonemic awareness and literacy skills appears to be bidirectional. The development of phonemic awareness has not only been found to be a precursor of reading, but also to be a consequence of it (Goswami, 2001; Snow, Burns & Griffin, 1998).

In addition to phonemic awareness impairments, deficits in other phonological skills, such as activation of phonological codes for naming and direct repetition of sequences of words, have been identified in dyslexia. Therefore, several authors point to a more central component of the phonological module as the core deficit in dyslexia (Brady, 1997; Elbro, 1998; Mody, 2003; Snowling, 2001; Swan & Goswami, 1997). According to this so-called phonological 'representation' hypothesis, an inaccurate phonological encoding of lexical representations is the core factor causing problems in literacy skill acquisition: phonology is less accurately coded in dyslexia. The ability to segment consciously or manipulate phonological information is considered to be, at least to a large extent, dependent on the quality of the underlying phonological representations (Elbro, 1998; Goswami, 2000). From this point of view, phonemic awareness deficits are considered secondary to underspecified phonological representations (Swan & Goswami, 1997).

Although this implies that these two phonological aspects are related, both neuropsychological and factor-analytical studies revealed that they are partly independent processes (Hickok & Poeppel, 2000; Pennington, Van Orden, Smith, Green & Haith, 1990). For instance, a recent review of neuroanatomical findings indicated that two pathways can be distinguished in phonological processing (Hickok & Poeppel, 2000). Tasks that require conscious access to speech segments (i.e. phonemic awareness) appear to rely on a dorsal pathway, which involves left inferior parietal and frontal systems, whereas a ventral pathway, which involves cortex in the vicinity of the temporal-parietal-occipital junction, appears to play a greater role in the processing of phonological representations in the mental lexicon. One of the most sophisticated models of speech processing, that of Levelt (Levelt, 1989; Levelt, Roelofs & Meyer, 1999), closely concurs with this neuroanatomical model. Levelt distinguishes a lexical level of phonological processing, in which semantic representations activate a sequence of phonological codes, and a sub-lexical level in which these phonological representations are syllabified and prepared for articulation. Levelt and co-workers demonstrated that conscious access is only possible at this sub-lexical level (Levelt et al., 1999). In accordance, Windfuhr and Snowling (2001) distinguish explicit (sub-lexical) and implicit phonological (lexical) processing. In this sense, phonemic awareness tasks are assumed to tap explicit phonological processing, whereas implicit phonological processing is reflected in tasks as digit or word span.

Beside the evidence for phonological deficits, verbal memory problems, such as paired associate learning, list learning and story recall, have also been regularly reported in dyslexia over the years (Howes, Bigler, Lawson & Burlingame, 1999; Johnson, 1993; Kinsbourne, Rufo, Gamzu, Palmer & Berliner, 1991; Nelson & Warrington, 1980; O'Neill & Douglass, 1991; Snow et al., 1998). Clinically, the pre-school histories of dyslexics usually contain reports of memory difficulties, such as problems in remembering colour or number names, the names of the days of the week and the months of the year, and other verbal sequences (Pennington, 1991; Shaywitz, 1998).

Different components can be distinguished in verbal memory. Two systems that are considered to be basically independent are the acquisition and consolidation of verbal information (Helmstaedter, Grunwald, Lehnertz, Gleißner & Elger, 1997). However, the number of studies aimed at specifying the verbal memory impairment associated with

dyslexia has been very limited. Only recently, the precise nature of verbal memory deficits in individuals with dyslexia has been studied. In a carefully designed experiment, Kramer, Knee & Delis (2000) examined the locus of the verbal memory impairment in dyslexia. For this, the California Verbal Learning Test-Children's Version (CVLT-C) was used, a list-learning task that quantifies, among other things, immediate recall, brief and long delayed recall and recognition. Comparison of dyslexic children and non-dyslexic controls revealed that those in the dyslexic group learned the list items more slowly, but were able to retain the words to a normal extent on both the brief and long delayed recall. It was concluded that children with dyslexia had less efficient acquisition mechanisms, but had no problems with the consolidation or retrieval of the information, once it was learned.

On the basis of the results of Kramer et al. (2000), it could be hypothesised that an inaccurate encoding of the phonological characteristics of the stimulus are the cause of the verbal memory impairments in dyslexia. Thus, it suggests that phonological deficits and verbal memory impairments stem from the same root. This suggestion is supported by neuropsychological evidence, which indicates that acquisition of verbal information involves the left posterior superior temporal gyrus, an area that is also associated with phonological coding activities, whereas temporomesial structures play a greater role in the consolidation of verbal material (Alvarez & Squire, 1994; Helmstaedter et al., 1997; Wise et al., 2001). Unfortunately, Kramer et al. (2000) did not examine the phonological processing skills of their participants, nor their reading and spelling abilities. Consequently, it remains unclear whether the acquisition impairment is related to the phonological processing problems or an individual factor affecting reading and spelling skills or a co-occuring impairment that is unrelated to both phonological and literacy skills.

Therefore, the aim of the present study was to extend the results of Kramer et al. (2000) by examining the processes underlying the verbal memory performance and phonological skills of those with dyslexia. In order to reveal these processes, a number of phonological tasks and a list-learning verbal memory task were used. It was expected that a factor which reflects the encoding of phonological characteristics is primary to both the phonological and verbal memory skills. In addition, two other factors were expected. As mentioned above, phonemic awareness appears to be a partly independent phonological skill. Therefore, a second factor was expected that is related to phonological tasks, i.e. phonemic awareness. Since in verbal memory the acquisition and the consolidation of information are considered separable processes, a third factor was expected that is related to memory, i.e. consolidation. Subsequently, the influence of these factors on reading and spelling skills was examined. When, as hypothesised, phonological encoding is the core factor underlying both verbal memory impairment and phonological deficits in dyslexia, it would be expected that this factor is most consistently related to the participants' literacy skills.

Method

Participants

The sample in this study comprised children, who were referred to the IWAL-institute[2] because they were falling behind at school with respect to reading and writing. Participants in

an age range from 10-14 years were selected. To be included in the study, participants had to be at least one standard deviation below average in their reading or spelling abilities. In addition, they needed to be deficient in the phonological processing of words. Criteria for exclusion were an IQ-score one standard deviation or more below average, problems with auditory discrimination of speech sounds, problems with visual discrimination of figures, or broad neurological problems. The sample (n = 267) included 189 males and 78 females, with a mean age of 11.85 years (SD = 1.44). The mean IQ of the sample was 108.53 (SD = 10.42). One-sample t-tests revealed that the sample performed significantly below the population mean on all phonological tasks (all $p < 0.01$).

Instruments

Reading and Spelling Tests

Word Reading Rate. Reading skills were assessed by the One-Minute-Test (Brus & Voeten, 1973), a time-limited test in which the number of correctly read unrelated words within one minute determined the score (r = 0.89 to 0.93, test-retest).

Text Reading Accuracy and *Text Reading Rate* were assessed by the 'Livingstone' text (Schaap, 1986). This text consists of 64 lines, which subjects are required to read. Subjects are instructed to read the text both fast and accurately. The words represent the various problems in the Dutch written language. The number of reading errors and the time taken for reading the text provide the outcome measures (accuracy: r = 0.93 to 0.94; rate: r = 0.97 to 0.99, test-retest).

Spelling. Spelling skills were assessed using the IWAL-Standard Dictation (Harel & Schaap, 1981). This dictation contains 19 sentences. The words making up the sentences are familiar to all elementary-school children. Moreover, the collection of words is a representative sample of the various spelling problems in Dutch (Harel & Schaap, 1981). Scoring is based upon the number of spelling-errors (r = 0.90, test-retest).

Phonological Tests

Phoneme Synthesis. The subtest Auditory Synthesis of the Language test for Children (TVK; Van Bon, 1982) was used to examine the ability to synthesise phones into a word. This test is analogous to the Blending Words subtest of the Comprehensive Test of Phonological Processing (CTOPP; Wagner, Torgesen & Rashotte, 1999). The Auditory Synthesis test consists of 29 items presented using a tape recorder. Each word is presented phone by phone. Participants are asked to say the word that results when phones are blended. Scoring is based upon the number of correct responses (r = 0.89, internal consistency).

Auditory Closure. Also, a Dutch version of the Illinois Test of Psycholinguistic Abilities (ITPA) subtest Auditory Closure was used (TvK-Word Recognition; Van Bon, 1982). Participants were presented with words in which one or more phonemes are deleted and replaced by a short silence. Participants are required to say the word. This test includes 29 items. Scoring is based upon the number of correct responses (r = 0.74, internal consistency).

Digit Span. A Dutch version of the Digit Span subtest of the WISC (WISC-RN; Van Haasen et al., 1985) was used. The number of digits that a participant could repeat in correct

or reversed serial order immediately after hearing them represents the score on this test. Scoring criteria are given in the test manual (r = 0.78 to 0.85, internal consistency).

Auditory Interference. The IWAL-Auditory Interference test, in which two lists of three words are used to produce inter-list interference, was administered (Schaap, 1984). The test comprises six items. Each item consists of two groups of three monosyllabic words, which are presented orally. After presentation of the two groups, participants are asked to repeat the first group and after that to repeat the second group, or to repeat the second group and after that the first group. Scoring is based upon the number of words repeated correctly (r = 0.67 to 0.72, internal consistency).

Verbal Memory Test

Verbal memory abilities were assessed using a list learning task, the 15-word test (Schaap, 1987). This test requires learning of a list of 15 concrete and highly frequent words (read aloud at the rate of one word per second) in five consecutive learning trials, each followed by immediate recall. After a 30-minute delay during which non-verbal tasks were administered, a long delay free recall was assessed. Two scores were used for analysis. Analogous to the approach of Kramer et al. (2000), verbal acquisition was represented by the highest score of the learning trials, and verbal consolidation was represented by the long-delay free recall score (r = 0.88 to 0.89, internal consistency).

Table 6.1. Descriptive statistics of phonological processing, verbal memory, reading and spelling

	Mean	SD	Range	Maximum Score
Restricted Tests				
Phoneme Synthesis	21.48 [a]	(4.94)	3 – 29	29
Auditory Closure	24.06 [a]	(2.67)	13 – 29	29
Digit Span	9.39 [a]	(2.23)	5 – 17	24
Auditory Interference	31.86 [a]	(7.89)	16 – 59	66
Highest Learning Trials	11.99 [a]	(1.80)	5 – 15	15
Long-delay Recall	10.31 [a]	(2.38)	3 – 15	15
Word Reading Rate	51.48 [a, c]	(13.65)	18 – 90	116
	76.56 [b]	(14.38)	31 – 115	160
Unrestricted Tests				
Text Reading Accuracy	44.03 [a, d]	(24.95)	5 – 164	
	83.24 [b]	(24.26)	0 – 122	
Text Reading Rate	569.90 [a, e]	(237.31)	270 – 1181	
	60.69 [b]	(41.37)	0 – 116	
Spelling	43.45 [a, d]	(27.94)	7 – 138	
	56.66 [b]	(35.31)	0 – 103	

Notes. Restricted tests: tests imposing a limit on the errors that can be committed. Unrestricted tests: tests allowing unlimited error rates or time. [a]Raw score. [b]Standard score (mean = 100; standard deviation = 15). [c]Number of words correctly read within 1 minute. [d]Number of errors. [e]Time in seconds.

Results

Descriptive statistics for the scores of reading, spelling, phonological processing and verbal memory are presented in Table 1.

Phonological Processing and Verbal Memory

To identify the underlying factors of verbal memory and phonological processing skills, a principal-component factor analysis was conducted on the scores of the four phonological tasks, the highest score of the learning trials and the long-delay recall measure of the verbal memory test. Factors were extracted using the eigenvalue-one procedure.

The factor analysis with varimax rotation yielded three factors, which accounted for respectively 29.8%, 25.2% and 16.6% of the variance. The factor loadings are presented in Table 2. As can be seen from the table, the two tasks that required the participants to consciously manipulate speech sounds, i.e. phoneme synthesis and auditory closure, loaded strongly on the first factor. Therefore, the first factor was termed 'phonemic awareness'. Most importantly, the two other phonological tasks, digit span and interference, and verbal memory highest learning trial loaded on the second factor. Because these three tasks share the encoding of the phonological characteristics of information, this factor was termed 'phonological memory'. The third factor was labelled 'verbal consolidation'; only verbal memory long-delay recall loaded highly on this factor.

Table 6.2. Varimax rotated factor loadings

	factor 1	factor 2	factor 3
Phoneme Synthesis	.93	.11	-.01
Auditory Closure	.94	-.04	-.01
Digit Span	-.00	.78	-.21
Interference	.10	.64	.11
Highest Learning Trials	-.06	.64	.42
Long-delay Recall	.00	.03	.93

The Impact on the Reading and Spelling Skills

For further analysis the three factor scores were used, i.e. phonemic awareness, phonological memory and verbal consolidation. The influence of these three factors on the reading and spelling performance of the dyslexic children was assessed using hierarchical regression analyses.

The results of these analyses are presented in Table 3. As seen in the table, the levels of reading and spelling were not related in any systematic way to phonemic awareness, nor to verbal consolidation. By contrast, phonological memory was significantly related to all four reading and spelling abilities. The direction of these significant relations indicated that more serious phonological memory deficits were accompanied by weaker reading and spelling levels.

Table 6.3. Hierarchical regression analyses with the reading and spelling skills as dependent variables and factor scores as the predictor variables

	Word Reading Rate			Text Reading Accuracy			Text Reading Rate			Spelling		
	β	r^2	r^2 change	β	r^2	r^2 change	β	r^2	r^2 change	β	r^2	r^2 change
Verbal Consolidation	-.03	.00	.00	.02	.00	.00	-.01	.00	.00	.03	.00	.00
Phonemic Awareness	-.09	.01	.01	-.09	.01	.01	-.04	.00	.00	-.05	.00	.00
Phonological memory	.20	.05	.04**	.21	.05	.04**	.17	.03	.03**	.15	.03	.02*

Notes. * $p < .05$ ** $p < .01$

Discussion

The main purpose of the present study was to examine whether phonological processing and verbal memory deficits in dyslexia stem from a common cause. The starting point was the study of Kramer et al. (2000), which indicated that the verbal memory impairment of dyslexics were within the acquisition phase, and were not related to consolidation or retrieval deficits. In the present study, both the phonological and the verbal memory skills of dyslexic children were examined. As hypothesised, three factors underlying their phonological and verbal memory skills were revealed, termed 'phonemic awareness', 'phonological memory' and 'consolidation'. The most important finding was that acquisition of verbal memory and phonological processing were related to the same factor, i.e. phonological memory. Arguably, this result indicates that the acquisition impediment of verbal memory and at least part of the phonological processing deficits in dyslexia stem from a common underlying impairment, which seemingly reflects an inaccurate encoding of the phonological characteristics of verbal information. Moreover, this phonological coding function was systematically related to the reading and spelling levels of dyslexics. More serious phonological coding deficits were accompanied by poorer literacy skills. In contrast, the verbal consolidation abilities appeared not to be of any relevance in dyslexia: consolidation was not related with phonological processing, nor was it associated with the dyslexics' reading and spelling skills.

Thus, the findings of Kramer et al. (2000) were confirmed and extended by the results of the present study. Furthermore, it can be concluded that verbal memory impairment and phonological deficits in dyslexia do not represent a double-deficit, but are two manifestations from a common root, that is, a dysfunction in the encoding of speech sounds.

A more specific account of the nature of the verbal memory impairment can be derived from phonological representation theory. As indicated above, this theory postulates that the core problem in dyslexia are inaccurate phonological representations. In the mental lexicon, these inaccurate or unstable sequence of phonological codes of a word form will result in an inefficient activation of the semantic properties of this word form (Lukatela, Carello, Savić, Urošević & Turvey, 1998). In memory formation, the acquisition of incoming stimuli supposedly follows a series of processing levels, for instance, from sensory registering to phonemic to semantic processing. According to the levels of processing theory (Craik & Lockhart, 1972; Brown & Craik, 2000), deeper, semantic levels of processing lead to a more optimal consolidating of the material than encoding of phonological characteristics of the material. Arguably, in dyslexia the inaccurate phonological representation interferes with the semantic processing and, consequently, with the acquisition of the verbal material. Once the deeper, semantic level is activated, no further problems appear to be encountered and consolidation of the verbal information takes place as normal. This assumption fits with the results of both the present study and the study of Kramer et al. (2000), though, it is clear that further research is needed to support it. The problems experienced by those with dyslexia on digit span or word repetition tasks have also been explained in terms of an inaccurate phonological representation (Hulme & Roodenrys, 1995; Irausquin & De Gelder, 1997; McDougall & Donohoe, 2002; Snowling, 2000). Verbal material can be held in a phonetic buffer for a short period of time. This memory trace will decay, unless being held active by

rehearsal mechanisms or redintegration mechanisms for reconstruction of decaying memory traces. These mechanisms are assumed to act on the basis of the phonological representation. When a decaying memory trace is to be held active in a system of inaccurate or unstable phonological representations, the chances of altering or loosing the trace increases.

In accordance with ample research, the results of the present study revealed a second phonological factor, named phonemic awareness. On the basis of psycholinguistic (Levelt et al., 1999) and neuroanatomical models (Hickok & Poeppel, 2000) of speech processing, it can be argued that this factor reflects sub-lexical, explicit phonological processing. These explicit phonological abilities appeared to be unrelated to the verbal memory skills of those with dyslexia. At the same time, the results of the present study failed to reveal significant associations between the phonemic awareness skills of those with dyslexia and their reading and spelling skills. It is important to note that this result does not imply that the dyslexic participants had no poor phonemic awareness skills. The current pattern of findings does suggest, however, that in the present dyslexic sample phonemic awareness does not make a unique contribution to the reading and spelling skills, independent of the contribution of phonological memory.

A possible explanation for this lack of association between phonemic awareness and reading and spelling skills in dyslexia involves the differences in the most salient characteristics of dyslexia between languages. In English, a deep orthography, phonemic awareness appears to be a persistent problem in dyslexia. In a shallow orthography such as German, these phonemic awareness difficulties appear to be more transient; although there is evidence for an early phonemic awareness deficit of German dyslexic children, these children seem to have overcome these difficulties by the end of their second year in school (Goswami, 2002; Landerl, 2003; Wimmer, 1996). Goswami (2000) suggests that the relatively consistent feedback from grapheme-phoneme relations in shallow orthographies provides beginning readers more opportunities to develop an adequate level of phoneme awareness. The orthographic depth of Dutch is considered to be in between English and German, being somewhat less consistent than German (Grigorenko, 2001; Seymour, Aro & Erskine, 2003). The sample of the present study consisted of Dutch dyslexic children at the end of elementary education. Therefore, it remains possible that in the early stages of reading, phoneme awareness did have an impact on the reading and spelling development of these children. The present lack of association between their phonemic awareness skills and reading and spelling abilities can thus be interpreted in terms of Goswami's assumption.

When it is assumed that, as is argued above, the phonological memory factor reflects the quality of the phonological codes in the mental lexicon, a more speculative interpretation of the negative findings on phonemic awareness can be outlined. In addressing the nature of phonemic awareness skills, several authors hold the assumption that dyslexics' poor performance on phonemic awareness tasks does not reflect a core deficit, but is secondary to the accuracy of phonological coding in the mental lexicon (Elbro, 1998; Goswami, 2000; Snowling, 2001). Although phonemic awareness as a specific phonological factor and its importance in learning to read are not disregarded, it is assumed that poor readers have difficulty in explicit phonological skills due, at least in part, to poorly coded phonological representations (Goswami, 2000; Mody, 2003). Support for this assumption comes from a

study of Swan and Goswami (1997), in which it was shown that differences in performance on phonemic awareness tasks between dyslexics and controls disappeared once representational quality was taken into account. Additional evidence has been reported by Landerl and Wimmer (2000), who revealed for both German and English dyslexic children that most errors on a phonemic awareness task (i.e. a spoonerism task), were related to phonological memory problems; only a minority of the errors was related to segmentation problems. The present study, which arguably disentangled explicit phonemic awareness and implicit phonological coding, revealed no specific relation between phonemic awareness and reading and spelling. In this sense, the results of the present study do not contradict this phonological representations hypothesis. However, the present study has two potential weaknesses. First, only dyslexic participants, having poor phonological abilities, were used in the present study. Second, the distribution of scores on the two tasks that loaded strongly on the phonemic awareness factor showed a tendency towards ceiling effects. Consequently, although the large sample size provided a high level of power to detect effects, these two limitations might have reduced the variability in phonemic awareness skills, which implies that the negative results of the present study concerning phonemic awareness should be interpreted with some caution.

A clinical implication from the present study is that list-learning verbal memory tests are useful instruments in diagnosing children with reading and spelling disorders (cf. Nichols et al., in press). In practice, phonemic awareness tasks are most often used for investigating phonological deficits in diagnosing dyslexia (Beitchman & Young, 1997; Gustafson & Samuelsson, 1999). The current findings suggest that in the studied age range (10-14 years of age), list-learning tasks can be a fruitful addition to these phonemic awareness tasks because of their sensitivity to both the reading and spelling deficits of dyslexics.

Notes

1. This chapter is published in *Journal of Research in Reading, 27,* 300-310.
2. The IWAL-institute was founded by members of the Department of Psychology of the University of Amsterdam in 1983 in order to bring scientific knowledge of dyslexia into practice. It is specialised in research, assessment and treatment in the field of dyslexia.

Chapter 7

The development of reading and spelling skills during treatment in relation with the phonological coding capacities of dyslexic children

Abstract

Purpose of this study was to assess to what extent the effects of a treatment of dyslexia vary as a function of the dyslexics' phonological coding deficits. Two hundred sixty-seven 10- to 14-year-old Dutch children with dyslexia received a psycholinguistic treatment for reading and spelling difficulties. It was shown that the phonological coding capacities were not predictive for the effects of this treatment. However, phonological coding did systematically affect the duration of treatment; more serious phonological coding deficits were accompanied by a longer duration of treatment. It appeared that by providing more time to the participants with more serious coding deficits, they could attain a literacy level at the end of treatment that was comparable to the level of those with a less serious coding deficit.

Introduction

The present study addressed the question to what extent the effects of a treatment of dyslexia vary as a function of the dyslexics' phonological processing deficit. Dyslexia refers to a specific language-based disorder, characterized by severe difficulty in the acquisition of reading and spelling skills under the conditions of adequate education and a normal developmental environment. There is a broad consensus that it is a neurological disorder with a genetic origin (Grigorenko, 2001, 2003b; Lyon, 1995a; Ramus, 2003). On the basis of a large body of converging evidence, dyslexia is considered to be caused by a deficit in the module of the language system which processes phonological information (for reviews, see Ramus, 2003; Vellutino, Fletcher, Snowling, & Scanlon, 2004).

Past research on the intervention of dyslexia often failed to substantiate the effectiveness of treatment programs in helping dyslexic children to acquire adequate reading skills (Cossu, 1999; Lovett et al., 2000; Torgesen et al., 2001). But in recent years, a growing number of studies reported positive effects of phonologically based training on the reading and spelling skills of dyslexics (Hatcher, 2000; Lovett et al., 2000; Tijms, Hoeks, Paulussen-Hoogeboom, & Smolenaars, 2003; Torgesen et al., 2001; Wise, Ring, & Olson, 2000).

Notwithstanding these positive developments, some individuals appeared far less susceptible to intervention than others (Lyon & Moats, 1997; Torgesen et al., 2001; Wise et al., 2000). This variability in treatment response suggests that individuals with different cognitive profiles may well respond differently to (different kinds of) intervention, and consequently, that these individual differences can play an important role in determining prognosis (Snowling, 2000). Congruently, the identification of individual characteristics which act as moderators of treatment effects is generally considered to be an important step in

the development of an effective treatment program (Kazdin, 2003; Kendall, Flannery-Schroeder, & Ford, 1999).

Since problems in the processing of phonological information constitute the central deficit in dyslexia, differences in phonological capacities might be a critical factor in an individual's susceptibility to a certain kind of treatment (cf. Lovett & Steinbach, 1997). Several studies addressed the predictive value of the seriousness of the phonological deficit on treatment success. The results concerning the impact of phonological deficits, however, appear to be far from consistent; some studies did find a relation (Hatcher & Hulme, 1999; Wise et al., 2000), whereas others did not (Pogorzelski & Wheldall, 2002; Torgesen et al., 2001). Hatcher and Hulme (1999), for example, compared three forms of training, which were limited to phonology, reading, or reading with phonology. In the phonology training, tuition focused mainly on phonological concepts (e.g., segmenting words into phones). The reading training was modeled on the work of Clay (1985) and focused on reading books. The reading with phonology training included elements of both other training-methods. Hatcher and Hulme (1999) studied whether variations in phonological capacities were related to the gains made by the participants following one of these treatment programs. As predictors of treatment responsiveness, they did not use phonological test scores as such, but the factor scores derived from a factor analysis on a number of phonological tasks. This analysis yielded three phonological factors, coined phoneme manipulation, rhyme, and phonological memory. It was found that phoneme manipulation skills were a significant predictor of children's responsiveness to the reading treatment as well as to the reading with phonology treatment, but not to the phonology only training. Rhyme and phonological memory were not significantly related to treatment gains.

In the present study, a group of dyslexic children engaged in a Dutch phonologically based treatment for reading and spelling disabilities, named LEXY. The LEXY treatment presented these dyslexic participants with a learning system, which clarifies the basic elements and operations by which one's writing system encodes the characteristics of the spoken language system. The architecture of the program is constructed in line with production models of skill acquisition, and in particular with the theory of learning activity (Davydov, 1990/1995; Gal'perin, 1974/1989). Previous research provided evidence for the effectiveness of this treatment method. Tijms et al. (2003) evaluated the short and long-term effects of treatment. This study revealed clinically relevant treatment effects on word reading rate, text reading accuracy and spelling. More importantly, this study indicated that the improvements in word and text reading were stable over a 4-year follow-up period. Spelling showed a slight decline one year after treatment, but remained stable thereafter. The primary purpose of the present study was to examine the extent to which individual differences in phonological capacities determine the progress in reading and spelling skills during the LEXY treatment.

Method

Participants

The participants were the same as in the study of Tijms (2004). The sample comprised 267 participants, who were referred to the IWAL-institute[1] because they were falling behind at school with respect to reading and writing. Participants in an age range from 10 to 14 years were selected. To be included in the study, participants had to be at least one standard deviation below average in their reading or spelling abilities. In addition, they should be deficient in the phonological processing of words. Criteria for exclusion were an IQ-score one standard deviation or more below average, problems with auditory discrimination of speech sounds, problems with visual discrimination of figures, or broad neurological problems. Descriptive characteristics of these participants are summarized in Table 1.

Table 7.1. Characteristics of Participants

N	267	
Age (years)	11.8	(1.4)
IQ	108.5	(10.4)
Number of treatment sessions	46.8	(15.3)
Gender ratio (male : female)	2.4 : 1	
Word reading rate ZS	-1.56	(0.96)
Text Reading Accuracy ZS	-1.12	(1.62)
Text Reading Rate ZS	-2.60	(2.76)
Spelling ZS	-2.89	(2.35)

Note. Standard deviations in parentheses. ZS= z-score.

Instruments

Word Reading Rate. Reading skills were assessed by the One-Minute-Test (Brus & Voeten, 1973), a time-limited test in which the number of correctly read unrelated words within one minute determined the score (r = .89 to .93, test-retest).

Text Reading Accuracy and *Text Reading Rate* were assessed by the 'Livingstone' text (Schaap, 1986). This text consists of 64 lines which subjects are required to read. Subjects are instructed to read the text both fast and accurately. The words represent the various problems in the Dutch written language. The number of reading errors and the time taken for reading the text provide the outcome measures (accuracy: r = .93 to .94, rate: r = .97 to .99, test-retest).

Spelling. Spelling skills were assessed using the IWAL-Standard Dictation (Harel & Schaap, 1981). This dictation contains 19 sentences. The words making up the sentences are familiar to all elementary-school children. Moreover, the collection of words is a representative sample of the various spelling problems in Dutch (Harel & Schaap, 1981). Scoring is based upon the number of spelling-errors (r = .90, test-retest).

Multiple forms were used for all reading and spelling tests to avoid effects due to practice.

Procedure
Treatment was provided on a one-to-one basis in a 45-minute session, which took place once a week. Besides these sessions at the institute, participants were required to practice at home three times a week for 15 minutes per time. The treatment started with a focus on the phonological structure of Dutch words. Subsequently, operations were introduced to map the phonic word onto the correct orthographic word form. Later on, emphasis was shifted to implications of the morphological structure for the orthography of words.

The program was aimed at achieving a certain mastery level for each element of the program. An element was considered to be mastered when the percentage of correctly performed items during training was at least 80%. This implies that participants did not pass through the program at a fixed pace. A fuller, comprehensive description of the treatment can be found in Tijms et al. (2003).

Results

Data-analysis
Following Hatcher and Hulme (1999), factor scores were used as measure of phonological abilities instead of using the scores on the original phonological tests. The advantage of using factor scores is that the number of predictor variables is reduced. Furthermore, factor scores can provide a more stable and reliable measure of the participants´ phonological abilities than the original test scores (e.g., Thompson, 2004). In a previous experiment, Tijms (2004) conducted a factor analysis to analyze the underlying deficit of dyslexics´ reading and spelling difficulties. For this, a number of tasks on which dyslexics are repeatedly reported to perform poorly were administered. These tasks included explicit phonological tasks (two phoneme awareness tasks), implicit phonological tasks (number repetition, and auditory interference) and a list-learning verbal memory task (acquisition and retention of a list of 15 words). It was revealed that the core deficit associated with the dyslexics' reading and spelling difficulties was a factor, which seemingly reflects an inadequate phonological coding process. Both the implicit phonological tasks and the verbal memory acquisition loaded high on this factor. Therefore, the factor scores of the participants on phonological coding, as revealed in Tijms (2004), were used for analysis.

A path analysis was used to evaluate the influence of the phonological coding abilities on the reading and spelling gains following treatment. Instead of defining treatment gain as the absolute difference between the (standardized) pretest and posttest scores, a measure of relative gain was used. Treatment gain was represented as a gain index:

$$i_{g,ij} = \frac{x_{pre,ij} - x_{post,ij}}{x_{pre,ij}}$$, in which

$i_{g,ij}$ = the gain index of participant *i* on variable *j*,
$x_{pre,ij}$ = the score of participant *i* on variable *j* at the start of treatment, and
$x_{post,ij}$ = the score of participant *i* on variable *j* after treatment.

The gain index provides a proportional measure of the treatment gain. Thus, a participant committing 80 spelling-errors at the beginning of the treatment and 40 errors at the end of treatment, will be indexed by a gain of .5. An important advantage of this index is that

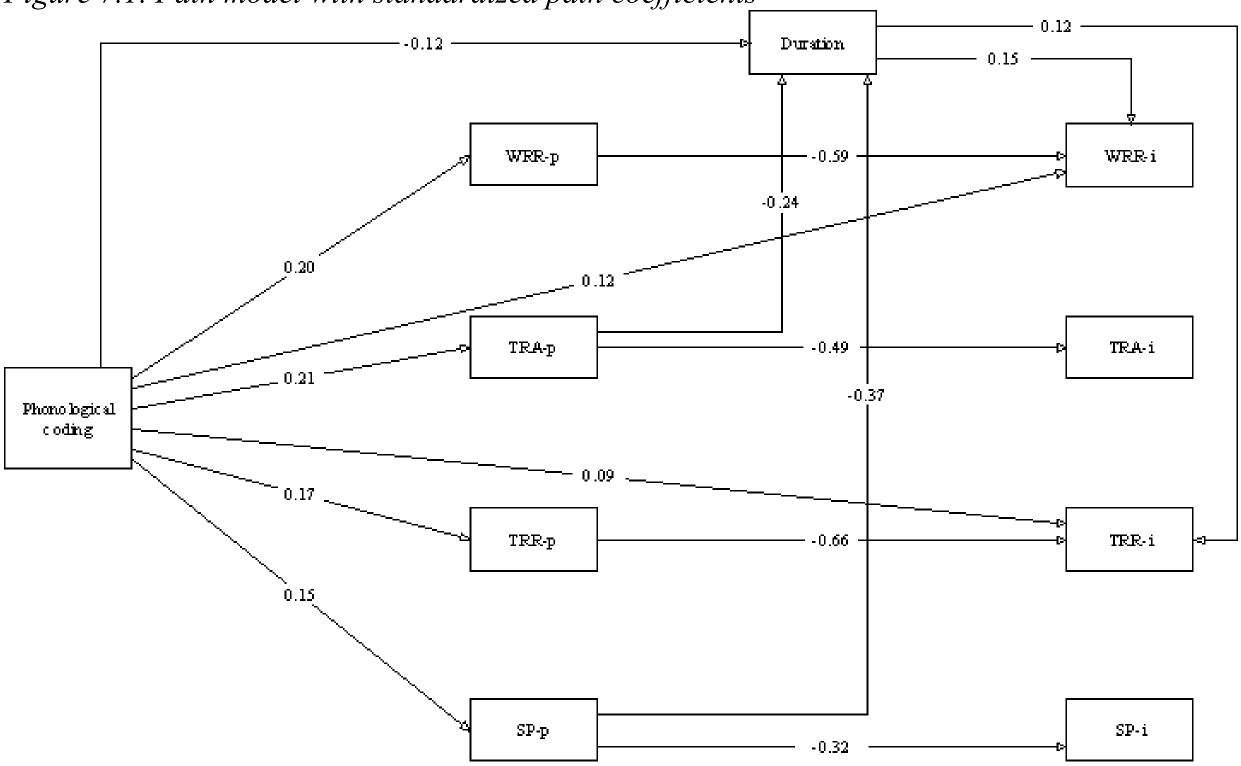
individual differences in pre-intervention levels of reading and spelling are partialled out. This also serves as a correction for a possible regression towards the mean.

Finally, to include variables that might moderate the influence of phonological coding abilities on treatment gains, pre-intervention reading and spelling levels and the duration of treatment were added to the analyses.

The path model was constructed on the basis of a series of (multiple) regression analyses, i.e. (a) regression analyses of phonological coding on the pre-intervention reading and spelling skills and on the duration of treatment (to examine the relation between phonological coding and the intermediary variables), and (b) multiple regression analyses with phonological coding, pre-intervention reading and spelling levels and the duration of treatment as predictors and treatment gains as dependent variables (to examine the relation between phonological coding and treatment gains as well as the relation between intermediary variables and treatment gains).

Path Model

Figure 7.1. Path model with standardized path coefficients



Note. Only significant path coefficients are shown ($p < .05$). WRR = Word Reading Rate, TRA = Text Reading Accuracy, TRR = Text Reading Rate, SP = Spelling; -p = pre-intervention level, -i = treatment gain index.

Phonological coding and treatment gain. The path model with standardized path coefficients for the significant paths between phonological coding and the reading and spelling gains is presented in Figure 1. As already reported in Tijms (2004), phonological coding was significantly related to all pre-intervention levels of reading and spelling. The

negative relations indicated that more serious phonological coding deficits were accompanied by weaker pre-intervention reading and spelling levels. Furthermore, the current analyses revealed a significant direct path from phonological coding to treatment gains on both word reading rate and text reading rate, but not to treatment gains on text reading accuracy or spelling. The direction of the significant paths suggested that participants with more serious phonological coding deficits gained less from treatment on the two reading rate variables.

Additionally, the results revealed indirect paths from phonological coding to treatment gains, mediated by the four pre-intervention reading and spelling levels and the duration of treatment. The effect of an indirect path is defined as the product of its path coefficients (predictor-mediator and mediator-dependent), with the total indirect effect being the sum of the indirect effects (cf. Kenny, 1979; Klem, 1995). Thus, for the relation between phonological coding and treatment gains on word reading rate, the total indirect effect is $\beta = -.15$ ($\beta = -.118$ for Phonological Coding → WRR-p → WRR-i; $\beta = -.018$ for Phonological Coding → Duration → WRR-i; $\beta = -.008$ for Phonological Coding → TRA-p → Duration → WRR-i; $\beta = -.008$ for Phonological Coding → SP-p → Duration → WRR-i). For the relation between phonological coding and treatment gains on text reading rate, the total indirect effect is $\beta = -.14$ ($\beta = -.112$ for Phonological Coding → TRR-p → TRR-i; $\beta = -.014$ for Phonological Coding → Duration → TRR-i; $\beta = -.006$ for Phonological Coding → TRA-p → Duration →TRR-i; $\beta = -.007$ for Phonological Coding → SP-p → Duration → TRR-i). Notably, the direction of these indirect effects was opposite to that of the direct effects of phonological coding on the reading rate gains. The magnitude of these indirect effects counterbalanced the negative influence of the direct effects (for word reading rate: total indirect effect $\beta = -.15$ vs. direct effect $\beta = .12$; for text reading rate: total indirect effect $\beta = -.14$ vs. direct effect $\beta = .09$). Consequently, as the total effect of a predictor variable on a dependent variable is defined as the sum of direct and indirect effects (Kenny, 1979; Klem, 1995), the overall impact of individual differences in phonological coding abilities on the gains made following treatment is approximately zero.

Phonological coding and duration of treatment. Phonological coding had a negative direct effect on the duration of treatment. Results revealed indirect paths on the duration of treatment as well, mediated by pre-intervention levels of text reading accuracy and spelling. Contrary to the situation for the effects on treatment gain, in this case the indirect effects had the same direction as the direct path and, therefore, added to the total negative effect of phonological coding on the duration of treatment.

Pre-intervention levels of reading and spelling and treatment gains. The pre-intervention levels of spelling and reading accuracy had a negative effect on the duration of treatment. The treatment duration, on its turn, had a significant positive effect on the treatment gains on the two reading rate measures. Finally, the results yielded clear associations between all four initial reading and spelling levels and the treatment gain on the relevant measure. These relations were all negative, indicating that individuals with larger initial deficits made greater progress.

Discussion

The main objective of the present study was to examine the progress in reading and spelling skills following treatment in relation to the phonological capacities of the dyslexic individual. To this end, a group of dyslexic children followed a phonologically based treatment method that presented them with a learning system clarifying the basic elements and operations by which one's writing system encodes the characteristics of the spoken language system.

The present study demonstrated that the effects of this treatment program did not vary as a function of the individual differences in phonological abilities within a group of dyslexic children. The results revealed no relation between phonological coding and treatment gains on reading accuracy and spelling, but did show both a direct and an indirect path between phonological coding and treatment gains on reading rate. The direct and mediated effect on reading rate were of equal strength, but had an opposite direction. As a result, phonological coding had no overall impact on these treatment gains. However, phonological coding did systematically affect the duration of treatment. More serious phonological coding deficits were accompanied by a longer duration of treatment. It appeared that providing the participants with more serious coding deficits more time caused them to attain a level of reading rate at the end of treatment that was comparable to the level of those with a less serious coding deficit. This result is promising, since reading rate has generally been shown to be the aspect that is most resistant to intervention (Lyon & Moats, 1997; Torgesen et al., 2001).

In sum, the pattern of findings indicated that it is possible to intervene in the negative impact of the phonological coding impairment on the course of literacy skill acquisition by means of a phonologically-oriented treatment, and that dyslexic children with more and less serious phonological coding deficits do not differ in terms of the final effect but in the "dose" required to get there.

Besides the results concerning the impact of phonological coding capacities on treatment gains, the present study also revealed two other notable results concerning the relation between the initial literacy levels and treatment progress. First, the pre-intervention levels of spelling accuracy and reading accuracy had a negative effect on the duration of treatment, which, in turn, had a significant positive effect on the treatment gains of the two reading rate measures. This apparent paradox can be explained by the 'production model' framework of the treatment. As mentioned in the introduction, the treatment is constructed according to the principles of production models, in particular the theory of learning activity. A core element of this theory is a strategy of errorless learning. It is assumed that (parts of the) system should first be accurately mastered, before the execution of this system can be gradually automatized (Gal'perin, 1974/1989). In terms of the treatment program, this implies that the focus is primarily on the step-by-step accurate mastering of a 'production system of reading', whereby speeded reading is expected to gradually follow accurate reading as practice progresses. It can be argued that, as a consequence of this strategy, less accurate participants will take more time to pass through the consecutive components of the treatment. This prolonged treatment period, however, provides these participants with more time to automatize the learned system, i.e. to accelerate reading rate. Hence, the reversed relation

between accuracy and rate on the one hand and treatment duration on the other hand seems to be parsimonious with the theory of learning activity.

Second, a relation was found between the initial literacy levels and the treatment gains. Although a proportional measure of treatment gain, which corrected for initial differences in reading and spelling levels between the participants, was used, the study revealed that the individuals who entered the treatment program with the weakest initial reading and spelling skills tended to gain most from it. This finding indicates that those children who are most in need of treatment benefit most from it.

As mentioned in the introduction, studies of the relation between phonological capacities and treatment effects revealed inconsistent results. The results of the present study may add some insight in the factors contributing to these inconsistencies. Hatcher and Hulme (1999) already pointed to the content of a treatment as a factor in this. They revealed that phonological awareness was related to treatment response in treatments with no or partial phonological instruction, but not in the most explicitly phonological program. Based on these results, they suggested that in treatments with the most emphasis on explicit phonological training the level of initial phonological skills is least associated with treatment outcome, because those treatments are designed to overcome these phonological weaknesses. The present study used a treatment method, which explicitly directed the pupil towards the (morpho)phonological elements that are critical for reading and spelling skills. Conforming to the assumption of Hatcher and Hulme (1999), phonological abilities had no impact on the reading and spelling gains at the end of treatment. However, the results of Wise et al. (2000) are inconsistent with this assumption; they also used a treatment consisting of explicit phonological exercises, but did find their participants' responsiveness to be dependent on the (pre-intervention) phonological awareness skills. The results of the present study suggest that an additional explanation for the differences in outcomes can be found in the duration or intensity of treatment. As reported, participants with more serious phonological deficits attained literacy skills at the end of treatment that were comparable to those of less phonologically disabled participants, but they needed more treatment sessions to do so. That is, as long as they are provided with sufficient training opportunities, pupils with more serious phonological deficits could attain a level of reading and spelling skills that is comparable to that of pupils with less serious phonological deficits. Consequently, one might argue that individual differences in phonological abilities are more likely to be related to treatment response in short-term treatments than in more intensive treatment programs. Indeed, the treatment of Wise et al. (2000), who did report a relation between phonological awareness and treatment gains, had a substantially smaller number of training hours (27 to 29 h) than the treatments used in the study of Torgesen et al. (67.5 h of training) and the present study (about 35 h of training on average plus an equal amount of time for homework assignments), where treatment gains were unrelated to the dyslexics' phonological abilities. Unfortunately, research on the relation between phonological abilities and responsiveness to treatment only related this participant characteristic to the gains or attained levels at the end of treatment. Therefore, to provide a more detailed window on this issue, it appears that future research should not only address this relation at the final state, but should also focus on monitoring it over time.

Note

1. The IWAL-institute was founded by members of the department of psychology of the University of Amsterdam in 1983 in order to bring scientific knowledge of dyslexia into practice. It is specialized in research, assessment and treatment in the field of dyslexia.

Chapter 8

The development of reading accuracy and reading rate during treatment of dyslexia

Abstract

Two experiments were conducted to provide a window on the processes by which the accuracy and rate of reading develop during a psycholinguistic treatment for dyslexia. In experiment 1, 187 dyslexic children followed a treatment method that presented them with a learning system that clarifies the basic elements and operations by which one's writing system encodes the characteristics of the spoken language system. The results revealed that during the first six months of treatment most the progress made was on reading accuracy which gradually turned over into a preponderance of reading rate during the second half of treatment. Experiment 2 examined the reading of 46 dyslexic participants after termination of their treatment. It was shown that following mastering of the reading system, reading rate, as opposed to reading accuracy, continues to improve. These findings are discussed vis-a-vis the remediation of reading fluency.

Introduction

During the last decade, much progress has been made in the remediation of developmental dyslexia (Snowling & Nation, 1997; Swanson, 1999, Torgesen, 2002b). A growing body of research indicates the beneficial effects of training the phonemic structure of words on the reading and spelling difficulties of dyslexic participants (Hatcher, 2000; Lovett, et al., 2000; National Reading Panel, 2000; Torgesen, et al., 2001). However, these positive effects appeared to be mostly on reading accuracy, reading rate appearing much less amenable to these psycholinguistic treatment programs (Eden & Moats, 2002; Torgesen et al., 2001; Chard, Vaughn, & Tyler, 2002). Torgesen et al. (2001) suggested that this discrepancy could be due to the amount of text exposure. Dyslexic children miss out a clear amount of reading practice compared to average readers. Consequently, they acquire a substantially smaller body of 'sight word' representations that are assumed to be the basis of fluent reading. According to Torgesen et al. (2001), the duration of treatment is too short for closing this gap. Others, however, questioned whether psycholinguistic treatment methods that are based on the assumption of dyslexia being caused by a phonological processing deficit are sufficiently capable of tackling the reading rate problem in dyslexia (Wolff & Katzir-Cohen, 2001). Several authors stated that intervention studies have focused too strongly on accurate decoding skills and that future research should provide insight in the cognitive mechanisms which result in both reading accuracy and reading rate, i.e. fluent reading (Kame'enui & Simmons, 2001; Lyon & Moats, 1997; Torgesen, 2002b; Wolf, Miller & Donnelly, 2000). Accordingly, the goal of the present study is to provide a window on the processes by which the accuracy and rate of reading develop during a treatment of dyslexia.

The treatment used in this study is a Dutch psycholinguistic program for dyslexia, named LEXY. This program is based on general linguistic assumptions, considering writing systems to be an human artefact, developed as a response to our innate spoken language system and aiming at representing speech graphically (Liberman, 1997; Pinker, 1994). Therefore, the program focused on the linguistic structures that are productive for the writing system. This is done to give the dyslexic pupil insight in the way written language transcribes the characteristics of the spoken language system (cf. Olson, 1994; Perfetti, 2003). More specifically, the focus of this program is on the language units, the basic rules and the minimal heuristic knowledge needed to transform a spoken word into a correct orthographic word form (Schaap & Wielinga, 1979; Tijms, Hoeks, Paulussen-Hoogeboom & Smolenaars, 2003). Previous studies showed that this treatment has clinically significant effects on the reading skills of dyslexic individuals, although the treatment gains on reading accuracy were more pronounced than those on reading rate (Tijms et al., 2003).

The LEXY program remediates reading and spelling difficulties by implementing the basic linguistic elements and operations in a learning system, in which the central learning device is an algorithmic kernel and its graphic representation in which all elements are presented and operations can be learned and executed. Therefore, the architecture of the program is constructed in line with production models of skill acquisition, and in particular with the theory of learning activity (Gal'perin, 1969, 1974/1989; Davydov, 1990/1995; for reviews, see Grigorenko, 1998; Arievitch & Stetsenko, 2000). The theory of learning activity postulates a step-by-step learning process, focused on systematic knowledge of the abstract elements and operations that are essential for the correct execution of an action as well as the recognition of these essential principles in a concrete-particular situation (Davidov, 1990/1995; see also Anderson, 1993). In this learning process, a strategy of errorless learning is used. It is assumed that (parts of the) system should first be accurately mastered, before the execution of this system can be gradually automatized (Gal'perin, 1969; see also VanLehn, 1996). In terms of the treatment program, this implies that the focus is primary on the step-by-step accurate mastering of a 'production system of reading', whereby speeded reading is expected to gradually follow accurate reading as practice progresses.

In the present article, two studies are reported that were designed to provide a window on the dynamics of change in reading accuracy and reading rate during and after termination of this treatment program. It was expected that during the first parts of the treatment a relatively more pronounced change in accuracy would take place and that later on the development of reading rate would be more prominent. This expectation was the focus of experiment 1. At the end of treatment, the presented reading system should have been accurately mastered. However, as suggested by Torgesen et al. (2001), the duration of treatment may be too short for the system to be optimally automatized, in which case continuing exposure to reading will result in a further improvement of reading rate. Therefore, it was also expected that after termination of treatment there would be a continuing growth of reading rate, as opposed to reading accuracy. This prediction was tested in experiment 2.

EXPERIMENT 1

Method

Participants

The sample in this study comprised children, who were referred to the IWAL-institute for dyslexia in Amsterdam, The Netherlands because they had specific difficulties at school in the acquisition of reading and spelling. Participants were selected in an age range from about 10 to 14 years. To be included in the study, participants had to be below average in their text reading rate and text reading accuracy, with at least one of these two measures more than one standard deviation below average. In addition, they should be deficient in the phonological processing of words. Criteria for exclusion were an IQ-score one standard deviation or more below average, problems with auditory discrimination of speech sounds, problems with visual discrimination of figures, or broad neurological problems. In addition, a measure for word reading rate and one for spelling were included to verify the consistency of the reading and spelling deficit. The sample included 187 participants. Descriptive characteristics of these participants are summarized in Table 1. Finally, in view of the evidence indicating that phonological processing problems constitute the core deficit in dyslexia, six phonological tasks were administered to test whether the sample displayed phonological processing problems. One-sample Wilcoxon tests revealed that the participants differed significantly from the general population mean for all phonological tasks (ranging from $Z = -1.68$ to $Z = -8.33$, all $p < .05$) except one ($Z = -1.29$, $p = .10$), indicating that phonological processing problems were characteristic of the sample.

Table 8.1. Characteristics of Participants

n	187	
Age (years)	11.78	(1.39)
IQ	107.28	(10.38)
Number of treatment sessions	49.55	(15.21)
Gender ratio (male : female)	2.7 : 1	
Text Reading Accuracy ZS	-1.70	(1.54)
Text Reading Rate ZS	-3.14	(2.92)
Word Reading Rate ZS	-1.78	(0.92)
Spelling ZS	-3.41	(2.48)

Note. Standard deviations in parentheses. ZS= z-score.

Instruments

Reading and Spelling Tests

Text Reading Accuracy and *Text Reading Rate* were assessed by the 'Livingstone' text (Schaap, 1986). This text consists of 64 lines which subjects are required to read. Subjects are instructed to read the text both fast and accurately. The words represent the various problems in the Dutch written language. The number of reading errors and the time taken for reading

the text provide the outcome measures (accuracy: $r = .93$ to .94; rate: $r = .97$ to .99; test-retest).

Word Reading Rate. Reading skills were assessed by the One-Minute-Test (Brus & Voeten, 1973), a time-limited test in which the number of correctly read unrelated words within one minute determined the score ($r = .89$ to .93, test-retest).

Spelling. Spelling skills were assessed using the IWAL-Standard Dictation (Harel & Schaap, 1981). This dictation contains 19 sentences. The words making up the sentences are familiar to all elementary-school children. Moreover, the collection of words is a representative sample of the various spelling problems in Dutch (Harel & Schaap, 1981). Scoring is based upon the number of spelling-errors ($r = .90$, test-retest).

Procedure

The LEXY program is computerized and guides the recognition and use of the phonological and morphological structure of Dutch words. The attention of the dyslexic person is focused on the smallest pronounceable phonological structure, i.e. the syllable (Schaap, 1997). By choosing the syllable as unit of processing, the dyslexic person is better able to identify the individual phonic[1] elements of a word and, at the same time, the syllable is the level of a word on which the spelling operations are imposed. In Dutch, the last phonic element of a syllable is the important focus: the correspondence between a phonic element and its standard graphical representation can be dissociated, depending on the phonological category to which the terminal phonic element of a syllable belongs. In LEXY this is incorporated in its inferential algorithmic kernel, having the following structure:

$$\text{IF } p\ /\#\ \text{E}\ Pi \text{ then } O(p) \rightarrow g\ \text{E}\ G.$$

When the terminal phonic element p of a syllable belongs to the i^{th} category of phonic elements Pi then the result of an operator O on p will be mapped onto a graphic element g that need not be the standard mapping (Schaap, 1997). The basic principles of the Dutch written language can be realized within a learning system incorporating five types of operations as consequence of five types of terminal phonic elements: long vowels, short vowels, unvoiced consonants, sonoric vowels and unstressed morphemes. For example, in Dutch voiced consonants (/d/ and /b/) loose the property 'voice' in the terminal position, which is not reflected in their orthographic representation. Consequently, the operation says: if the last phone in a syllable is an unvoiced consonant then extend the word (operation) and if this results in a voiced consonant the voiced consonant graph should be written, otherwise the standard consonant.

All essential terms in the algorithm have an explicit and exhaustive description in the program: the set of phones, the categories of phones, the mapping operations and the orthographic elements. This description is the central procedural structure of the program and has a full graphical representation on the computerscreen; all elements of the description are also represented on a special keyboard.

The program aims at achieving a mastery level for each element of the program. This implies that participants did not pass through the program at a fixed pace. An element was considered mastered when the percentage of correctly performed items during training was at least 80%.

Treatment was provided on a one-to-one basis in a weekly 45-minute session. Besides these sessions at the institute, participants were required to practice at home three times a week for 15 minutes. The reading skills of the participants were assessed at the start of the treatment and after every three months until the end of the treatment. Due to all-day practice, after the first three months only word reading and no text reading measures were used and, consequentially, this measurement moment is omitted in the analyses. Multiple forms were used for the reading measures to avoid effects due to repeated testing.

Results

Table 8.2. Scores for Reading Accuracy and Reading Rate

	Reading Accuracy [a]		Reading Rate [b]	
Time of Treatment	mean	(s.d.)	mean	(s.d.)
start	52.72	(23.74)	612.40	(255.42)
6 months	28.24	(16.15)	487.19	(142.11)
9 months	24.08	(11.34)	472.39	(131.64)
12 months	23.10	(12.48)	454.81	(120.06)
15 months	21.96	(8.08)	432.29	(103.03)

Note. Standard deviations in parentheses. [a] Number of errors. [b] Time in seconds.

The means (and standard deviations) of the participants' scores for reading rate and reading accuracy at different times of treatment are presented in Table 2. As can be seen in this table, participants made progress in both reading accuracy and reading rate during treatment. For each participant, the two reading scores were transformed into a combined score that represents the number of errors per second, according to the following equation:

$$_{i}eps_{t} = \frac{_{i}x_{ra,\,t}}{_{i}x_{rr,\,t}}, \qquad (1)$$

where $_{i}eps_{t}$ = the number of errors per second on text reading of participant *i* at time *t*,
$_{i}x_{ra,t}$ = the score (in number of errors) of participant *i* on text reading accuracy at time *t*,
and $_{i}x_{rr,t}$ = the score (in seconds) of participant *i* on text reading rate at time *t*.

To examine the development of the rate and accuracy of reading during treatment, the difference in the number of errors per second between two consecutive measurement moments (eps_{tn+1} - eps_{tn}) was calculated for each participant. When the difference is negative, i.e. less errors per second at time n+1, than the reading skill of the participant has become relatively more accurate during that treatment period. When the difference is positive, reading has become relatively faster. The proportions of participants with positive and negative difference scores per treatment period are presented in Table 3.[2] Inspection of table 3 suggests a reversed rate of progress in reading accuracy and reading rate: during the first six months of treatment most progress seems to be on reading accuracy which is gradually changing into a preponderance of reading rate in the second half of treatment. These visual impressions have been tested by a logistic regression analysis. The results of this analysis are presented in Table 4. These results revealed that the probability of a participant progressing more in accuracy than in speed decreases with treatment time. This implies that throughout treatment there is a

significant shift from a predominant growth in reading accuracy towards a predominant growth in reading rate.

Table 8.3. Proportion of participants who progressed more on accuracy or speed per treatment period

	Treatment period				Overall
	start-6 months	6 – 9 months	9 – 12 months	12 – 15 months	start-end
accuracy	81.9%	50.0%	47.7%	34%	91.0%
speed	18.1%	50.0%	52.3%	66%	9.0%

Table 8.4. Logistic regression analysis of time in treatment on reading progress (accuracy vs speed)

	Beta	S.E.	Wald	p	Exp (B) / Odds ratio
time in treatment	-.706	.103	47.332	<.001	.493
constant	1.870	.239			

Note. Nagelkerke R^2 = .14, Percentage correct estimates of reading progress = 64%.

EXPERIMENT 2

Method

To examine whether the emphasis of growth on reading rate continues after finishing the treatment, a second sample was selected. The participants of this sample were tested one to four years following the termination of their treatment.

Table 8.5. Characteristics of Participants

n	46	
Age (years)	15.27	(8.04)
IQ	109.98	(9.11)
Number of treatment sessions	47.93	(15.62)
Time between treatment termination and follow-up measurement (in years)	2.35	(1.18)
Gender ratio (male : female)	2.5 : 1	
Text Reading Accuracy ZS	-1.24	(1.32)
Text Reading Rate ZS	-2.82	(2.73)
Word Reading Rate ZS	-1.83	(.92)
Spelling ZS	-2.96	(2.86)

Note. Standard deviations in parentheses. ZS= z-score.

The criteria for participant selection were identical to those of Experiment 1. The sample included 46 participants. Descriptive characteristics of these participants are summarized in Table 5. Five phonological tasks were administered to test whether the sample displayed phonological processing problems. One-sample Wilcoxon tests revealed that the

participants differed significantly from the general population mean for all phonological tasks (ranging from $Z = -2.34$ to $Z = -3.62$, all $p < .05$) except one ($Z = -1.54$, $p = .06$), indicating the presence of phonological processing problems.

Results

The means (and standard deviations) of the participants' scores for reading rate and reading accuracy at different times are presented in Table 6. As can be seen in this table, both reading accuracy and reading rate improved during treatment. Following treatment, however, the level of reading accuracy seems to have stabilized, whereas growth in reading rate continued.

Table 8.6. Scores for Reading Accuracy and Reading Rate

	Reading Accuracy [a]		Reading Rate [b]	
Time of Treatment	mean	(s.d.)	mean	(s.d.)
start	47.54	(22.78)	605.97	(277.69)
end	20.86	(10.34)	459.03	(143.05)
follow-up	20.24	(10.03)	369.59	(69.16)

Note. Standard deviations in parentheses. [a] Number of errors. [b] Time in seconds.

Adopting the same procedure as in Experiment 1, the two reading scores were transformed into a combined score that represents the number of errors per second (see equation 1). Consequently, to examine the development of the rate and accuracy of reading during treatment, the difference in the number of errors per second between two consecutive measurement moments was calculated for each participant. The percentages of participants with positive and negative difference scores per period are presented in Table 7.[3] It can be seen that about two thirds of the participants made more progress on reading rate than on reading accuracy after termination of their treatment. These visual impressions were verified by Chi-square test for goodness-of-fit. Results revealed that the participants improved significantly more on reading rate than on reading accuracy (X^2 (1) = 5.57, $p < .05$, effect size $w = .35$ (medium; Cohen, 1988)).

These results are in line with the expectation that after the termination of treatment, the speed of reading will continue to improve due to further exposure to written language. It could be argued, however, that maturation in general speed of processing, not exposure to writing, is responsible for the participants' more pronounced progress in reading rate after termination of their treatment. It is well-known, that processing speed increases throughout childhood and adolescence (Kail, 1991). Thus, assuming that the speeding up of reading rate is part of a more basic developmental change in processing speed, it can be predicted that reading rate should be correlated significantly with age. But the results of a logistic regression analysis failed to produce a significant relation (Wald = 1.128, $p = .29$). Since a nonlinear relationship between the logit of age and reading progress could result in a lack of power of the analysis, a Box-Tidwell transformation test was also conducted. This test failed to show nonlinearity in the logit (interaction term: Wald = .47, $p = .49$). Thus, it can be safely

concluded that the progress on reading after termination of treatment is independent of the development of speed of processing.

Table 9.7. Proportion of participants who progressed more on accuracy or speed per treatment period

	Treatment period	
	start – end	end – follow-up
accuracy	93.5%	32.6%
speed	6.5%	67.4%

Discussion

The present study aimed at providing a window on the development of reading rate and reading accuracy during a psycholinguistic treatment for dyslexia. According to the principles of production models of skill acquisition (in particular, the theory of learning activity (Gal'perin, 1974/1989; Davidov, 1990/1995)), the dyslexic participants followed a treatment method that presented them with a learning system clarifying the basic elements and operations by which one's writing system encodes the characteristics of the spoken language system.

The study showed a differentiated pattern of development of reading accuracy and reading rate. In the first experiment, it was found that during the first six months of treatment most reading progress was on reading accuracy, which gradually turned over into a preponderance of reading rate during the second half of treatment. Experiment 2 showed, as expected, that after the reading system is mastered during treatment, reading rate, as opposed to reading accuracy, continued to develop after termination of the treatment.

Furthermore, experiment 1 suggested that the dyslexic sample made considerable progress on both reading accuracy and reading rate in first half of their treatment. This result should be interpreted with caution since it reflects changes in group means, whereas the present research question requires data pertaining to within-subject changes. Nonetheless, it suggests that the development of reading accuracy and the development of reading rate should not be interpreted as direct opposites. Instead, this finding, together with the other results, suggests that these reading skills show a more subtly differentiated developmental pattern, in which the development of reading rate gradually follows the accurate establishment of the reading system.

In sum, the present study showed that the treatment program was able to ameliorate not only reading accuracy but reading rate as well. These results support the hypothesis that, in concordance with production models of skill acquisition, the treatment method first results in a more prominent development of reading accuracy, which appears to reflect the accurate formation of the system of essential elements and operations underlying the skill of reading. Subsequently, it results in a more prominent development of reading rate, which is assumed to reflect the optimization of the execution of this system. Therefore, this study provides evidence that psycholinguistic treatments are suitable for remediating the reading fluency of dyslexic individuals.

Notwithstanding the above, the question remains why evaluations of phonologically based treatment methods have repeatedly failed to demonstrate significant progress on the reading rate levels of dyslexic children. A possible explanation is that most programs are too short to yield effects on reading rate. Notably, many treatment studies span a substantially shorter period of time than the presented program (Simmerman & Swanson, 2001). Moreover, most treatment evaluations did not monitor the development of reading skills following treatment termination. As stated by Torgesen et al. (2001), dyslexic children miss out a clear amount of reading practice. Torgesen et al. (2001) argued that, as these children have got a grip on the reading process and have become more accurate readers by intervention, it will take an amount of practice to become increasingly fluent readers that exceeds the limits of the usual treatment period. The present finding that reading rate continues to growth after the treatment has ceased, does provide support for this assumption.

Another, albeit more speculative, explanation is that some programs focus on linguistic (phonemic) elements, but, without explicitly directing the dyslexic pupil to integrate these elements into a procedural system focused on the morphophonological rules that are critical to the differences between the spoken and the written level of expression (cf. Chomsky, 1970; Mann, 2003). Arguably, in this situation, (repeated) practice results at best in the memorization of the trained words, while it is assumed that mastery of the procedural knowledge underlying the function of the skill is essential to generalize and speed up the trained skill (Andersen, 1993, VanLehn, 1996, Grigorenko, 1998, Davidov, 1990/1995). In line with this explanation, Kjeldsen, Niemi and Olofsson (2003) revealed that a strictly systematic phonological training was clearly more effective than a comparable but less structured program. Moreover, structure of training appeares to be more important than quantity of training for the reading development in the long term. Kjeldsen et al. (2003) speculated that a structured, systematic approach is effective because it provides a 'self-teaching' mechanism, which is in operation towards the end of the training period.

In conclusion, although dyslexia is characterized by reading and spelling difficulties (Dietrich & Brady, 2001; Lyon, 1995a; Van Orden, Bosman, Goldinger & Farrar, 1997), the focus of the present study was on reading only. This choice was forced by the fact that there is no measure for spelling rate available in The Netherlands. Another point of consideration is that in this study a generally accepted, but arguably somewhat narrow definition of reading fluency was used. The development of prosody, an element included in broader definitions of reading fluency, remains unknown in the present study. It can be expected that during the process of automatization of the system of reading actions, the prosodic quality of reading will develop together with reading rate. Again, future research should shed a light on this issue.

Notes

1. A phone is a perceptual class of speech sounds with a singular linguistic function. The terms phonic and phone are used to express the perceptual character of speech sounds, phonemes being abstract linguistic entities within a phonetic or phonological theory.
2. Some participants finished their treatment before 15 months, which could have biased the results concerning the last measurement moment. Therefore, the distribution of scores of the group representing this last

measurement and the group who finished their treatment earlier were compared for all other measurement moments. A chi-square test revealed that the distribution of reading scores per measurement moment did not differ significantly between the two groups (X^2 = 3.92, *p* = .27). Thus, there are no indications for a bias due to participant 'drop out'.

3. Unfortunately, besides the follow-up score, only the reading scores at the start and the end of treatment were available for this sample. However, a chi-square test revealed no significant difference in the change in number of errors per second from start to end of treatment between the present sample and the sample of experiment 1 (model of independence of sample and distribution of reading score: X^2 (1) = .26, *p* = .61).

Chapter 9

Concluding remarks

In this thesis, the focus was on the efficacy of a Dutch psycholinguistic treatment of dyslexia, coined LEXY, resulted from the seminal work done by Theo Schaap and coworkers. LEXY presents dyslexic participants with a learning system clarifying the basic (linguistic) elements and operations by which one's writing system encodes the characteristics of the spoken language system. In this concluding chapter, the reported findings will be brought to bear on the main issues dominating the literature on the evaluation of the treatment of dyslexia.

Clinical relevance

In order to have clinical significance, a treatment's aim should be to change a dysfunctional ability into a functional level (Jacobson & Truax, 1991; Kendall, Marrs-Garcia, Nath, & Sheldrick, 1999). In the case of dyslexia, the main goal can be defined as bringing reading and spelling skills at such a level that the treated dyslexic can function normally at school or in society.

Therefore, in this thesis, the focus was not so much on statistically significant changes during treatment, but rather on the degree of which the dyslexic pupils attained functional levels of reading and spelling skill. In the same way, the focus was not on subcomponents or subprocesses of reading, such as non-word decoding skills or phonetic awareness, but on general reading and spelling skills, as required at school or in society.

The study reported in chapter 3 tackled this issue by evaluating the attained levels of word reading, text reading and spelling in a sample of both dyslexic children and adults. The results of this study revealed that clear gains were already demonstrable halfway the treatment. These improvements ranged from a nearly halving the distance between the scores of the participants and the norm for word reading to a reduction of this distance for more than three quarters for spelling. At the end of treatment, these skills improved further. Following treatment, the dyslexics obtained a normal level of text reading and spelling. Word reading, however, was not normalized after treatment, although large effect sizes showed that the treatment gain was substantial.

In addition to these actual effects, the perceived effects on the part of the participant are critical as well (Foster & Mash, 1999). Feeling competent has a clear value on its own for someone's functioning, apart from being competent (Kazdin, 1999). Therefore, the impact of the treatment as experienced by the participants was evaluated. It was shown that the subjective experiences of the participants were congruent with the actual treatment effects; the large majority of participants indicated that they experienced substantially less hindrance by their reading and spelling in everyday life and that their functioning at school or in society has been easier for them after termination of their treatment.

Obviously, to be valid, treatment effects have to be reliable. In order to support the reliability of the reported efficacy of the treatment, a consecutive study was conducted that aimed to replicate the effects of treatment (cf. Kazdin, 2003). Therefore, in chapter 5, a study was presented that also evaluated the attained reading and spelling levels, using two large samples of dyslexic children. In this study, we were able to replicate the positive effects of the treatment program reported in the previous study. Moreover, the two treatment groups showed a highly similar pattern of results, supporting the reliability of the treatment effects. At the end of treatment, participants of both groups attained an average level of reading accuracy and spelling. The attained level of reading rate was comparable to the lower bound of the normal range.

The clinical relevance of a treatment can also be related to the variability of response to treatment within the sample (Jacobson & Truax, 1991; Torgesen, 2002b). As indicated in chapter 5, the large majority of the participants attained a level of proficiency within the average range (i.e., a standard score of at least 90 (M=100, sd=15), cf. Torgesen et al., 2001). That is, for text reading accuracy and spelling; most of the participants (about 70%) attained a level equal to, or above, the norm for these skills. Moreover, half of the participants were within the normal range for reading rate.

A critical issue in respect to treatment significance is the transfer of training. It has been indicated by several researchers that many intervention studies, while reporting results of treatment on phoneme awareness and non-word decoding skills, fail to obtain or report effects of transfer (Lovett, Barron, & Benson, 2003; Lyon & Moats, 1997; Moats & Foorman, 1997; Snowling, 1996). The current studies aimed at demonstrating transfer of effects by assessing reading and spelling skills employing words that differ from the words used in the treatment. Moreover, the words making up the (text) reading and spelling measures can be considered as representative samples of the typical problems of the Dutch writing system. Consequently, the reported effects can be interpreted as the transfer of the learned concepts into generalized reading and spelling gains.

In sum, the reported studies provided clear evidence of clinically relevant effects of the LEXY treatment, demonstrating transfer of the learned concepts into functional levels of general reading and spelling skills of the large majority of dyslexic participants.

Long-term maintenance of treatment effects

Since the goal of any treatment is to obtain long-lasting changes, this aspect should be one of the primary criteria of treatment evaluations (Glasgow, Bull, Gillette, Klesges, & Dzewaltowski, 2002; Lyon & Moats, 1997; Nelson & Epstein, 2002). Clearly, reported treatment effects immediately upon treatment completion may not be indicative of long-term outcomes (Kendall, Flannery-Schroeder, & Ford, 1999). In this regard, it is surprising that only a small number of long-term evaluations of interventions of dyslexia have been reported. In the present thesis, the third chapter concerned the evaluation of both the short-term and long-term effects of the LEXY treatment. It was revealed that the attained levels of reading words and reading text remained stable one to four years after the treatment has been ceased. Spelling showed a slight decline in the first year after termination of treatment, but remained

stable in the consecutive years. So, most importantly, it can be concluded that the effects of the treatment program are long-lasting, i.e., the participants maintain their functional levels of reading and spelling.

Relating the effects of the treatment to its theoretical base

A deeper understanding of the mechanisms mediating treatment effects is vital for the development of effective treatment programs (Kazdin, 2002; Moras, 1998). In order to understand why treatments produce change and how treatment effects can be improved, there is a need for studies that are designed to provide a window on the temporal dynamics of the mechanisms underlying the effects of treatment programs (cf. Kazdin, 2003, p. 271).

In this field, most evaluation studies consist of a pre- vs. post-test design, without considering the process by which effects are obtained (Lyon & Moats, 1997). Although some important issues have been clarified by comparing different treatment programs (e.g., Lovett et al., 2000; Wise et al., 1999, 2000), the process by which treatment effects have been attained remains largely unclear. In a review of the pertinent literature, Lyon and Moats (1997) concluded that limitations remain with respect to the knowledge of why specific treatment programs are effective and that “we have yet to solidify and refine our knowledge” (cf. Lyon & Moats, 1997, p. 580).

This lack of knowledge on the processes underlying treatment effects inspired our procedural evaluation of the LEXY treatment. This procedural evaluation was the objective of chapter 4. The primary purpose of this study was to provide a detailed window on the dynamics of change by examining the relation between the timing of treatment effects and the presentation order of treatment components. It was anticipated that the timing of an effect is closely tied to the corresponding treatment module. In conformity with this expectation, the study revealed that the time course of treatment effects accurately matched the predicted temporal ordering. The children showed a cascade of improvements that corresponded to the presentation order of the treatment components.

The treatment started with a focus on the phonetic structure of words and, as anticipated, at the end of the first module participants had made most progress on related aspects of the writing system. Following training the phonetic structure, attention is shifted to situations where the correspondence between a phonic element and its standard graphic representation is dissociated. For this, operations were introduced to map the phonetic structure onto the correct orthographic word form. As predicted, the largest effect on operations related to monosyllabic words was attained at the end of module 1, and on operations related to polysyllabic words at the end of module 2. At the end of the second module, morpheme-related errors were still being made. Participants made most progress on this aspect following the next module, which specifically addressed the causes of morphological errors. The last module concerned verbs. It was only after this module that an effect on this aspect was present. Besides providing insight in the mechanisms through which changes during treatment occur, these findings provide important support for the validity of the LEXY-treatment. That is, the findings indicated that the effects of treatment cannot be attributed to non-specific factors (e.g., time in treatment, maturation, other instruction) as

these factors would have produced general effects unrelated to the timing of specific treatment modules.

Based on this pattern of findings, several implications can be derived for designing dyslexia treatments. The current findings support the generally assumed beneficial effects of explicit instruction in both phonological awareness and sound-symbol correspondences. However, the results suggested also that knowledge of the phoneme system is insufficient for a dyslexic to handle situations, in which the correspondence between a phonic element and its standard graphic representation is dissociated. It appears that explicit instruction concerning the phonological rules, underlying these dissociations is important to obtain further improvement. Additionally, the importance of focusing on the influence of morphological elements on the orthography is emphasized. These findings thus indicate that in designing a treatment program for dyslexia it is important to include a full system of the basic linguistic (i.e., morphophonological) principles which organize the writing system.

Reading accuracy versus reading rate

A much debated topic in dyslexia treatment studies relates to the effects of treatment on reading accuracy versus the effects on reading rate. Whereas intervention studies have reported positive effects of treatment on reading accuracy, reading rate appeared much less amenable to psycholinguistic treatment programs (Torgesen et al., 2001; Wolff & Katzir-Cohen, 2001). This discrepancy in amenability brought several authors to argue that intervention studies have focused too strongly on accurate decoding skills and that future research should provide insight in the cognitive mechanisms which result in both reading accuracy and reading rate; that is, fluent reading (Kame'enui & Simmons, 2001; Lovett et al., 2003; Lyon & Moats, 1997; Torgesen, 2002b; Wolf & Katzir-Cohen, 2001).

In view of this urge, the goal of chapter 8 was to provide a window on the dynamics of change in reading accuracy and reading rate during and after termination of the treatment program. As indicated in chapter 2, the LEXY program aims at remediating reading and spelling difficulties by implementing the basic linguistic elements and operations in a learning system, in which the central learning device is an algorithmic kernel. Therefore, the architecture of the program is constructed in line with production models of skill acquisition, and in particular with the theory of learning activity (Davidov, 1990/1995; Gal'perin, 1974/1989). Central to this learning process is a strategy of errorless learning. It is assumed that (parts of) the system should first be accurately mastered, before the execution of this system can be gradually automatized (Gal'perin, 1974/1989; VanLehn, 1996). In terms of the treatment program, this implies that the focus is primary on the step-by-step accurate mastering of a 'production system of reading', whereby speeded reading is expected to gradually follow accurate reading as practice progresses.

The study revealed that, in concordance with production models of skill acquisition, the treatment method first results in a more prominent development of reading accuracy, which appears to reflect the accurate formation of the system of essential elements and operations underlying the skill of reading (Grigorenko, 1998). Subsequently, it results in a more prominent development of reading rate, which is assumed to reflect the optimization of

the execution of this system. This process was also reflected in the finding that after the reading system is mastered during treatment, reading rate, as opposed to reading accuracy, continued to develop after termination of the treatment.

These results substantiate the role of the implementation of production models of skill acquisition, and thereby the notion, presented in chapter 2, that a treatment should not only be focused on optimizing its linguistic adequacy, but also on its psychological and didactic adequacy. In a similar vein, others have stressed the importance of presenting the linguistic concepts in a systematic framework in the treatment of dyslexia (Benson, Lovett, & Kroeber, 1997; Kjeldsen, Niemi, & Olofsson, 2003; Lovett, 1999). Lovett and coworkers (Benson et al., 1997; Lovett, 1999) suggested that a systematic treatment in a rule-based framework, which is directed to the core processing deficits, i.e. phonologically-oriented, is most suitable for obtaining generalized reading gains. Similarly, Kjeldsen et al. (2003) revealed that a strictly systematic phonological training was clearly more effective than a comparable but less structured program. Moreover, structure of training appeared to be more important than quantity of training for the reading development in the long term (Kjeldsen et al., 2003). Likewise, the results of chapter 8 supported the effectiveness of explicitly directing the dyslexic pupil to a procedural system focused on the morphophonological units and rules that are critical to the differences between the spoken and the written language. More specifically, the results supported the beneficial impact of the theory of learning activity as a framework for this.

Dyslexia as a spelling disorder

In most intervention studies the focus is mainly on reading and there is only a minor or no attention on spelling skills (Berninger et al., 2000). This imbalance between the focus on reading and spelling seems surprising, since reading and spelling deficits are both characteristic symptoms of dyslexia (Lyon, 1995a; Snowling, 2000). They are secondary language functions derived from spoken language and, consequently, both dependent on knowledge about how the writing system encodes spoken language (Grigorenko, 2003a; Liberman, 1997; Perfetti, 2003). Reading and spelling are, thus, assumed to be strongly correlated and to develop concurrently (Fletcher-Flinn, Shankweiler, & Frost, in press; Grigorenko, 2003a; Shankweiler & Lundquist, 1992). Accordingly, reading and spelling deficits should be targets of an integrated treatment program. In LEXY, reading and spelling skills are simultaneously addressed. As demonstrated in this thesis, the integrated approach resulted in solid effects on the spelling skills of the dyslexics.

Individual differences

Individual differences in dyslexic pupils' response to intervention are reported repeatedly-some make large profits, others appear far less amenable to intervention (Snowling, 2000). Thus, it is of primordial importance to assess which individual characteristics act as moderators of treatment effects (Glasgow, Klesges, Dzewaltowski, Bull, & Estabrooks, 2004; Kendall et al., 1999; Snowling, 2000).

A large body of converging evidence indicates that dyslexia stems from an underlying deficit in the phonological processing system. Consequently, a considerable number of studies investigated the predictive value of the seriousness of the phonological deficit on treatment success. The results that emerged from these studies, however, appear to be far from consistent (Hatcher & Hulme, 1999; Pogorzelski & Wheldall, 2002; Torgesen et al., 2001; Van Daal & Reitsma, 1999; Wise et al., 1999, 2000). This inspired us to have a closer look at the LEXY treatment effects in relation to individual variations in phonological processing. The results reported in chapter 6 indicated that phonological coding deficits are the core factor in the reading and spelling deficits of the dyslexic children. Therefore, in chapter 7, the influence of the phonological coding abilities on the responsiveness to treatment was addressed. Phonological coding had no impact on the attained reading and spelling levels. However, the duration of treatment did vary as a function of the phonological coding ability of the dyslexic child. This pattern of findings, then, seems to indicate that participants with more and less serious phonological coding deficits do not differ in terms of the obtained treatment effect but in the “dose” required to get there.

Age-related differences in susceptibility to treatment have also been subject of investigation. Several authors have claimed that dyslexic children as they grow older become increasingly impervious to treatment (Baker, et al., 1996; Cossu, 1999; Lyon, 1995b; Wentink & Verhoeven, 2001). Others, however, revealed that effectiveness of treatment does not necessarily decrease with increasing age (e.g., Lovett & Steinbach, 1997). Chapters 3 and 4 addressed the question whether there are developmental, age-related boundaries beyond which dyslexic children cannot be successfully remediated. In both studies, the effectiveness of treatment was not age-dependent. Older dyslexic children benefited equally from treatment as younger children. Moreover, treatment appeared as effective for adolescents and adults as it was for elementary school children.[1] This last result was of particular interest, as dyslexia treatments typically focus on children only. In the first study of this thesis, however, adolescents and adults were also included, and it was shown that treatment can have beneficial effects on these age-groups as well.

Another individual characteristic of interest refers to the seriousness of the initial reading and spelling deficit. Dyslexic individuals enter their treatment program with a broad variability of reading and spelling skills and it seems fair to pose that those whose reading and spelling levels are most behind are most in need of a effective treatment. It is, therefore, of interest to examine treatment gains vis-à-vis the individuals’ initial literacy profiles. As shown in chapters 5 and 7, the treatment effects depended on the initial literacy skills. The participants with the lowest initial reading and spelling levels tended to gain most from treatment. This finding indicates that those children who need treatment the most benefit most from it.

Finally, treatment effects did not vary as a function of IQ or social-economic status. Taken together, the current findings suggest that the treatment program is very robust against individual differences.

Final conclusion

The results that emerged from the present series of studies provided strong support for the internal validity of the LEXY treatment. The data revealed that the time course of treatment effects accurately matched the presentation order of the corresponding linguistic components of the treatment. Thus, this thesis indicated that the effects of the LEXY-program are treatment-specific; that is, they can be confidently attributed to the treatment's theoretical underpinnings, and that these effects are not the result of extraneous factors.

Moreover, it has been shown that reading progress, both during treatment and after termination of it, is congruent with the course of development as expected on the basis of the production models of skill acquisition, which are implemented in the treatment's architecture. Again, substantiating the processes by which the theoretical underpinnings of LEXY are related to its effects.

Solid support is also provided for LEXY's external validity. A first aspect relating to the external validity is the extent to which the treatment effects generalize to the population for which the treatment is intended (Glasgow et al., 2002). Usually, selection of a dyslexic sample is based primarily on the presence of reading difficulties. In this thesis, however, participants were explicitly selected on the basis of phonologically based reading and spelling deficits. Phonological deficits were included as an additional selection criterion because this deficit is generally considered as the core factor causing dyslexia, and the inclusion of a causal factor provides the possibility to select a homogenous sample, making generalization and replication of results possible (Lovett, Borden, DeLuca, Lacerenza, Benson, & Brackstone, 1994; Torgesen et al., 1999). Exclusion criteria were kept to the standard exclusionary characteristics, being uncorrected sensory disabilities, broad neurological deficits and insufficient education. Furthermore, most samples of dyslexics used in this thesis consisted of at least 100 participants, which is substantially more than the usual sample size in evaluations of interventions of dyslexia. Additionally, not only dyslexic children were included, but adolescents and adults as well. At the same time, the results failed to reveal individual characteristics that exerted a moderating influence on the effects of treatment. Thus, it seems valid to generalize the treatment outcomes to the full spectrum of the population of dyslexic individuals.

Another topic of the external validity refers to the transfer of learning (Lovett et al., 2003). In the reported studies, as mentioned above, reading and spelling skills were assessed with words that differ from the words used in the treatment. At the same time, the (text) reading and spelling measures include collections of words that can be considered as representative samples of the typical problems of the Dutch writing system. Consequently, the reported effects can be considered a reflection of the transfer of the learned concepts into generalized reading and spelling gains. Finally, the treatment resulted in clinically significant changes in reading and spelling. That is, the treatment effects generalized into functional levels of reading and spelling skills, which were maintained in the subsequent years following the termination of treatment.

Next to a treatment's external and internal validity social significance is important. Social significance relates to the impact of treatment for society at large (Kazdin, 1999; Yates,

1999). Recently, the UNESCO reported that gross national products highly correlate with literacy levels (Grigorenko, 2003b). This can be considered a reflection of the development of modern society towards becoming an information society, in which written communication is a core component (McQuail, 2000; Snow, Burns, & Griffin, 1998). It is obvious that a disability in written communication is the core symptom of dyslexia. As a result, dyslexics, among other things, attain lower academic levels and are more prone to underemployment or unemployment (Beitchman & Young, 1997; Blackorby & Wagner, 1997; Warnke, 1999). Dyslexia can also have a clear impact on the educational system. Besides being reported as the primary cause of repeating grades in Dutch elementary education, it is also reported a primary cause for placement in special education (Van der Leij, 1991). The costs per student per year of special education are more than twice as high as those of regular education (Ministerie OCenW, 2002b). However, special education, in general, appears to be unable to close the gap in reading and spelling ability of dyslexic children with non-impaired children (Torgesen, 2001; Van Weerden, Bechger, & Hemker, 1999; Vaughn, Moody, & Schumm, 1998). Thus, by ameliorating the literacy skills of dyslexics to a functional level the treatment can be potentially cost beneficial for society (cf. Yates, 1999), due to a reduction of repeating grades and of the utilization of special education resources, as well as enabling dyslexics to realize their full potential on the labor market.

Notes

1. Recall that for the older participants in absence of adult norms the concept functional level was defined as the normal level of skill that is attained after termination of the Dutch primary education, as explained in chapter 1.

Before closing, four issues need to be addressed again. In the first place, it could be argued that the study yielded gains that were inflated because of inappropriate norms for the older participants. Secondly, the reported relation between initial severity and gains of treatment could have been biased by regression to the mean. Thirdly, current gain should be compared to the alleged benefits of other treatment programs in the Netherlands. Finally, we would like to address the limitations of our design.

Reading Norms. We chose to examine the effects of the LEXY treatment program not only to ameliorate the reading of primary school children but the deficient reading of adults as well (in chapter 3) since the disorder is life-long and the disabilities and their consequences will thus be ever lasting. However, for reading skills, such as tested by the Dutch EMT reading test (Brus & Voeten, 1973), there are no adult norms. For these older participants we used the norm at the end of primary education as the criterion for a normal level of reading proficiency, based on the following reasoning (see chapter 1 for a more extensive argumentation):

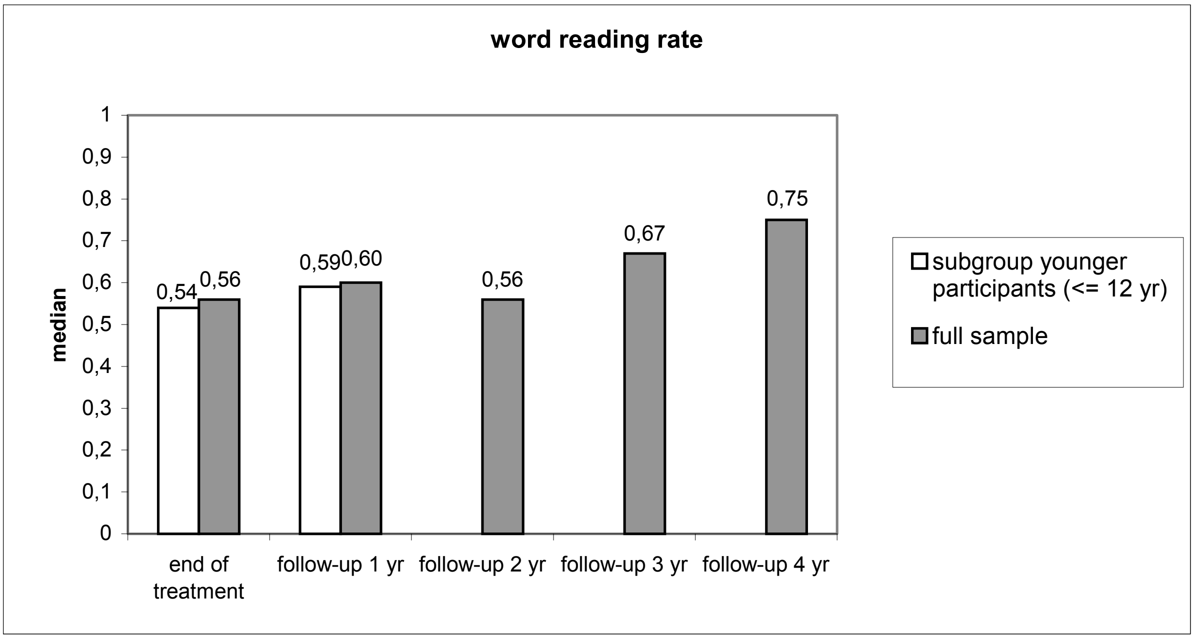
1. As stated in Dutch law, a formal core goal of primary education is to provide students with a normal, functional level of technical reading and spelling skills. That is, at the end of their primary education, students have to possess a proficiency in these written communication skills according to the accepted rules and norms of our society and at a level in which they can function normally in society (see also Ministerie van OCW, 2002a; Sijtstra, Van der Schoot, & Hemker, 2002).
2. Technical reading (as well as Dutch standard spelling) is no longer a subject of education in Dutch secondary education (e.g., Aarnoutse, 1991; Henneman & Kleijnen, 2002; Verhoeven & Van der Leij, 2002). According to Verhoeven & Van der Leij (1992) word decoding skills are basically automatised during the last two grades of primary education and attention is almost fully focussed on acquisition of information from texts during this period.
3. Longitudinal research revealed that reading skills develop with a slowing coefficient as a function of age—the reading curve leveling off at approximately the end of primary education (e.g., McCardle, Scarborough, & Catts, 2001; Verhoeven & Van Leeuwe, 2003). Thus, the degree of skill children attain at the end of primary education is about the level of achievement they will have to rely on for the remainder of their lives (McCardle et al., 2001).

Based on the above arguments, it seems fair to conclude that the average level of reading skill at the end of primary education is an appropriate criterion for a normal, functional level of reading to test the attained levels of our older participants against.
At this point, it should be noted, however, the our conclusion seems to be challenged by a recent study of Kuipers, Van der Leij, Been, Van Leeuwen, Ter Keurs, Schreuder, & Van den Bos (2003). In this study, the EMT test (Word Reading Rate) and a test for general verbal competence (subtest of the Wechsler Adult Intelligence Scale) were administrated to a sample of adolescents who were in the fourth grade of secondary education and their parents. The results of the study revealed that the reading scores of the sample of secondary school

children were on average above the average level of the norms of end primary education, while the parent group, on their turn, outperformed the secondary school sample. This outcome led the authors to conclude that word reading rate continues to improve during the secondary education and well into the adult years (Kuipers et al., 2003).

The conclusion derived by Kuipers et al. (2003) from their findings can be questioned, however, as, the participants in their study do not appear to be a-select samples of the general population.Their samples did not include lower levels of secondary education (the lowest 8 to 10% of the population of secondary school children were not included (cf. Ministerie van OCW, 2002b). In addition, the average performance of the VBO and MAVO pupils on the WAIS verbal competence scale was between half a standard deviation and one standard deviation above the level expected by the general capacities of these levels of education (e.g. Van Dijk & Tellegen, 1994). Consequentially, the average WAIS verbal competence of the secondary school children in the kuipers et al. study is half a standard deviation above the average of the WAIS norms. In addition, the adult (parent) participants' WAIS verbal competence score was even one standard deviation above the average of the Dutch adult population (A clear overrepresentation of the highest levels of education was present in the adult sample (cf. CBS, 1995)). Finally, when comparing the parent sample with the only subgroup of secondary school children who had an approximately equivalent WAIS score on verbal competence (i.e.,VWO level students), than the reading scores do not differ between 15-16 year-olds and the adult participants. In conclusion, then, the current re-evaluation of the samples participating in Kuipers et al. indicates that the development of reading throughout the adult years is more apparent than real.

Figure 1: Median values of the remedial indices for the group of younger participants and for the full sample

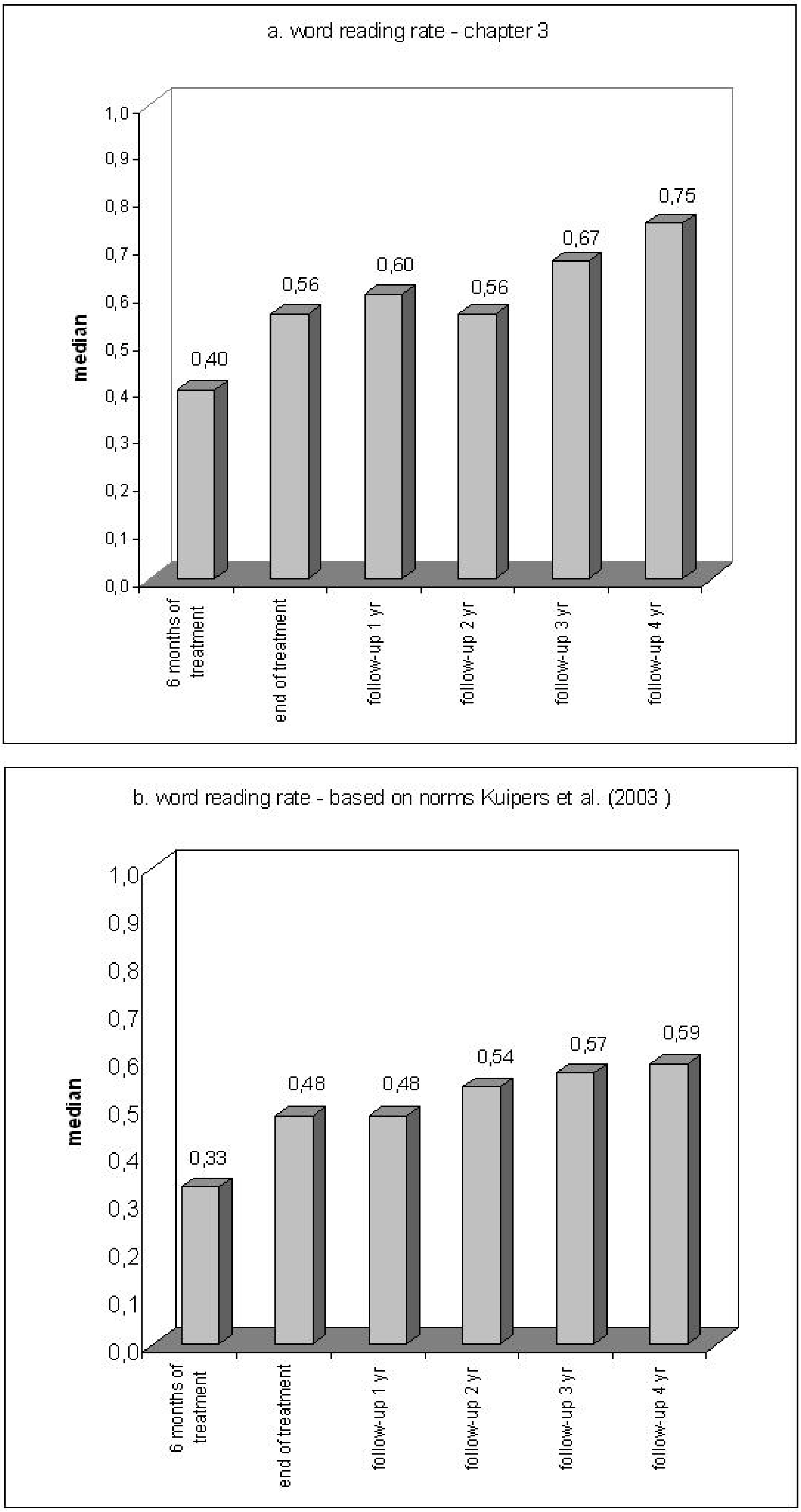


Note. The subgroup of younger participants consisted of the 1-yr follow-up and some of the 2-yr follow-up participants.

Nonetheless, it might be insightful to analyze our data of Chapter 3 including the norms as provided by Kuipers et al. (2003). Therefore, the data presented in chapter 3 were re-analysed by comparing the participants who are within the age range for which the EMT-test is normed (that is, students of primary education (≤ 12 yr)) to the older participants. The results yielded no significant differences between these two groups in treatment effects at the end of treatment (t-test: $t = .50$, $p = 0.62$). For the analysis of long-term treatment effects, the four follow-up groups were pooled. Again, no significant differences between the younger participants and the older ones were found (t-test: $t = -.89$, $p = 0.38$). The median values of the remedial indices for the group younger participants and for the full sample are presented in Figure 1. It can be seen that the short- and long-term effects of the subgroup of younger participants equal the effects of the full sample. Thus, the results indicate that the effects of treatment were not compromised by the inclusion of older dyslexics.

The outcome of a complementary analysis led to the same conclusion. Let us assume a linear growth from the start of secondary education to the fourth grade of secondary education (about 15, 16 years of age) as well as one from grade four to the age of 47 years. Let us then use the norms based on the above assumption. Thus, the indices of the treatment effect were recalculated according to the new norms.[1] The median values of the remedial indices at the times of measurement are presented in Table 2. It can be seen that, in general, the index scores were somewhat lower than the original indices. But, importantly, the overall growth trajectory remained the same. Most significantly, the effects of treatment persisted on the long term. For analysis, the statistical procedure of chapter 3 was used, showing a pattern of results similar to the results revealed in chapter 3. Thus, a one-tailed t-test revealed that the participants made significant improvements after six months of treatment ($t = 11.17$, $p < 0.001$). The participants' levels of word reading after six months of treatment, at the end of treatment and 1, 2, 3, and 4 years after treatment were compared using Anova with follow-up groups (1, 2, 3 or 4 years after treatment) as a between-subjects factor and times of measurement (after six months of treatment, at the end of treatment, and follow-up) as within-subjects factor. The Anova revealed no main effect of groups, ($F(3,96) = 0.10$, $p = 0.96$), but a significant one of times of measurement, ($F(2,192) = 16.65$, $p < 0.001$). There was no significant interaction ($F(6,192) = 0.48$, $p = 0.82$). Follow-up tests indicated, firstly, that word reading was significantly improved at the end of treatment ($F(1,96) = 21.25$, $p < 0.001$), and, secondly, that the participants' word reading levels at the follow-up measurements were not inferior to the levels at the end of treatment ($F(1,96) = 0.58$, $p = 0.45$). Finally, the effect-sizes of the gains halfway the treatment ($d = 1.53$ vs. $d = 1.63$ in the original analysis) and the gains at the second half of treatment ($d = 0.66$ vs. $d = 0.54$) were comparable between the new and the original analysis. Taken together, the current pattern of results provide support for the efficacy of the LEXY program, even when it is assumed that reading skill improves into adulthood.

Figure 2: *Median values of the remedial indices*



Regression to the mean. The current results (see chapter 5 and 7), indicated that the participants with the lowest initial reading and spelling levels tended to gain most from the LEXY treatment. This outcome was derived from regressing the change from entry to follow-up on the initial entry score. It could be argued, however, that this analysis may produce an inflated outcome due to random measurement error and within subject variability in performance (Edland, 2000). This bias is induced by regression towards the mean within the random component of the measure. Obviously, it is important to control for this bias. For a two-wave design, as used in chapters 5 and 7, Oldham's method provides the most appropriate adjustment (otherwise Blomqvist's method is the preferred (e.g., Edland, 2000; Tu, Maddick, Griffiths, & Gilthorpe, 2004)). Oldham's method deals with the bias by regressing change on the arithmetic mean of the pre- and post-treatment value. These two values are statistically independent and therefore uncorrelated (Oldham, 1962; Tu et al., 2004). Application of Oldham's method to the current results revealed that the adjusted correlation between the initial value and subsequent change was significant for all four outcome measures: word reading rate ($r = 0.12$, $p < 0.02$), text reading accuracy ($r = 0.75$, $p < 0.001$), text reading rate ($r = 0.80$, $p < 0.001$), and spelling ($r = 0.93$, $p < 0.001$). Note, however, that although the association for word reading rate (Oldham's $r = 0.12$) is statistically significant, it is far from substantial. Nonetheless, the re-analysis of the current results indicates that the conclusion drawn in chapters 5 and 7 is valid: Children who need treatment the most benefit most from the LEXY treatment.

Comparison of LEXY to other treatments. The most thorough evaluation of a treatment of dyslexia in the Netherlands is the study of Kappers (1997), which has been cited in Chapter 1. Kappers evaluated the effects of a treatment method that combined Bakker's (1983, 1986) training (i.e., hemispheric stimulation) with other remedial methods, such as auditory blending and grapheme-phoneme conversions. A sample of 80 dyslexic children, age-range 7-15 years at the start of treatment, received approximately a total of 60 hours of individual treatment, spread over a 15-months period. Unfortunately, Kappers only reported rate of gain defined as reading age / educational age (i.e., the average student has a rate of gain of 1.00). Although a direct comparison between the effects of LEXY and the Kappers treatment program is difficult, one outcome measure is shared between studies (i.e., word reading (EMT, Brus & Voeten, 1973)).

The short-term effects obtained by Kappers (1997) consisted of a rate of gain of 1.07, indicating progress but one that did not go beyond the progress made by the average reader . In contrast, as shown in chapter 5, the LEXY participants made progress AND did improve their position within the norm-group.[2] As to the long-term effects, the Kappers study, showed that the rate of gain was lost and reading growth was approximately similar to pre-treatment level (about 0.50). In contrast, the follow-up results of LEXY revealed (both for the full sample as for the subgroup younger than 12 years) that the rate of growth continued to equal the normal growth rate when treatment was terminated. Finally, an interesting difference between the results of the two studies resides in the relationship between the initial reading proficiency and the treatment effects. In the Kappers study, the children with the highest initial reading levels tended to gain most from treatment, whereas in LEXY the most severely reading disabled children benefited most from treatment. However, it is important to

emphasize that these comparisons are indirect and, therefore, should be interpreted with caution.

Design. The present thesis was designed to evaluate the efficacy of a Dutch psycholinguistic treatment method, named LEXY. The results strongly support the effects of this treatment, revealing clinically significant effects, which seem to generalize to the full spectrum of the population of dyslexic individuals. The effects were replicated and it has also been demonstrated that the effects can be attributed to the theoretical underpinnings of the treatment. Thus, the results of the current thesis on the treatment of dyslexia in the Dutch language support an international consensus that psycholinguistic treatment programs are most promising in treating the reading and spelling disabilities of those with dyslexia.

However, the design of the thesis has limitations, which are especially related to the lack of use of control groups in a formal sense. This design issue has been justified on both ethical and methodological grounds. However, an important, missing control condition is a comparison of LEXY with another treatment method. Comparison of a treatment to an alternative, traditional treatment is considered to be a strong control for its effectiveness (Carrol & Rounsaville, 2003; Kazdin, 2002; Ollendick & King, 2004). By comparing a treatment to an appropriate alternative treatment method in a controlled outcome study, its superiority or surplus in effects can be directly substantiated. This control condition is, therefore, an important step to be made, and we hope to be able to set up such a comparative outcome study in the nearby future.

Footnotes

[1] Remedial index: $r_{ixt} = \dfrac{{}_i x_t - {}_i x_0}{{}_i x_{nt} - {}_i x_0}$

in which ${}_i x_t$ = the score of participant *i* on test *x* at time *t*;

${}_i x_0$ = the score of participant *i* on test *x* at the start of the treatment; and

${}_i x_{nt}$ = the norm for test *x* corresponding to the age of participant *i* at time *t*

The remedial index of person *i*, at time *t*, for test *x* is the ratio of two distances: 1) the one it would have covered ideally, from its first deficient score to the general norm at the time of measurement. This is expressed in the denominator; and 2) the one it covered actually in that time interval. This is expressed in the numerator.

[2] Since the samples of chapter 5 included some pupils of secondary education, we re-analysed our data of chapter 5 including the norms as provided by Kuipers et al. (2003). The results of these re-analyses were basically similar to the original results of chapter 5: significant gains of standardised scores were revealed for both treatment groups (Wilcoxon matched pairs tests; group 1: $Z = -8.16$, $p < 0.001$; group 2: $Z = -8.54$, $p < 0.001$).

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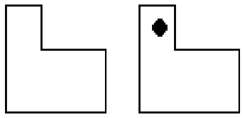
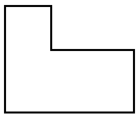
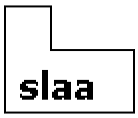
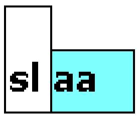
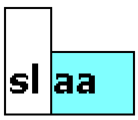
Appendix A

Syllable algorithm© used for “slapen” (to sleep)

tutor says:	**participant says[1]:**	**participant acts[1]:**		**program[2]:**	
‘Slapen’, divide this words in syllables	/slaa/, /pen/				
First syllable is a ..? Second syllable is a ..?	A stressed syllable An unstressed syllable	presses the stressed syllable icon on the soundboard, followed by the unstressed syllable icon	➔		both syllable icons are projected on the screen
					the first syllable icon appears on the screen
Which sounds are present in the first syllable?	/s/ /l/ /aa/	types the syllable sound by sound (/s/,/l/,/aa/)	➔		phones are projected in the icon
The syllable ends with?	/aa/	presses icon ‘last sound syllable’	➔		terminal phone is isolated
To which class does that sound belong?	It’s a long vowel	presses icon for the type of phone to which the last sound belongs (= long vowel)	➔	**  *aa ee oo uu 	*all phones belonging to the indicated type of phone appear on the screen **the rule belonging to this type of phone appears on the screen

What happens when a long vowel end a syllable?	If the last sound of the syllable is a long vowel, then it is written with one graph	presses icon for the operation	➔	sl aa	one graph of the long vowel is selected for deletion
		confirms the operation as shown on the screen by pressing the icon '•' (end operation)	➔	sl a sla	operation is carried out and the word in its final form is shown next to the syllable icon
				•	the second syllable icon appears on the screen
Which sounds are present in the second syllable?	/p/ /en/	types the syllable sound by sound (/p/,/en/)	➔	• pen	phones are projected in the icon
The syllable ends with?	/en/	presses icon 'last sound syllable'	➔	• p en	terminal phone is isolated
To which class does that sound belong?	morpheme-sounds	presses icon for the type of phone to which the last sound belongs and then presses icon '•'	➔	**slapen**	'-pen' is added to the already projected 'sla'

1. When participants say something wrong the tutor corrects them, when they make an error on the computer, it gives feedback on their error

2. graphs representing phones (which are located within the syllable icon) are colored red, graphs representing the written form are colored black. Operators (rule icons) are colored yellow.

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Samenvatting

Summary in Dutch

Dyslexie is een leerstoornis, met problemen in de verwerving van de lees- en spellingsvaardigheden als meest kenmerkende symptomen. Er is een grote hoeveelheid convergerend bewijs dat indiceert dat dyslexie voortkomt uit een deficiet in het fonologisch verwerkingssysteem. In dit proefschrift wordt een evaluatie gerapporteerd van de werkzaamheid van een Nederlandstalige psycholinguïstische behandeling voor dyslexie, genaamd LEXY. Deze psycholinguïstische benadering sluit aan bij de bovengenoemde wetenschappelijke consensus omtrent de etiologie van dyslexie. LEXY presenteert aan de dyslectici een leersysteem, waarin de basale (linguïstische) elementen en operaties duidelijk gemaakt worden die essentieel zijn voor de grafische representatie van de gesproken taal. Het is een computerondersteund programma, gericht op het leren herkennen en gebruik maken van de fonologische en morfologische structuur van het Nederlandse woord. De dyslecticus dient zich deze elementen stapsgewijs eigen te maken om zo een juiste relatie tussen de gesproken en geschreven taal te leggen.

De doelstelling van de studie in hoofdstuk drie was het evalueren van de korte en lange-termijn effecten van de behandeling. Het betrof de evaluatie van de bereikte niveaus van losse woorden lezen, verbonden tekst lezen en spelling in een steekproef bestaande uit zowel kinderen als volwassenen met dyslexie. Uit de resultaten van dit onderzoek bleek dat halverwege de behandeling reeds duidelijke winsten waarneembaar waren. Deze verbeteringen varieerden van bijna een halvering van de afstand tussen de scores van de participanten en de norm in het geval van losse woorden lezen, tot een reductie van deze afstand met meer dan driekwart bij het spellen. Aan het einde van de behandeling bleken de lees- en spellingsvaardigheden nog verder vooruitgegaan te zijn. Na het volgen van de behandeling bereikten de dyslectici een functioneel niveau van tekst lezen en spellen. Het lezen van losse woorden was echter niet genormaliseerd aan het einde van de behandeling, al liet een grote effectsize zien dat winst van de behandeling ook hier substantieel was.

Daar iedere behandeling tot doel zal hebben langdurige effecten te bewerkstelligen, dient dit aspect beschouwd te worden als een van de primaire criteria voor de evaluatie van een behandeling. Het is duidelijk dat de effecten die aan het einde van de behandeling behaald zijn niet zonder meer een indicatie vormen voor de uitkomsten op de lange termijn (Kendall, Flannery-Schroeder, & Ford, 1999). In dit opzicht is het dan ook verrassend dat slechts een klein aantal lange-termijn evaluaties van interventies voor dyslexie is gerapporteerd. Derhalve was het derde hoofdstuk gericht op effectiviteit op de lange termijn, d.i. één tot vier jaar na afloop van de behandeling. Uit deze evaluatie kwam naar voren dat de bereikte niveaus van woorden lezen en tekst lezen tot vier jaar na afloop gehandhaafd bleven. Spelling vertoonde een kleine terugval in het eerste jaar na beëindiging van de behandeling, maar bleef stabiel in de daarop volgende jaren. Een belangrijke conclusie die derhalve getrokken kan worden is dat de effecten van de behandeling langdurig zijn. De gevonden (korte- en lange termijn) effecten

bleken onafhankelijk te zijn van leeftijd, sekse, IQ en sociaal-economische status van de deelnemers.

Behalve deze feitelijke effecten zijn de effecten zoals die door de participant worden ervaren eveneens van kritiek belang (Foster & Mash, 1999). Naast het competent zijn, geeft tevens het zich competent voelen een duidelijke bijdrage aan iemands functioneren (Kazdin, 1999). Om die reden is het door de participanten ervaren effect in de evaluatie meegenomen. De subjectieve ervaringen van de participanten bleken overeen te stemmen met de feitelijke behandelingseffecten; de grote meerderheid van de participanten gaf aan dat ze na afloop van de behandeling beduidend minder hinder van hun lees- en spellingsvaardigheden ondervonden in hun dagelijks leven en dat hun functioneren op school of in de maatschappij gemakkelijker was geworden.

Teneinde effectieve behandelingsprogramma's te ontwikkelen, is het van vitaal belang een nauwkeurig inzicht te hebben in de mechanismen waarmee behandelingseffecten tot stand gebracht worden (Kazdin, 2002; Moras, 1998). Om tot een goed begrip te komen van de wijze waarop behandelingen verandering teweeg brengen en van de manier waarop behandelingseffecten kunnen worden geoptimaliseerd, zijn studies noodzakelijk die zo ontworpen zijn dat ze inzicht geven in de temporele dynamiek van de mechanismen die onderliggend zijn aan de effecten van een behandelingsprogramma (cf. Kazdin, 2003, p. 271). In het onderhavige veld bestaan de meeste evaluatieonderzoeken uit een pre- vs. post-test design, zonder aandacht te hebben voor de processen waardoor de effecten tot stand zijn gekomen (Lyon & Moats, 1997). Al zijn enkele belangrijke kwesties verhelderd door het vergelijken van verschillende behandelingsprogramma's (bijv., Lovett et al., 2000; Wise et al., 1999, 2000), de processen waardoor de behandelingseffecten zijn bereikt blijven grotendeels onderbelicht. In een overzicht van de relevante literatuur concluderen Lyon en Moats (1997) dat de kennis omtrent de reden waarom specifieke behandelingsprogramma's effectief zijn nog altijd beperkt is en stellen dat we onze kennis op dit vlak moeten gaan verstevigen en verfijnen.

Dit gebrek aan kennis ten aanzien van de aan de behandelingseffecten onderliggende processen inspireerde ons tot het opzetten van een procedurele evaluatie van de LEXY behandeling. Deze procedurele evaluatie stond centraal in hoofdstuk vier. Het primaire doel bij deze studie was het bieden van een gedetailleerd beeld van de veranderingsdynamiek door middel van het onderzoeken van de relatie tussen de temporele orde van de behandelingseffecten en de volgorde van presentatie van de behandelingscomponenten. De verwachting was hierbij dat het optreden van een effect in tijd nauw verbonden is met het aanbieden van de corresponderende behandelingsmodule. Deze verbondenheid in tijd werd bevestigd door de onderzoeksresultaten; de kinderen lieten een cascade van verbeteringen zien die correspondeerde met de presentatieorde van de behandelingscomponenten.

De behandeling richtte zich in eerste instantie op de fonetische structuur van woorden. Zoals verwacht bleken de participanten aan het einde van de eerste module de meeste vooruitgang gemaakt te hebben op de hieraan gerelateerde aspecten van het schrift. Aansluitend op deze training van de fonetische structuur verschoof de aandacht naar situaties waarin de correspondentie tussen een fonetisch element en zijn standaard grafische representatie is doorbroken. Hiertoe werden operaties geïntroduceerd om de fonetische

structuur in de correcte orthografische woordvorm te transformeren. Als voorspeld werd het grootste effect voor de operaties betreffende monosyllabische woorden bereikt aan het einde van module 1 en voor operaties betreffende polysyllabische woorden aan het einde van module 2. Morfeem gerelateerde fouten waren echter nog altijd aanwezig aan het einde van module 2. De meeste winst op dit onderdeel boekten de participanten na het doorlopen van de hierop volgende module, welke specifiek gericht was op de oorzaken van morfeemfouten. De laatste module betrof werkwoordstructuren. Het was pas na deze module dat er ten aanzien van dit aspect een effect optrad. Deze bevindingen geven enerzijds inzicht in de mechanismen waarmee de veranderingen tijdens de behandeling plaatsvinden, anderzijds bieden ze een belangrijke ondersteuning voor de (interne) validiteit van de LEXY-behandeling. Dat wil zeggen, de bevindingen tonen aan dat de behandelingseffecten niet toegekend kunnen worden aan niet-specifieke factoren (zoals behandelingsduur, rijping, andere instructie), aangezien deze factoren algemene effecten geproduceerd zouden hebben die ongerelateerd zouden zijn aan de timing van de specifieke behandelingsmodules.

Aan het gevonden patroon van effecten kunnen verschillende implicaties ontleend worden voor het opzetten van een behandeling voor dyslexie. De resultaten geven ondersteuning voor de algemeen veronderstelde positieve effecten van expliciete instructie in zowel foneem bewustzijn als klank-teken relaties. Tegelijkertijd geven de resultaten echter aan dat kennis van het foneemsysteem voor de dyslecticus onvoldoende is om te kunnen omgaan met situaties waarin de correspondentie tussen een fonetisch element en zijn standaard grafische representatie doorbroken is. Het blijkt dat expliciete instructie gericht op de fonologische regels die aan deze dissociaties ten grondslag liggen, belangrijk is voor het bereiken van verdere vooruitgang. Bovendien wordt benadrukt dat het belangrijk is de aandacht ook te richten op de invloed van morfologische elementen op de orthografie. Derhalve indiceren deze bevindingen dat het bij het opzetten van een behandelingsprogramma van belang is om een volledig systeem te creëren van de basale linguïstische (d.i. morfofonologische) principes die het schrijfsysteem organiseren.

Het is duidelijk dat behandelingseffecten om valide te zijn, betrouwbaar moeten zijn. Om de betrouwbaarheid van de gerapporteerde werkzaamheid van de behandeling te ondersteunen, is in hoofdstuk vijf een onderzoek beschreven welk tot doel had de in hoofdstuk drie gerapporteerde behandelingseffecten te repliceren. In hoofdstuk vijf werden de bereikte niveaus van lezen en spellen derhalve opnieuw geëvalueerd, gebruik makend van twee grote steekproeven van dyslectische kinderen (10-14 jaar). De resultaten van deze studie bleken de positieve behandelingseffecten uit het voorafgaande onderzoek te repliceren. Bovendien vertoonden de twee steekproeven een in hoge mate overeenkomstig patroon van resultaten, hetgeen een verdere ondersteuning vormt voor de betrouwbaarheid van de behandelingseffecten. Aan het einde van de behandeling bereikten de participanten van beide steekproeven een gemiddeld niveau van spellen en van accuraatheid van het lezen. Het bereikte niveau van leessnelheid kwam overeen met de ondergrens van de normale range.

De klinische relevantie van een behandeling kan ook gerelateerd worden aan de variabiliteit van de respons op behandeling binnen de steekproef (Jacobson & Truax, 1991; Torgesen, 2002). Zoals in hoofdstuk vijf naar voren kwam wist de grote meerderheid van de participanten een vaardigheidsniveau te bereiken dat binnen de normale range lag (d.i. een

standaardscore van tenminste 90 (M=100, sd=15), cf. Torgesen et al., 2001). Dit gold voor de nauwkeurigheid van tekst lezen en voor de spelling: de meeste participanten (rond de 70%) bereikten een niveau dat gelijk aan of boven de norm lag voor deze vaardigheden. Daarnaast wist de helft van de participanten bij de leessnelheid een niveau te verwerven dat binnen de normale range lag.

Een kritische kwestie aangaande de betekenis van behandelingseffecten betreft de transfer van het geleerde. In hoofdstuk vijf, alsmede in de andere gerapporteerde evaluatiestudies, is beoogd transfer van effecten te demonstreren door bij het meten van de lees- en spellingsvaardigheden gebruik te maken van woorden die verschillen van de woorden die in de behandeling zijn gebruikt. Bovendien kunnen de woorden waaruit de spelling- en (tekst) leestests zijn opgebouwd beschouwd worden als een representatieve steekproef van de typische problemen van het Nederlandse schrift. Dientengevolge kunnen de gerapporteerde effecten geïnterpreteerd worden als de transfer van de geleerde concepten in gegeneraliseerde lees- en spellingswinsten.

Hoofdstuk zes was meer fundamenteel van aard dan de andere hoofdstukken; het onderzoek was gericht op de relatie tussen verbale geheugenproblemen en fonologische verwerkingsproblemen bij dyslexie. Het onderzoek sluit aan op dat van Kramer, Knee en Delis (2000), die hadden laten zien dat de problematiek van dyslectici in het verbale geheugendomein terug te voeren was op een minder efficiënt verwervingsmechanisme in de geheugenopbouw. Aansluitend hierop is in hoofdstuk zes bij de groep dyslectische kinderen een aantal expliciet fonologische taken (foneem bewustzijnstaken), impliciet fonologische taken (cijfers herhalen en auditieve interferentie) en een list-learning verbale geheugentest (opbouw en retentie) afgenomen.

Een factor-analyse wees uit dat de opbouw van het verbaal geheugen en de impliciet fonologische taken op een gemeenschappelijke factor laden. Deze factor bleek systematisch gerelateerd te zijn aan de lees- en spellingsvaardigheden van de dyslectici. De resultaten suggereren dat de verbale geheugenproblemen en fonologische problemen bij dyslexie twee expressies zijn van een gemeenschappelijk onderliggende stoornis, die omschreven kan worden als een inaccurate encodering van de fonologische karakteristieken van verbale informatie. Een tweede factor die uit de analyse tevoorschijn kwam was het fonetisch bewustzijn. Opmerkelijk was dat de fonetisch bewustzijnsfactor geen unieke, van de fonologische encodering onafhankelijke bijdrage bleek te leveren aan de lees- en spellingsvaardigheden.

Vervolgens is in hoofdstuk zeven de voorspellende waarde van de fonologische encodering voor de responsiviteit op de behandeling nader onderzocht. De ernst van het fonologisch encoderingsprobleem bleek geen impact te hebben op de bereikte lees- en spellingsniveaus. Wel bleek de duur van de behandeling te variëren als functie van het fonologisch encoderingsvermogen van het dyslectische kind. Dit patroon van resultaten lijkt erop te wijzen dat participanten met meer en minder ernstige fonologische encoderingsproblemen niet verschillen in termen van het behaalde behandelingseffect, maar in de "dosis" behandeling die nodig is om dit te bereiken. Een andere individuele karakteristiek wiens voorspellende waarde op het behandelingseffect geanalyseerd werd in hoofdstuk zeven, is het initiële lees- en spellingsniveau. De dyslectische deelnemers gaan de behandeling in met

een brede variëteit aan lees- en spellingsvaardigheden en het lijkt eerlijk om te stellen dat degenen met de meest ernstige lees- en spellingsachterstanden een effectieve behandeling het hardst nodig hebben. De behandelingseffecten leken inderdaad afhankelijk te zijn van het initiële niveau van lezen en spellen. De resultaten suggereerden dat degenen met de laagste initiële niveaus de meeste winst haalden uit de behandeling.

Een onderwerp van debat binnen de literatuur omtrent de behandeling van dyslexie, betreft de effecten van behandeling op leesnauwkeurigheid versus leessnelheid. Daar waar interventiestudies positieve behandelingseffecten gerapporteerd hebben op de nauwkeurigheid van het lezen, is de leessnelheid veel minder ontvankelijk gebleken voor psycholinguïstische behandelingsprogramma's (Torgesen et al., 2001; Wolff & Katzir-Cohen, 2001). Deze discrepantie heeft verschillende onderzoekers tot de opvatting gebracht dat de interventiestudies zich te sterk gericht hebben op nauwkeurige decodeervaardigheden en dat toekomstig onderzoek inzicht zou moeten bieden in de cognitieve mechanismen die resulteren in zowel leesnauwkeurigheid als leessnelheid, oftewel in vloeiend lezen (bijv. Lovett et al., 2003; Wolf & Katzir-Cohen, 2001).

Met het oog op dit streven was het doel van hoofdstuk acht zicht te bieden op de dynamiek van veranderingen in leesnauwkeurigheid en leessnelheid tijdens en na afloop van de behandeling. Zoals aangegeven in hoofdstuk twee, richt het LEXY-programma zich op het remediëren van lees- en spellingsproblemen door de meest basale linguïstische elementen en operaties te implementeren in een leersysteem, gestuurd vanuit een algoritmische structuur. De architectuur van het programma is derhalve in overeenstemming met productiemodellen van vaardigheidsverwerving, in het bijzonder met de theorie van leeractiviteit (Davidov, 1990/1995; Gal'perin, 1974/1989). In dit leerproces staat de strategie van foutloos leren centraal. Men verondersteld dat (delen van) het systeem allereerst accuraat beheerst dient te worden, alvorens de uitvoering ervan geleidelijk kan worden geautomatiseerd. In termen van het behandelingsprogramma betekent dit dat de aandacht primair gericht is op het stap voor stap nauwkeurig beheersen van een 'productiesysteem van lezen'. Hierbij wordt verondersteld dat naarmate de training vordert, de leessnelheid de ontwikkeling van de nauwkeurigheid van het lezen geleidelijkerwijs volgt.

In overeenstemming met de productiemodellen van vaardigheidsverwerving, liet het onderzoek zien dat de behandeling eerst resulteerde in een meer prominente ontwikkeling van de leesnauwkeurigheid, hetgeen een reflectie lijkt van de accurate vorming van het systeem van essentiële elementen en operaties die aan de vaardigheid van het lezen ten grondslag liggen (Grigorenko, 1998). In een later stadium resulteerde het in een meer prominente ontwikkeling van de leessnelheid, hetgeen verondersteld wordt een weerspiegeling te zijn van het optimaliseren van de uitvoering van het systeem. Dit proces bleek ook uit de bevinding dat de leessnelheid, in tegenstelling tot de nauwkeurigheid van het lezen, zich bleef ontwikkelen na beëindiging van de behandeling.

Deze uitkomsten onderbouwen het belang van de implementatie van productiemodellen van vaardigheidsverwerving en hiermee de in hoofdstuk twee gepresenteerde opvatting dat een behandeling niet alleen gericht moet zijn op het optimaliseren van zijn linguïstische adequaatheid, maar ook gericht dient te zijn op de psychologische en didactische adequaatheid. De resultaten van hoofdstuk acht bieden

ondersteuning voor de effectiviteit van een aanpak waarbij de dyslecticus expliciet gericht wordt op een procedureel systeem van morfofonologische eenheden en regels die kritisch zijn voor het verschil tussen de gesproken en de geschreven taal. Meer in het bijzonder ondersteunen de resultaten de positieve impact van de theorie van leeractiviteit als kader hiervoor.

Dankbetuiging

De weg die geleid heeft tot dit proefschrift is gelukkig niet in eenzaamheid afgelegd en er zijn dan ook veel mensen die ik dankbaar ben voor hun steun onderweg.

Allereerst wil ik natuurlijk mijn promotor Maurits van der Molen en co-promotor Jan Hoeks bedanken voor al de begeleiding en richting die ze mij onderweg geboden hebben. Evenzeer ben ik veel dank verschuldigd aan Theo Schaap die op meerdere wijzen aan de wieg stond van dit proefschrift en wiens kennis en enthousiasme een bijzondere bron van inspiratie zijn geweest.

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Charlotte Lokin is verantwoordelijk voor de prachtige cover, waarbinnen het als proefschrift prettig vertoeven is. En tenslotte gaat natuurlijk voor al haar steun veel dank uit naar Mascha.

In Memoriam

Theo Schaap (25 november 1943 – 5 augustus 2002)

Het onderhavige proefschrift dankt veel aan het gedachtegoed van Theo Schaap. Na verbonden te zijn geweest aan de Rijksuniversiteit Groningen en de Universiteit van Amsterdam was Theo Schaap in 1983 initiatiefnemer en medeoprichter van het Instituut voor Woordblindheid en Andere Leerproblemen, later IWAL, met als doel de wetenschappelijke theorie en de praktijk van leerproblemen te doen samensmelten. Vanuit deze doelstelling en vanuit een taalpsychologische benadering van dyslexie ontwierp hij begin jaren tachtig het beschreven behandelprogramma LEXY.

Meer in het bijzonder was Theo de initiator van het beschreven evaluatieonderzoek. Zijn onuitputtelijke ideeënstroom en tomeloze enthousiasme zijn bij de verwezenlijking van dit project ook een grote bron van inspiratie geweest. Het is jammer dat Theo het eindresultaat van het project niet heeft mogen meemaken. In de zomer van 2002, temidden van zijn talloze werkzaamheden in Praag en Amsterdam is Theo ons plotseling ontvallen.