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Abstract

The effects of regularity, frequency, lexicality, and granularity on single word reading in Norwegian children with dyslexia and control children matched for age and reading level were examined. The reading impaired children showed the same pattern of performance as younger children matched for reading level on most tasks except for the fact that they worse at nonword reading. The findings are discussed against different theoretical models of reading.

Introduction

Learning to decode is the most challenging task confronting the beginning reader, and developmental dyslexia is typically associated with deficits in decoding. The goal of the present study was to investigate characteristics of word decoding in Norwegian children with developmental dyslexia. Of particular interest was how theoretically important effects such as frequency, regularity, lexicality, and orthographic grain size influence decoding in children with reading impairments compared to normally reading children matched for chronological age or for reading-level.

Reading acquisition and dyslexia

Learning to read involves two basic component skills: word decoding and comprehension of written language. Children with dyslexia (or specific reading disability) typically demonstrate inferior single-word recognition in the presence of normal reading comprehension and otherwise normal cognitive abilities (Lyon, 1995), as opposed to children with hyperlexia, who typically demonstrate advanced word-recognition skills in the presence of poor reading comprehension and otherwise poor cognitive abilities (Nation, 1999).

In order to learn to read an alphabetic script, such as Norwegian, the child must learn how the letters in printed words relate to the sounds in spoken words. More specifically, the child must learn the associations between visual patterns (i.e., individual letters or letter clusters) and segmented speech sounds. Numerous of theories and studies suggest that the acquisition of word-decoding skills are highly dependent on the child's phonological awareness and alphabetic knowledge (see e.g. Ehri, 1998; Treiman, 2000; Muter, Hulme, Snowling, & Stevenson, 2004). Essentially, grasping the alphabetic principle requires the ability to segment spoken words into their constituent phonemes, and learning the associations, or mappings, between sound segments and the letters in printed words.

Understanding this alphabetic principle gives the child the opportunity to decode new words that have not been encountered previously.

A possible causal link between phonological awareness, especially phoneme awareness, and the development of single-word decoding is supported by longitudinal studies (e.g., Hulme, Hatcher, Nation, Brown, Adams, & Stuart, 2002; Muter, Hulme, Snowling, & Stevenson, 2004; Wagner, Torgesen, & Rashotte, 1994; de Jong & van der Leij, 1999) and experimental training studies (e.g. Lundberg, Frost, & Petersen, 1988; Hatcher, Hulme, & Ellis, 1994; Hatcher, Hulme, & Snowling, 2004). In children with dyslexia, a deficit in word-recognition is the core problem and mounting evidence suggest that phonological processing deficiencies are the probable causes of this deficit (for a review, see e.g. Scarborough, 1998; Velluntino, Fletcher, Snowling, & Scanlon, 2004). A growing number of cross-linguistic studies demonstrate that the underlying causes of dyslexia are universal and stem from impaired development of the phonological system (Fowler, 1991; Metsala & Walley, 1998; Snowling & Hulme, 1994; Swan & Goswami, 1997), although manifestation of dyslexia differs by language (Goswami, 2000, 2002; Grigorenko, 2001; Paulesu et al., 2001; Ziegler & Goswami, 2005).

Reading acquisition and developmental dyslexia across different languages

About two-thirds of all published research on developmental dyslexia is conducted in English-speaking countries (Ziegler et al., 2003). The generalizability of the findings from English studies to other orthographies is a controversial issue, however. A study by Seymour, Aro, Erskine and collaborators (2003) compared word and nonword reading performance after one year with reading instruction across 13 European countries. Results revealed that basic decoding skills developed less effectively in English than most other European orthographies. In fact, the rate of development was more than twice as slow in English children compared to children acquiring shallow orthographies, i.e. orthographies with

consistent mappings between spelling and sound. Similarly, Landerl, Wimmer, and Frith (1997) showed that English children with dyslexia suffered from more severe reading impairments in both word and nonword reading than their German counterparts. A number of monolingual studies conducted in other orthographies than English have contributed to the knowledge that reading profiles in dyslexic children acquiring shallow orthographies are different from that of English children with dyslexia (for an account of developmental dyslexia in different orthographies, see Goulandris, 2003). Typically, children acquiring irregular orthographies (such as English, French and Danish) demonstrate both poor reading accuracy and low reading speed whereas children acquiring regular orthographies (such as Greek, Italian, German and Dutch) exhibit high reading accuracy but low reading speed for both words and nonwords. In recent years, therefore, a growing number of monolingual and cross-linguistic studies have addressed the question of whether findings from English-speaking countries can be generalized to shallow orthographies, and whether developmental dyslexia in different languages is universal or language-specific.

However, Ziegler, Perry, Ma-Wyatt, Ladner, and Schulte-Körne (2003) note that, although knowledge about absolute differences in accuracy and speed between languages is intriguing, the currently available cross-linguistic comparisons of dyslexia give little insight into the process of underlying reading deficits. To gain insight into the processes underlying reading in different languages, Ziegler et al. emphasize, one must go beyond absolute levels of accuracy and speed by considering psycholinguistic marker effects underlying reading. In their cross-linguistic study of English and German children with developmental dyslexia, Ziegler et al. included measures of the 'lexicality effect' to investigate whether the phonological decoding deficit was similar across the two languages, the 'length effect' to quantify serial processes in word and nonword reading, and the 'body N effect' to examine sensitivity to larger orthographic units in these children. Both English and German children

with dyslexia exhibited a reading speed deficit, a nonword reading deficit that was greater than their word reading deficit, and an extremely slow and serial phonological decoding mechanism. These deficits were of similar size across the English and the German samples, and persisted in comparison to younger reading-level controls. These findings led the authors to conclude that the similarities between dyslexic readers using different orthographies are far bigger than their differences, and that dyslexia research using the English language can be generalized to more regular orthographies, provided that "culturally fair" marker effects of the reading process in different orthographies are being used.

Some marker effects are highly language-dependent, however, and provide linguistic structures that may cause specific errors in reading and spelling. For example, the alphabetic nature of Norwegian orthography poses several problems to children with dyslexia, although it is considered a transparent orthography because of the fairly consistent mappings between letters and sounds (Seymour, Aro, & Erskine et al., 2003). Norwegian consists of numerous word-pairs where differences in semantic content are signalled by differences in vowel length in speech (e.g., *mine* ['miːňe] (my; mine) – *minne* ['miň:e] (memory; remind)). In Norwegian orthography, vowel length is signalled by the subsequent consonants. That is, long vowel pronunciations are represented by a single consonant whereas short vowel pronunciations are represented by two identical consonants, e.g.., *lege* (doctor) – *legge* (lay; place); *leke* (play; toy) – *lekke* (leak). Case-studies of four 10-year-old children with dyslexia showed that the vowel length error type totalled 36.7 – 57.1 % of all reading mistakes in single-word reading. Apparently, 'vowel length categorization' is an important marker effect of reading process in Norwegian and represents a major obstacle for children with reading disorders (Nergård-Nilssen, in press a, b). A similar manifestation of dyslexia is reported in Finnish, where reading errors associated with phonemic quantity more sensitively differentiate between good and poor readers than errors concerning phonemic identity (Lyytinen et al., 2004).

Considerations of marker effects of single-word reading within different theoretical models

The present study was designed to examine theoretically important marker effects of the reading process in Norwegian other than 'vowel length categorization', including the effects of 'regularity' (i.e., superior performance in regular word reading over irregular word reading), 'frequency' (i.e., superior performance in recognition of high-frequency over low-frequency words), 'lexicality' (i.e., superior performance in real word reading over nonword reading), and 'granularity' (i.e., superior performance in either small or larger grain size recoding strategies, given the consistency of the orthography being acquired). These four marker effects have been interpreted within different theoretical models of reading, such as dual-route, connectionist, and cross-linguistic theories.

The *dual-route model*, as proposed by Castles & Coltheart (1993, 1996), contends that in word reading there are two separate routes into the mental lexicon. These two mechanisms work in fundamentally different ways. The 'indirect' or '*sublexical route*' is based on grapheme-phoneme translation in order to identify the word (e.g. a new word that has not been encountered previously or a nonword). The 'direct' or '*lexical route*' permits a fast retrieval of the orthographic patterns in the lexicon for known words. A further assumption of the dual-route models is that subjects with developmental dyslexia (and acquired dyslexia) have problems with either of these two routes to lexicon. Surface dyslexics appear to experience problems with the lexical procedure, i.e. with learning to recognize words directly. Surface dyslexics read regular words and nonwords well, but demonstrate poor irregular or exception word reading. Phonological dyslexics, in contrast, appear to have a selective impairment of the sub-lexical procedure. These subjects experience deficits in nonword and regular word reading in the presence of normal exception or irregular word reading. Within dual-route models (Castle & Coltheart, 1993, 1996; Kinoshita & Lupker, 2003), the '*frequency effect*' is assumed to be a lexical effect, reflecting the faster retrieval of whole-

word pronunciations from the output lexicon for high-frequency words than for low-frequency words. The *'regularity effect'* is assumed to be a sublexical effect, reflecting the finding that regular words are read faster than irregular or exception words, and is assumed to arise because the 'sublexical route' generates regularisations of irregular words, resulting in incorrect pronunciations of these words. Finally, the *'lexicality effect'* refers to the observation that nonwords are read aloud more slowly than words (either regular or irregular words), even though these items are matched on various factors. According to dual-route models, the lexicality effect is due to the lexical route being faster than the nonlexical route in general (Kinoshita & Lupker, 2003).

Connectionist (or parallel distributed processing) *models* are computer-based models, in which approximations to "brainlike" architectures give rise to many behavioural qualities that are typical of human cognition. The connectionist networks are made up of large numbers of artificial "neurons" (units) that are richly interconnected both within and between layers (Ashcraft, 2002; Metsala & Brown, 1998; Seidenberg & McClelland, 1989; Plaut, McClelland, Seidenberg, & Patterson, 1996). In "neural networks", input and output units are connected via 'hidden' units. In computational models that simulate detailed aspect of reading performance, "input units" represent the written forms of words, whereas "output units" represent word pronunciations. By abstracting the statistical relationships between the orthographic inputs (orthographic patterns) and the phonological outputs (word pronunciations), the network is able to "read" new words. In contrast to dual-route models, connectionist models maintain that word reading involves computing the appropriate codes on the basis of written input rather than "accessing" entries in a mental dictionary (Seidenberg, 1992), and that word and nonword reading are accomplished using a single mechanism operating over distributed representations of orthographic and phonological units (Seidenberg & McClelland, 1989). The connectionist approach holds that two pathways are necessary in

reading, not because different principles apply to different types of items (as claimed by dual-route models), but because different tasks must be performed. One involves reading-specific processes; *the phonological pathway* transforms orthographic representations into phonological representations (a reading specific task). The other reflects a more general aspect of language; *the semantic pathway* transforms orthographic representations into semantic representations, and semantic representations into phonological representations (Plaut et al., 1996). According to the connectionist approach, the phonological pathway maintains an intrinsic sensitivity to both word frequency and spelling-sound consistency, and there can never be a complete dissociation of *'frequency effects'* and *'regularity effects'*. However, Plaut et al. stress that this sensitivity takes a specific form: Items that are frequent, regular or both will have an advantage over low frequency and/or irregular items. Those items that are both frequent and regular will, however, not enjoy an additional advantage over those items that are either frequent or regular. In other words, regular words show little effect of frequency, and high-frequency words show little effects of consistency. A result of this frequency-consistency equation is that low-frequency irregular words are read disproportionately more slowly than high-frequency regular words, and that the absolute magnitudes of the frequency and regularity effects diminish as reading experience accumulates in skilled readers.

Ziegler and Goswami (2005) maintain that connectionist models fail to capture the cross-language learning rate effect because they deal only with the implicit aspects of the learning process. They suggest that new connectionist models need to be equipped to capture the different training environments provided by different orthographies and different methods of instruction in order to better reflect the development of phonological representations prior to reading, the development of these representations through reading, and the emergence of orthographic representations as a result of reading. In an attempt to integrate the rich cross-

language database into a theoretical framework for understanding reading acquisition, skilled reading, and dyslexia in different languages, Ziegler and Goswami (2005) have developed the *'Psycholinguistic Grain Size Theory of Reading'*. In essence, the theory proposes that, because languages vary in phonological structure and the consistency with which phonology is represented in orthography, there will be developmental differences in the grain size of lexical representations and reading strategies across languages. The lexical organization and processing strategies that are characteristic of skilled reading in different orthographies may be affected by these differing developmental constraints. Ziegler and Goswami suggests that the differences in reading speed and reading accuracy found across orthographies reflect fundamental differences in the nature of the phonological recoding and reading strategies that are developing in response to the orthography. Salient units of different grain size emerge in response to the pressure provided by a given orthography. Thus, children who are learning more orthographically transparent languages rely heavily on grapheme-phoneme recoding (small grain size) strategies because grapheme-phoneme correspondences are relatively consistent, whereas children learning to read less orthographically consistent languages, such as English, cannot use smaller grain sizes as easily because the inconsistency is much higher for smaller grapheme units than for larger units (e.g. rimes). For this reason, English-speaking children develop a variety of recoding strategies, i.e. both small unit and large unit recoding strategies, in parallel. A central claim of the grain size theory is that children with dyslexia in all countries show comparable phonological deficits and that because of their reduced phonological sensitivity, they show comparable difficulties in phonological recoding at small psycholinguistic grain sizes. For the present purpose, the *'granularity effect'* in reading can be defined as superior performance in either small or larger grain size recoding strategies, given the consistency of the orthography being acquired. A corollary of this is that children

acquiring transparent orthographies, such as Norwegian, should demonstrate superior performance in small unit recoding strategies over large unit recoding strategies.

Overview of the present study

The present study compares a group of children with dyslexia to two control groups, one matched on chronological age (CA) and one matched on reading level (RL). There are advantages and disadvantages associated with both kinds of control group. Shankweiler, Crain, Brady, and Macaruso (1992) argue that the use of CA matched controls can narrow down possible explanations of reading disability, and that a combination of positive and negative results in CA-match designs allow us to isolate the source of several symptoms of reading disability. However, as Rack, Snowling, and Olson (1992) maintain, the normal and impaired readers matched on age may show differing profiles, but it is difficult to know whether the profiles are features of the different reading levels or whether they are distinctive characteristics of the subject groups. Reading-level match designs, on the other hand, are better suited to making inferences about the distinctive characteristics of subjects with because such studies can rule out the possibility that the differences are caused by the level of reading skill. By employing both CA and RL control groups, the present study will assess how aspects of lexical structure influence reading process in reading impaired children compared to normal readers.

This study investigates the effects of frequency, lexicality, regularity and granularity on single-word and nonword reading performance of Norwegian children with dyslexia compared to normally reading peers and younger children at the same reading-level. Previous research suggests that reading latencies rather than errors are the most sensitive variable when comparing reading performance across languages (e.g., Ziegler, Perry, Ma-Wyatt, Ladner, & Schulte-Körne, 2003). Because the Norwegian orthography is fairly consistent, the present study focused exclusively on the reading speed for correctly read items.

The 'regularity' and 'frequency' effect

A quantitative meta-analysis of studies examining spelling-to-sound regularity effects in individuals with reading disabilities was conducted by Metsala, Stanovich, and Brown (1998). This meta-analysis compared studies employing reading-level control groups, and was designed to test the prediction of the dual-route version of the phonological-deficit model. That is, the normal use of a sublexical route is impaired in children with dyslexia, and, hence, there should be no reason to expect a word recognition advantage for regular versus exception words. However, this meta-analysis yielded strong evidence against this prediction and showed that the magnitude of 'regularity effect' in children with dyslexia did not differ from that of reading-level control groups.

However, the seventeen studies included in the Metsala et al. meta-analysis were all conducted in English, i.e. in an opaque orthography. To date, very few studies on regularity effects have been conducted in more regular languages. This may partially be due to the fact that there are only very few genuine irregular words in these languages (Ziegler, Perry, & Coltheart, 2003). The present study was undertaken to examine whether reading impaired children acquiring Norwegian, which has a fairly transparent orthography, would show a similar trend as the English-speaking children. More specifically, the study addressed the question of whether a superior performance in regular versus irregular words could be observed in the three reader groups, and, if so, whether the magnitude of such a regularity effect would be the same across the reader groups.

The frequency effect refers to the observation of superior performance in recognition of high-frequency, compared to low-frequency words. A robust finding is that there is an interaction between regularity and frequency. That is, high-frequency words are relatively unaffected by regularity whereas low-frequency words are affected by regularity. The frequency effect would thus allow an investigation of whether there was an interaction effect

between the high- and low-frequency words with regular and irregular spellings, and whether there was difference in the magnitude of the frequency effect between reading impaired and control groups.

The 'lexicality effect'

The 'lexicality effect' is marked by a difference in nonword decoding and word reading skills, with superior performance on "real words" (either regular or irregular) over "nonsense words". Both the study by Landerl et al. (1997) and Ziegler et al. (2003) compared the lexicality effect on reading time (for correctly read items) in German and English children with dyslexia, with each dyslexic group being compared with two controls groups. All cross-linguistic comparison stimuli were matched for meaning, pronunciation, and spelling. However, the two studies reached different findings and conclusions. The Landerl et al. (1997) study found a reading speed advantage of the German over the English reading impaired children, and that the word–nonword difference was smaller in German dyslexic children than for their English counterparts. This orthography dependent lexicality effect appeared to differ with item length. In English children with dyslexia the word-nonword difference was particularly pronounced for one-syllable items, with fairly fast reading times for words but very slow reading times for nonwords. This trend was persistent in comparison with reading level controls: English dyslexic children read one-syllable words faster while for the corresponding nonwords they were slower. The German children with dyslexia, on the other hand, showed a lexicality effect that was fairly consistent across all item lengths. Compared to younger reading-level controls they showed very similar reading times for words, but performed worse on nonwords. Ziegler et al. (2003 a) found that words were read much faster than nonwords. This finding persisted in both languages even in the comparison with younger reading level controls. However, Ziegler et al. did not find a triple interaction between effects of lexicality, reader group, and language. This finding led the authors to

conclude that dyslexic children in both languages show large deficits in nonword reading speed, and, contrary to the conclusion of Landerl et al., that the size of the nonword reading deficit did not differ across orthographies.

By comparing words (collapsed across frequency and regularity) with nonwords (collapsed across phonological complexity) the present study addressed the question of whether a lexicality effect could be found in Norwegian, and whether there was difference in the magnitude of the lexicality effect between reading impaired children and control groups.

The 'granularity effect'

The 'granularity effect' is indicated by a difference in the grain size of lexical representations and accompanying differences in reading strategies in response to orthographic constraints. That is, children acquiring transparent orthographies (such as German) appear to rely heavily on grapheme-phoneme decoding strategies whereas children acquiring non-transparent orthographies (such as English) appear to use a variety of decoding strategies (including whole-word recognition).

A cross-linguistic study conducted by Goswami, Ziegler, Dalton, and Schneider (2001) compared the size of the 'pseudohomophone effect' in German and English children. Two different pseudohomophone tasks were used: reading aloud and lexical decision. In the reading aloud task, English children showed a significant advantage in naming pseudohomophones compared to orthographic control nonwords, whereas German children did not. In the lexical decision task, in contrast, German children showed a significant pseudohomophone effect over orthographic control nonwords, whereas English children did not. In a later study, Goswami, Ziegler, Dalton, and Schneider (2003) carried out a cross-language blocking experiment using nonwords that could only be read using small-grain grapheme-phoneme correspondences (small-unit nonwords) and phonologically identical nonwords that could be decoded using larger correspondences (large-unit nonwords). The

small-unit and large-unit nonwords were either presented mixed together in the same list or blocked by unit size. Results showed that English children, but not German children, showed blocking effects. Goswami et al. suggested that in mixed lists, English readers had to switch back and forth between small-unit and large-unit processing, resulting in switching costs. Taken together, the results from the two studies were interpreted in terms of the levels of orthography and phonology that underlie the reading procedures being developed by children who are learning to read orthographies with differential transparency.

Given that grapheme-phoneme correspondences are fairly consistent in the Norwegian orthography, Norwegian children should presumably show a 'small grain-size effect', i.e. they should rely more heavily on grapheme-phoneme recoding strategies than on the application of orthographic patterns at a larger grain-size. This hypothesis was examined by means of nonwords varying in orthographic and phonological complexity, because nonwords omit the problem of frequency. The present study addressed two main questions. Firstly, do Norwegian children demonstrate a 'small grain-size effect', i.e. do they show advantages for grapheme-phoneme recoding strategies than application of orthographic patterns at a larger grain-size? Secondly, do reading impaired and control groups employ different grain size units in phonological decoding?

Method

Participants

The children with dyslexia were drawn from the Oslo Longitudinal Study of Dyslexia, which had followed children born at familial risk for dyslexia from age 2 years through third grade (for more details, see Hagtvet et al., 1998). A follow-up assessment was conducted when these children were in fifth grade, with an average age 10 years 7 months old. To qualify for the follow-up study, the children should have attained an IQ score of 85 or above on the Wechsler Preschool and Primary Scale of Intelligence (WPPSI) at age 5 years, and

they should not have shown any history of auditory, visual, neurological, or emotional problems that could impede their ability to learn to read. Those children that exhibited a performance below –1 SD on a composite score across three subtests (i.e., the word recognition, the orthographic choice, and the pseudohomophone selection tasks) on the Standardized Test of Decoding and Spelling (Klinkenberg & Skaar, 2002), and exhibited a reading speed of less than 80 words per minute despite good reading comprehension (i.e. less than 20% comprehension errors) on the Carlsten test of connected text (Carlsten, 2002) were diagnosed as reading impaired. Sixteen out of forty-eight children met these selection criteria and were drawn to the present study.

Sixty-four control children from schools in the Oslo area, for whom parental consent was obtained, took part in the study. The control children were monolingual native speakers of Norwegian and were rated by their teachers as being normal readers of average general ability. Thirty-two children from Grade 5 were selected as age-matched controls, whereas thirty-two children from Grade 3 were selected as reading-level controls. The reading-level control children were matched for irregular word reading. This choice of matching procedure was influenced by the argument put forward by Rack et al. (1992), that (low-frequency) regular words essentially are nonwords, and that the chances of finding a nonword deficit in the dyslexic group will be reduced if the children with dyslexia can read regular words at a similar level as the control group.

In Norway, children enter school in August of the year they turn six years. However, children do not receive formal reading instruction before Grade 2, i.e. the year they turn seven years. As in most other transparent orthographies, reading instruction in Norway is typically carried out with emphasis on phonics instruction the first year. The cross-linguistic study carried out by Seymour et al. (2003) confirms that Norwegian children become accurate and fluent in foundation level reading before the end of the first year of reading instruction.

Table 1 shows characteristics of the three reader groups and the performance on the assessment battery used to diagnose dyslexia. The distributions of scores on all variables were approximately normally distributed.

Please insert Table 1 here

Design and material

Seidenberg, Petersen, MacDonald, and Plaut (1996) point out that the extent to which effects of a given factor can be assessed depends on how well other potentially confounding factors are controlled. The stimuli used in the present study were selected from the STAS battery (abbr. for Standardisert Test i Avkoding og Staving; English translation: Standardized Test in Decoding and Spelling) devised by Klinkenberg and Skaar (2001). All stimuli are presented in isolation and it was therefore not possible to guess the words from the context. All conditions were assessed by time-restricted reading-aloud tasks of words and nonwords presented in continuous lists. The time restriction for each list was 40 seconds, and the child was instructed to read as quickly and accurately as possible. The score on each list was the number of words or nonwords read correctly in 40 seconds.

Single-word reading. Each child read four lists of single-words that were grouped into the following conditions: high-frequency regular words, high-frequency irregular words, low-frequency regular words, and low-frequency irregular words. The words across each list were matched for number of letters, syllables, and for consonant clusters in same position and were thus matched for length and complexity.

Nonword decoding. Nonword decoding omits the problems of defining regularity (Rack et al., 1992) and was for the present purpose used as an index of phonological reading skills. The nonwords were grouped into three conditions in terms of phonological structure

and complexity, all comprising monosyllabic nonwords formed from the structures CV, VC, CVC and CVCC, and bisyllabic nonwords using the structures CVCV and CCVCV.

The first block of nonwords is created from "uncommon" or "unfamiliar" letter sequences and syllables, and is assumed to tap skills in sound blending of simple grapheme-phoneme correspondences, i.e. units at a small grain size. These nonwords could only be read by assembling grapheme-phoneme correspondences, because they had no orthographic rime neighbours. It is important to note, however, that the nonwords did not violate rules of Norwegian orthography. The second block contained nonwords with "commonly" and "regularly" spelled syllables, and was used to assess phonological decoding of units at a large grain size. The third block consisted of nonwords constructed from "commonly" but "irregularly" spelled syllables, onsets and orthographic clusters encouraging a large-unit reading strategy. To read these nonwords correctly, the children had to be familiar with orthographic rules. Here, it is important to note that the nonwords in the second and third blocks have little similarity to existing Norwegian words although they were created from common syllables or letter clusters.

General procedure

The children with dyslexia came to the laboratory at the University of Oslo and were tested in a 3-hour session, including breaks as required. The control children were tested on a shorter test battery, lasting about 1 hour, in a quiet room at their school. All children were tested individually.

The word and nonword reading tests were preceded with practice items to familiarize the child with task demands. Reading was audio taped for later analyses.

Results

The number of words and nonwords read correctly within the time limit are shown in Table 2 for all three groups. The research questions were addressed by using mixed analyses

of variance (mixed ANOVAs) with Reader Group (children with dyslexia vs. CA- vs. RL-controls) as the between-group factor, and Regularity (low-frequency regular vs. low-frequency irregular words), Frequency (high-frequency regular vs. high-frequency irregular words), Lexicality (word reading vs. nonword decoding; nonwords vs. irregular words), and Granularity (psycholinguistic units at different size) as within-group factors. The presentation of the analyses is organized according to the theoretical questions described earlier.

Please insert Table 2 here

Regularity and Frequency Effects

One aim of this study was to investigate whether the effects of regularity and frequency could be observed on single-word reading in the three Norwegian reader groups, and, if so, a further aim was to investigate whether the magnitude of these effects were the same for children with dyslexia as for the normally achieving children.

The data in Table 2 indicate that all three groups exhibited a similar pattern of single-word reading with more high-frequency than low-frequency words being read correctly within the time limit in all groups.

The data were subjected to an ANOVA in which Reader group, Regularity, and Frequency were variables, followed by pairwise contrasts (with Bonferroni correction). This showed a main effect of Reader group, $F(2, 77) = 27.94$, p < .0005, $\eta^2 = .421$, and a significant main effect of Frequency, $F(1, 77) = 532.18$, p < .0005, $\eta^2 = .874$. The main effect of Regularity was not significant, however, $F(1, 77) = 3.78$, p = .056, $\eta^2 = .047$. The planned contrast testing the interaction between Reader group and Regularity was not significant, $F(2, 77) = 0.35$, p = .956, $\eta^2 = .001$, whereas the interaction between Reader group and Frequency reached significance, $F(2, 77)\ 3.57$, p = .033, $\eta^2 = .047$. The interaction effect between

Regularity and Frequency was highly significant, however, $F(1, 77) = 72.10$, p < .0005, $\eta^2 =$ .484. Also, the triple interaction between Regularity, Frequency, and Reader group reached significance, $F(2, 77) = 4.83$, p < .05, $\eta^2 = .111$.

Pairwise comparisons adjusted for Bonferroni showed that low-frequency regular words were read significantly faster and more accurately (at the .001 level) than low-frequency irregular words. In contrast, there were no significant differences between high-frequency regular and high-frequency irregular words. Further, pairwise comparisons showed that there were significant differences between CA controls and both other reader groups, but not between children with dyslexia and RL controls.

In summary, the present analyses found clear main effects of Reader group and Frequency, but not of Regularity. Interaction effects were found between Reader group and Frequency, and between Regularity and Frequency, but not between Reader group and Regularity. Taken together, the present findings suggest that all three groups demonstrated greater effects of word frequency than of word regularity. A regularity effect was found only for low-frequency words, and this effect was similar in size in all three reader groups.

Lexicality effect

The present study further addressed the question of whether a Lexicality effect could be found in Norwegian, and if so, whether there was difference in the magnitude of the lexicality effect between reading impaired children and control groups. The size of the lexicality effect was estimated by comparing the difference between word and nonword reading across the three reader groups. The words were collapsed across frequency and regularity to get an estimate of word recognition, whereas nonwords were collapsed across phonological complexity to get an estimate of nonword decoding. However, to weight for the unequal number of items within the two blocks (i.e., there were four word lists and only three

nonword lists) the raw scores were divided by the number of lists to get an estimate of the average number of correctly read items within each block.

A univariate ANOVA indicated a significant effect of Lexicality, F (2, 77) = 24.96, p < .0005, η^2 = .393, suggesting that words were read faster and more accurately than nonwords. Paired samples t tests confirmed that there were significant differences between lexical and non-lexical items within the dyslexic reader group, t (15) = 10.13, p < .0005, within CA controls, t (31) = 13.63, p < .0005, and within RL control group, t (31) = 10.79, p < .0005. Pairwise comparisons adjusted for Bonferroni showed that there were significant group differences in this lexicality effect: CA-controls differed significantly from both other reader groups (both pairwise comparisons yielded p < .0005), but no differences were found between children with dyslexia and RL-controls (p = 1). Thus, the present study found a robust lexicality effect in both dyslexic and normal readers. However, data showed that the magnitude of this lexicality differed by reader group, with CA controls exhibiting a stronger lexicality effect than children at a lower reading level. The magnitude of the lexicality effect did not differ between children with dyslexia and the younger reading-level controls.

Arguably, comparing performance on irregular words and nonwords is probably an even more sensitive test for differential use of phonological reading strategies and sight word recognition, and for the assessment of a nonword reading deficit (Rack et al., 1992). Therefore, an additional comparison of irregular words with nonwords was carried out. Here, too, raw scores were divided by the number of lists to get an estimate of the average number of correctly read items within each block (i.e., there were two lists of irregular words and three lists of nonwords).

A repeated measures ANOVA indicated a significant effect of irregular vs. nonword difference, F (1, 77) = 274.51, p < .0005, η^2 = .781, and a significant effect of Group, F (2, 77) = 24.88, p < .0005, η^2 = .393. Accordingly, paired-samples t tests showed that nonwords

were read significantly less well than irregular words in the dyslexic group, t (15) = 8.38, p <

.0005, in the RL control group, t (31) = 9.81, p < .0005, and in the CA control group, t (32) =

13.15, p < .0005. The ANOVA further showed a significant interaction between the irregular

word–nonword difference and Reader Group, F (2, 77) = 22.99, p < .0005, η^2 = .374. Pairwise

comparisons employing the Bonferroni post-hoc test showed significant group differences

between CA-controls and both other reader groups (ps < .0005), but not between the dyslexic

group and RL-controls (p = 1). Thus, the present data showed that nonword decoding was

poorer than irregular word recognition in all reader groups, but that dyslexic readers did not

exhibit a greater difference between nonwords and irregular words than RL controls.

Notwithstanding, there were significant group differences with respect to nonword

decoding, F (2, 77) = 15.18, p < .0005, η^2 = .283. Pairwise comparisons adjusted for

Bonferroni showed that the mean difference between children with dyslexia and RL-controls

was significant (p = .004). This clearly shows that the Norwegian children with dyslexia

performed significantly less well than RL controls on nonword decoding tasks, despite being

matched for irregular word reading.

Granularity effect

In a further attempt to identify which psycholinguistic markers influence decoding in

the three Norwegian reader groups the following two questions were asked: First, do the

present children demonstrate a 'small grain-size effect', i.e. do they show advantages for

grapheme-phoneme recoding strategies compared to application of orthographic patterns at a

larger grain-size? Second, do reading impaired children prefer other grain-size units than

either control groups of normal readers? The granularity effect was examined by means of

nonwords varying in phonological grain size.

As mentioned earlier, one list of nonwords was created from "unfamiliar" but

"regularly spelled" letter sequences and syllables, and was assumed to tap skills in sound

blending of simple grapheme-phoneme correspondences, i.e. units at a small grain size, as they could only be read by assembling grapheme-phoneme correspondences. A second list contained nonwords with "familiar" and "regularly" spelled syllables, and was used to assess phonological decoding of units at a large grain size. A third list consisted of nonwords constructed from "commonly" but "irregularly" spelled syllables, onsets and orthographic clusters encouraging a large-unit reading strategy.

Visual examination of Table 2 suggests that all reader groups exhibited a similar pattern of performance on the nonword subtests. That is, irrespective of reader group, children obtained overall highest scores on the subtest containing nonwords with visually familiar and regular spellings.

A repeated measures ANOVA showed a main effect of nonword type, suggesting that mean scores for the three nonword subtests differed significantly, $F(2, 154) = 64.56$, p < .0005, $\eta^2 = .456$. Bonferroni pairwise comparisons for the within-subjects factor found a significant difference between the "regularly" spelled nonwords compared to both the "unfamiliarly" spelled and the "irregularly" spelled nonwords, whereas the difference between the two latter subtests was not significant (p > 1). Further, the main effect of Reader Group was significant, $F(2, 77) = 15.95$, p < .0005, $\eta^2 = .293$. Bonferroni pairwise comparisons for the between-subjects factor found a significant difference between the dyslexic reader group and CA-controls (p <.0005) and RL-controls (p <.004), and between CA and RL-controls (p = .020). However, the interaction between Reader group and Nonword Type was nonsignificant, $F(4, 77) = 1.96$, p < .104, $\eta^2 = .048$ confirming that all three groups exhibited a similar pattern of performance on the different nonword subtests.

Thus, contrary to the predictions by Ziegler and Goswami (2005), the data suggest that, independent of reader group, the present Norwegian children showed processing

advantages for nonwords representing familiar patterns with regularly spelled syllables encouraging reading at a large-unit grain size.

Discussion

The present study assessed the effects of regularity, frequency, lexicality, and granularity on word recognition and phonological decoding, as indexed by the accuracy and speed of reading in Norwegian children with dyslexia compared to normally reading control children. Given that Norwegian has a fairly transparent orthography, a further aim was to explore whether Norwegian children with dyslexia and control children matched on age and reading level would exhibit similar reading profiles as those described in the literature for English and German children.

Regularity and frequency effects

The study assessed whether regular words would be read more easily than irregular words and whether such an effect would differ in size between the three reader groups. A regularity effect was found only for low-frequency words; it was similar in size in all three reader groups. These results are consistent with the meta-analytic review by Metsala et al. (1998), which found a clear effect of word regularity for English-speaking individuals with dyslexia, the magnitude of which did not differ from the word regularity effect for reading level controls.

In a recent study, Ziegler, Perry, and Coltheart (2003 b) investigated the regularity effect in skilled French readers. Because French has more regular spelling-to-sound correspondences than English, the findings are interesting for the case of Norwegian. The study found a regularity effect both high- and low-frequency words in skilled French readers. Thus, the present findings from Norwegian are not consistent with the findings in French. Ziegler et al. (2003 b) suggest that the failure to find an interaction between frequency and regularity in French reflect fundamental differences in terms of lexical and non-lexical

processing speeds between languages, and that the more regular spelling-to-sound mappings seems to allow French readers to rely more heavily on non-lexical spelling-to-sound conversion. The price to pay for the stronger reliance on non-lexical processes, Ziegler et al. maintain, are quite large regularity effects for both high- and low-frequency words. However, according to the evaluation by Seymour, Aro, and Erskine et al. (2003), Norwegian is considered to have an even more transparent orthography than French. The present findings therefore appear to contradict the hypothesis put forward by Ziegler et al. (2003 b), at least for children who are still learning to read.

An elaborated version of the connectionist version of the frequency–consistency equation provides a basis for understanding the effects of semantics on naming performance (Plaut et al., 1996). That is, a stronger semantic contribution moves the overall input further along the asymptotic activation function, thereby diminishing the effects of other factors. As a result, words with a relatively weak semantic contribution exhibit a stronger frequency by consistency interaction. Plaut et al. (1996) further maintain that the combined effects of frequency and consistency in the connectionist account, together with the assumptions about the contributions of semantics, leads to the prediction that frequency and consistency can trade off against each other, so that the detrimental effects of spelling-sound inconsistency can always be overcome by sufficiently high word frequency. This connectionist account seem to capture the present finding that, irrespective of reader group, the overall best performance on single-word reading was obtained on high-frequency irregular words. It could be argued that the words in the high-frequency irregular list is more concrete (less abstract) and thus yield a stronger semantic contribution than any of the other lists.

Lexicality effect

A further aim of the study was to examine whether the children demonstrated better performance on words (collapsed across frequency and regularity) compared with nonwords

(collapsed across phonological complexity), and whether there was a difference in the magnitude of the lexicality effect between children with dyslexia and the control groups. The present study found a robust lexicality effect in both dyslexic and normal readers. However, data showed that the magnitude of this lexicality differed by reader group, with CA controls exhibiting a stronger lexicality effect than children with dyslexia and younger normally achieving readers (who did not differ). Olofsson (2003) reported a study in which the development of phonological and orthographic word decoding skill in eight cohorts of normal Swedish readers was studied. The Swedish data showed that, whereas phonological word decoding seemed to reach its asymptotic level by the end of primary school, orthographic decoding speed seemed to continue to develop into adulthood. The present results might reflect a similar trend, implying that the CA control group was proficient in phonological decoding but were about to extend their orthographic skills beyond the level of phonological skills. The finding that the less mature readers (i.e., both dyslexic readers and RL controls) also demonstrated a lexicality effect can be taken to imply that they benefit from semantic information, which is not provided in nonwords. An experiment conducted by Laing and Hulme (1999) demonstrated that semantic knowledge of a word does influence the ease with which it is learned by children in the early stages of reading development.

The present study included a comparison of irregular words and nonwords to get an even more sensitive estimate of the difference in word recognition skills and phonological decoding. Evidence for a phonological decoding deficit in dyslexia typically relies on finding that children with dyslexia exhibit a greater gap between (irregular) word reading and nonword reading than younger reading-level-matched control children. The present data failed to find a greater gap between performance on irregular words and nonwords in the dyslexic children than in RL controls. However, the results clearly showed that children with dyslexia were outperformed by their RL controls on nonword decoding. The present study thus yield

strong evidence for a phonological decoding deficit in the present Norwegian children with dyslexia. This finding is consistent with the many findings from both the opaque English language (e.g. Rack et al. 1992; Bruck, 1990) and in the far more transparent orthographies of German (Wimmer, 1996) and Dutch (de Jong, 2003).

Griffiths and Snowling (2002) examined predictors of exception (irregular) and nonword reading in English dyslexic children by employing multiple regression methods. They found that two measures of phonological skills predicted unique variance in nonword reading: phonological processing and verbal short-term memory skills. The only unique predictor of exception word reading, in contrast, was reading experience. Griffiths and Snowling hypothesized that the extent of the nonword reading deficit in dyslexia is determined by the underlying phonological impairment. Similarly, a still unpublished longitudinal study of the present group of children with dyslexia shows that impairments in preschool phoneme awareness predicted impairments in regular word decoding.

Granularity effect

The granularity effect was examined by comparing the efficiency of reading nonwords that varied in phonological complexity. On the grounds of the Grain Size Theory it was hypothesized that Norwegian children would show advantages for small grain-size units. More specifically, it was expected that the children in the present study should rely more heavily on direct grapheme-phoneme recoding strategies than on the application of orthographic patterns at a larger grain-size. However, results showed that all reader groups showed advantages for nonwords consisting of familiar orthographic patterns which, according to the theory by Ziegler and Goswami (2005), encourage application of a large grain size recoding strategy.

A counter argument is that the present conclusion is based on absolute processing differences between different groups of items (i.e., "uncommon", "common, regular", and

"common, irregular"). In the Ziegler et al. study (2003), in contrast, identical items were presented in both blocked lists and mixed lists. Blocking seemed to help the English readers, whereas German readers did not show such blocking effects. The results were taken as evidence for the flexible unit size hypothesis, suggesting that the choice of reading units in English children is flexible and adaptive. The present data also suggest a blocking effect across the tree reader groups. However, because the study did not incorporate mixed lists of large-unit nonwords and small-units nonwords, the present study cannot rule out the possibility that children reported here did *not* show blocking effects and thus would provide evidence for a reliance on general and efficient processing at a small-unit level.

As described above, a peculiar characteristic of the Norwegian language is that semantic information is signalled by vowel length duration in speech. In the orthography vowel duration is signalled by the subsequent consonants (i.e., a long vowel is followed by a single consonant whereas short vowel pronunciation is followed by two identical consonants). It could be the case that vowel length categorization in reading encourages Norwegian children to rely on both small unit and large unit sublexical recoding strategies in parallel. If this hypothesis is correct, it can easily explain why the present children did not show processing advantages for small-unit nonwords, despite the fairly consistent mappings between Norwegian phonology and orthography.

Conclusions

A main goal of the present study was to examine the ways in which psycholinguistic marker effects of regularity, frequency, lexicality, and grain size-units influence performance on single-word recognition and phonological decoding in Norwegian children with dyslexia compared to normally reading children matched for age and reading level. Taken together, the reading impaired children showed a pattern of psycholinguistic marker effects that were normal for the reading level they had reached. However, a nonword reading deficit was found.

Comparisons of nonword processing showed that, although dyslexic readers demonstrated similar processing advantages for nonwords representing familiar phonological and orthographic patterns, they did so significantly more poorly than RL controls. The present findings thus strongly suggest that a deficit in phonological decoding is associated with impairments in the development of sight word recognition in Norwegian.

Many important issues within reading research and dyslexia research are still left unanswered. In future, efforts should be made to gain deeper insight into the processes underlying reading and reading impairments across orthographies. For example, by considering psycholinguistic marker effects underlying reading in Norwegian and Finnish in comparison with languages in which semantic information is *not* signalled by vowel length duration, it is possible to address the issue of whether different orthographies and language-specific marker effects require different cognitive processing skills during reading.

Acknowledgements

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Table 1.

Characteristics of children with dyslexia, chronological-age controls and reading-level controls

	Age	STAS Composite[1]	STAS Irregular words[2]	Carlsten speed[3]	Carlsten comprehension[4]
Dyslexics (N = 16)					
Mean	10;7	83.50	33.50	55.75	1.19
SD	0.58	24.44	7.52	17.86	1.62
Range	9;9-10;9	50-133	14-46	24-80	0-6
CA-controls (N = 32)					
Mean	10;7	124.53	51.59	127.78	1.37
SD	0.54	33.97	11.62	32.46	2.07
Range	10;0-10;9	67-197	31-71	84-203	0-9
RL-controls (N =32)					
Mean	8;4	65.63	35.50	82.78	0.09
SD	0.31	20.32	8.66	26.15	0.30
Range	8;1-9;0	31-120	17-53	35-126	0-1

Note. [1] STAS composite score across one word recognition, one orthographic choice, and one pseudohomophone task; [2] Irregular naming task by which reading-level control children were selected; [3] words per minute; [4] number of errors (max = 25)

Table 2.

Mean performance (and SDs) of children with dyslexia, reading-level controls and chronological-age controls on core assessment battery[1]

	Dyslexic (n = 16)	RL-controls (n = 32)	CA-controls (n = 32)
Words			
High-frequency Regular	30.6 (6.0)	34.7 (8.5)	48.7 (12.7)
Low-frequency Regular	23.2 (5.1)	27.4 (8.0)	41.3 (12.1)
High-frequency Irregular	33.5 (7.5)	35.5 (8.7)	51.6 (11.6)
Low-frequency Irregular	18.9 (4.8)	24.9 (7.1)	36.3 (11.9)
Total words	106.2 (20.88)	122.5 (29.8)	177.7 (46.5)
Nonwords			
"Uncommon spellings"	14.9 (4.2)	19.1 (4.9)	21.7 (6.3)
"Common spellings"	19.2 (5.3)	25.7 (5.5)	30.4 (7.9)
"Irregular spellings"	14.9 (4.6)	20.5 (7.4)	24.2 (5.5)
Total nonwords	49.0 (13.0)	65.2 (15.8)	75.9 (17.5)

Note. [1] Items read correctly within time restrictions