DIFFERENCES IN PHONOLOGICAL ENCODING BETWEEN CHILDREN WITH DYSLEXIA AND NORMAL READERS

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ABSTRACT: Twenty four dyslexic children (aged 7;7 to 12;1) and 24 age-matched controls named pictures aloud as rapidly as they could while hearing sound segments that were either phonologically related to (i.e., part of) the target picture name or unrelated. Dyslexics had slower RTs and, for low frequency items, the degree of facilitation of phonologically related segments relative to unrelated segments was greater for dyslexics than for controls. Similarly, within the dyslexic group, phonological facilitation was greater for worse compared to better readers. The results suggest that children with dyslexia are less efficient in accessing and/or retrieving phonological information during picture naming, and that hearing part of the target word facilitates this process. The findings are consistent with the hypothesis that dyslexia can arise from poorly specified output phonological representations. An auditory lexical decision task failed to show a difference between the dyslexic and normally developing children. This suggests relatively normal access to input phonological representations for the dyslexic children, and that the phonological representation deficit is therefore specific to speech output.

INTRODUCTION

In the search for possible causes of developmental dyslexia many studies have shown impaired or reduced performance by dyslexic children compared to matched controls on a number of tasks demanding facility in the use of phonological structures (Catts, 1989; Snowling, 1981; Wolf, Michel & Ovrut, 1990). The implication has been drawn that a deficit in phonological processing underlies the poor acquisition of reading skills in many children with dyslexia. The hypothesised phonological deficit may be associated phonological codes required for speech perception, the ability to maintain and manipulate phonological codes in working memory, and/or the use of phonological codes in speech production (Rack, Snowling & Olson, 1992). A number of researchers have converged on the proposition that the phonological deficit is linked with problems in the formation and/or retrieval of phonological representations used for speech production (e.g., Catts, 1989; Elbro, 1998; Griffiths & Snowling, 2001; Swan & Goswami, 1997). A deficit at the level of output phonology is also important in modelling phonological dyslexia in connectionist models (e.g., Harm & Seidenberg, 1999).

The output phonology deficit hypothesis is supported principally by finding dyslexics perform worse than normal readers on a range of naming tasks that require access to output phonological representations. Dyslexics have, for example, been shown to be slower and/or less accurate in word and non-word naming with access via orthographic codes (e.g., Rack et al., 1992), and picture naming with access via object representations and semantic codes (e.g., Swan & Goswami, 1997). However, not all studies report differences in speeded naming when accessing output representations via non-orthographic sources. Hennessey and Kirsner (in preparation) found that dyslexic readers were slower at naming written words but not pictures. Further, differences in naming speed may arise because of an impairment in some other system or component process involved in naming such as semantic activation, visual (e.g., orthographic) processing, and speech motor control.

In addition, little research has investigated the manner in which output phonological representations are impaired in dyslexia. These representations have been variously described as coarse, less segmented, poorly specified, and lacking in sublexical detail (e.g., Brown, 1997; Catts, 1989; Elbro, 1998; Manis, Seidenberg, Doi, McBride & Peterssen, 1996). Elbro (1998), for example, suggests that dyslexic readers have less distinct output phonological representations compared to normal readers. Distinctness is the degree to which lexical representations represent their unique phonological qualities. Indistinct codes are more confusable and limit the "ease of access to sublexical phonological units of the representation" (Elbro, 1998, p. 152). Support for this proposition is found in distinctiveness ratings where dyslexics demonstrate a greater incidence of vowel reduction or elimination. This evidence is limited, however, in that differences in speech motor control rather than the phonological detail that feeds into the articulatory system may be confounding performance.
The present study employed an auditory segment interference task, modelled on picture-word interference tasks (e.g., Schriefers, Meyer & Levelt, 1990), to compare dyslexic readers with age-matched normal readers on effects linked directly with the activation of phonological codes during speech production. The research, therefore, provides a more direct test of the output phonology deficit hypothesis than that provided by overall speed measures of naming. In this task, children name pictures under speeded instructions but at the same time hear sound segments that are either phonologically related to (i.e., part of) the target picture name or unrelated. The sound segments are rhyming portions that, in the related condition, overlap with the target name at offset only. It is assumed that obligatory processing of the auditory input interacts with phonological encoding of the picture name prior to articulation (cf. Schriefers et al., 1990). When sound segments are consistent with the picture name, phonological retrieval will be facilitated and RTs faster relative to when segments are inconsistent. This may be accounted for by the auditory input also activating part of the phonological code corresponding to the picture name. Further, unrelated sound segments are expected to interfere with phonological encoding and delay responding relative to no sound through activating inappropriate phonological codes that compete with the target. Consistent with these expectations a number of studies have demonstrated phonological facilitation and interference during picture naming when the interfering stimuli are related and unrelated spoken words (e.g., Brooks & MacWhinney, 2000; Meyer & Schriefers, 1991; Schriefers et al., 1990).

One consequence of phonological representations being indistinct or poorly specified in children with dyslexia is that phonological encoding is likely to be slower and less efficient. Using an activation framework of name retrieval (e.g., Harm & Seidenberg, 1999), increased time to activate target phonology may arise because of greater competition among alternative phonological codes. Dyslexic children should show greater amounts of interference from hearing sound segments unrelated to the target picture name. Significantly greater facilitation from external sound cues is also expected. It is possible that dyslexic children have difficulty retrieving information at earlier levels of processing such as activating the correct semantic concept (Levelt, 1989). For this reason rhyme portions of each target were used as interfering stimuli rather than whole words. It was hypothesised that phonological facilitation is more likely to be located at the level of activating sub-lexical phonology, which is the level of deficit according to the output phonology deficit hypothesis.

**METHOD**

**Participants**

Table 1. Age, Reading Ability, Performance IQ, and Receptive and Expressive Language Test Scores for Dyslexic and Normal Readers.

<table>
<thead>
<tr>
<th></th>
<th>Dyslexics</th>
<th>Normal Readers</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>M</strong></td>
<td><strong>Range</strong></td>
<td><strong>M</strong></td>
</tr>
<tr>
<td>Age (months)</td>
<td>115</td>
<td>92-145</td>
</tr>
<tr>
<td>Woodcock</td>
<td>71</td>
<td>53-84</td>
</tr>
<tr>
<td>WISC-3 - Perf IQ</td>
<td>99</td>
<td>85-115</td>
</tr>
<tr>
<td>CELF - Expressive</td>
<td>5</td>
<td>3-8</td>
</tr>
<tr>
<td>CELF - Receptive</td>
<td>7</td>
<td>4-11</td>
</tr>
</tbody>
</table>

Note. Woodcock test scores and WISC-3 performance IQ are standard scores (M = 100); CELF scores are standard scores (M = 10, SD = 3).

Twenty four children (17 males & 7 females) aged between 7;8 and 12;1 years, were classified as dyslexic on the basis of at least an 18 month lag between reading age (based on the short form of the Woodcock Reading Mastery Test – 3rd edition), and chronological age. These children were recruited through two Language Development Centres and a reading clinic in the Perth Metropolitan area. As shown in Table 1, all dyslexic children had normal performance IQ. The dyslexics, as a group, also showed poor expressive and receptive language ability (based on the formulated sentences subtest, for expressive, and concepts and directions subtest, for receptive, from the Clinical Evaluation of Language Fundamentals – 3rd edition). Children with a known neurological condition, or diagnosed with dyspraxia or severe phonological disorder, were not included in the study. Twenty four age-
matched normal readers (10 males & 14 females) were recruited from a primary school local to one of the LDCs. Normal readers were reading at age-level and showed normal IQ and language ability.

Stimulus materials

Twenty black and white photographs of everyday objects were digitised for use in the study; 10 pictures had low frequency object names (M = 8 occurrences per million, Kucera & Francis, 1967), and 10 had high frequency names (M = 160 occurrences per million). At each level of frequency five names were 1 syllable and five were 2 syllable in length. Sound segments, consisting of rhyme portions matched to the final part of each picture name (e.g., “oom” for mushroom), were spoken in isolation and digitally recorded at a sampling frequency of 22050 Hz.

Procedure

PsyScope experimental software was used to present stimuli and record naming RT to millisecond accuracy. All children correctly named each picture twice before starting the experiment. Auditory stimuli were presented through headphones and pictures remained on the screen until the vocal response was picked up via a microphone. Children were told to name each picture as quickly as possible and ignore the sounds. Sound segments were presented at one of two stimulus onset asynchronies (SOA): either 50 ms after picture presentation, or 200 ms after. In the related sound segment condition segments matched the target picture name. In the unrelated condition the same sound segments were used, but were paired up with non-matching picture names. A third “silence” condition was included where no sound was presented. Children named each picture under each condition. Trials formed two blocks, one with 50 ms SOA, and the other with 200 ms SOA (a silence condition was included in both blocks). The order of SOA was counterbalanced across participants. Within each block pictures were named three times, once for each sound segment condition. Trials were intermixed using a different random order for each child. At least two trials intervened between repetitions of the same picture. The allocation of a sound segment condition for a given picture to the first, second or third presentation was counterbalanced across children within each group. Errors in naming were identified on-line by the experimenter.

RESULTS

RT means were calculated after excluding errors (6.7% of trials) and RT outliers (3.1% of trials being more than 2 SD from the mean for each condition for each participant). One dyslexic child showed an extreme overall RT mean (4,215 ms) and a high error rate (16%) and was excluded from the analysis. A five-way analysis of variance, with group (dyslexic vs. normal), sound segment (related, unrelated and silence), SOA (50 vs. 200 ms), word frequency (low vs. high), and counterbalancing order as factors, was used to test for significant effects. Because of space limitations, only key findings are reported. See Figure 1 for the mean RT, split by word frequency, but collapsing across SOA, for each type of sound segment for each group. Dyslexic RTs (1,098 ms) were slower overall compared to normal children (849 ms), F(1,43) = 21.07, p < .05. Pictures with low frequency names took longer to name than pictures with high frequency names (985 ms vs. 962 ms), F(1,43) = 4.76, p < .05. While there was a significant main effect of sound segment, F(2,86) = 57.51, p < .05, there was also a significant two-way interaction between sound segment and group, F(2,86) = 3.61, p < .05, and a close to significant three-way interaction between sound segment, group and word frequency, F(2,86) = 3.02, p = .054. The four-way interaction between sound segment, group, word frequency and SOA was not significant, F  1, nor was the main effect of SOA, F  1.

The interaction between sound segment and group was examined separately for low and high frequency conditions. For high frequency items, the interaction was not significant, F  1 (although the main effect of sound segment was, F(2,86) = 30.65, p < .05). For low frequency items the interaction was significant, F(2,86) = 4.07, p < .05. Simple effect contrasts showed that for dyslexics the 328 ms difference between the unrelated (1,295 ms) and silence (967 ms) conditions was significant, F(1,42) = 37.92, p < .05, and the related condition (1,095) was 200 ms faster than the unrelated condition, F(1,42) = 14.07, p < .05. The same contrasts were also significant for the normal children: the unrelated condition (931 ms) was 172 ms slower than the silence condition (759 ms), F(1,44) = 40.46, p < .05, and the related condition (864 ms) was 67 ms slower than the unrelated condition, F(1,44) = 6.26, p < .05. Because both groups show significant interference and phonological facilitation, the two-way interaction for low frequency items appears to be due to the enhancement of these effects.
for the dyslexic children. This conclusion is supported by an analysis of phonological facilitation in terms of the ratio of the related to unrelated RT mean. The mean ratio is significantly lower for dyslexics (.86) than for normal children (.94), \( t(45) = 2.47, p < .05 \). An analysis of the interference effect in terms of the ratio of the unrelated condition mean to the silence condition mean showed that the unrelated mean is on average 1.32 times the silence mean for dyslexics, but 1.22 times the silence mean for the normal children. This difference was close to significant, \( t(45) = 1.93, p = .06 \). The ratio of the related RT mean to the silence RT mean was not significantly different between groups, \( t(45) = 0.18, p > .05 \).

![Figure 1. Mean picture naming reaction time (ms) for dyslexic and normal readers for related, unrelated and silence sound segment conditions for low and high frequency words.](image)

The error data revealed no significant overall group difference, \( F(1,43) = 3.24, p > .05 \), although there was a tendency for dyslexics to produce more errors (7.6% vs. 5.4%). The group by sound segment interaction was not significant, \( F < 1 \), but the main effect of sound segment was, \( F(2,86) = 7.29, p < .05 \). Contrast analysis show more errors occurred in the unrelated condition (8.0%) compared to both the related condition (5.9%), \( F(1,86) = 8.54, p < .05 \), and silence condition (5.5%), \( F(1,86) = 12.88, p < .05 \). The difference between the related and silence conditions was not significant. The word frequency main effect was significant in the error data, \( F(1,43) = 6.26, p < .05 \), with more errors occurring for high frequency items (7.3% vs. 5.7%). Word frequency, however, did interact with group, \( F(1,43) = 5.15, p < .05 \). Dyslexics produced similar error rates for low and high frequency items (7.5% vs. 7.6%, respectively), \( F < 1 \). It was the normal children who produced significantly fewer errors for low frequency compared to high frequency items (3.9% vs. 6.9%), \( F(1,22) = 9.47, p < .05 \). No other main effects or interactions were significant.

A post hoc analysis explored phonological facilitation and interference for better and worse dyslexic readers, defined according to a median split of the Woodcock standard scores. There was a significant interaction between reading ability group and sound segment. Phonological facilitation (related compared to unrelated) was 244 ms for the worse dyslexic readers, \( F(1,18) = 23.19, p < .05 \), and 75 ms for the better dyslexic readers, \( F(1,20) = 2.29, p > .05 \). The 355 ms interference effect (between unrelated and silence condition) was large and significant for worse readers, \( F(1,18) = 48.95, p < .05 \). For better readers the 201 ms interference effect was smaller and significant, \( F(1,20) = 16.49, p < .05 \). Independent groups t-tests comparing the two dyslexic reading groups on WISC–3 scores, CELF subtest scores, and chronological age, failed to show any significant differences.

The children also completed an auditory lexical decision task as part of another research project. Two conditions involved presenting words repeated from an earlier speech production task. For the present purposes, the results from a condition using non-repeated items are most relevant (the items were 25 picture names). Mean RT for words was 1,291 ms for dyslexic children and 1,236 ms for
normal readers, but this difference is not significant, $F < 1$. Mean RT for non-words was 1,481 ms for dyslexics and 1,408 ms for normal children, also a non-significant difference, $t(45) = 1.15, p > .05$.

**DISCUSSION**

The children with dyslexia had longer picture naming RTs overall and enhanced facilitation from hearing related sound segments in comparison to age-matched normal readers. Facilitation is observed relative to naming pictures when the interfering sound segment is unrelated to the picture name. The size of the facilitation effect is proportionally greater than that observed in normal readers, given that the ratio of the related to unrelated RT mean is significantly smaller for dyslexics. Interference of picture naming from presenting unrelated sounds (relative to the silence condition) is also enhanced relative to normal children. The fact that RTs in the silence condition were consistently shorter than both related and unrelated conditions, suggests interference is present to some degree regardless of whether the sound matches the target name or not. It is suggested that phonological facilitation occurs at the level of encoding output phonology during picture naming, and is not associated with earlier stages of semantic activation or lemma activation (Levelt, 1989). The sound segments were rhyme portions of the target name (not whole words) and as such are unlikely to support any name retrieval process prior to the activation of at least some phonological content.

The results support the output phonological deficit hypothesis of dyslexia. This hypothesis states that reading difficulties experienced by many children with dyslexia stem from output phonological representations that are deficient in some way (e.g., poorly specified, lacking in sub-lexical detail, or less distinctive). A deficit at the level of output phonology is confirmed by showing differences in an experimental manipulation that targets phonological encoding specifically. In doing so, the research overcomes limitations of previous findings where the locus the underlying deficit is less clear-cut (e.g., overall naming RTs are ambiguous as to the source of increased processing time). The link between deficits in output phonology and reading difficulty is further supported by finding that phonological interference and facilitation is greater in worse dyslexic readers than better dyslexic readers. Poor quality output phonological representations may impact on reading development because distinct phonemic segments are not available to form reliable spelling to sound associations (see, also, the Harm & Seidenberg, 1999, simulations).

The present research also provides some insight into the nature of the underlying representational deficit. The data for the dyslexic children suggests a representational system characterised by greater interference or competition among phonological units (and therefore more subject to disruption). This feature is also characteristic of a retrieval mechanism that is less well automated. In contrast, a normal representational system will be fluent or efficient and begin to take on the characteristics of an encapsulated process relatively impervious to external influences. The findings are also consistent with suggestions by Elbro (1998) that phonological representations are less distinct in children with dyslexia. Representational units less distinct from each other will be more confusable and open to competition and increased facilitation.

A number of researchers propose reading difficulties may stem from deficits in speech perception (Griffiths & Snowling, 2001). Furthermore, phonological representations accessed during speech perception and production are often assumed to be equivalent. This would suggest that difficulties accessing output phonology would be accompanied by poor performance on a speech recognition task. However, deficits in speech perception are not consistently found in children classified as dyslexic. Joanisse, Manis, Keating and Seidenberg (2000) showed that speech perception difficulties may be confined to dyslexic children with language problems, and that phonological processing difficulties (as indicated on a phonemic awareness task) can be found in dyslexics who show no difficulties in speech perception. In Griffiths and Snowling’s (2001) study, dyslexics were poor at rapid naming but no different from controls on a gating task that measures the amount of auditory input, beginning from word onset, needed to accurately identify spoken words. In the present study there is a clear difference between dyslexic and normal children in the speed of retrieving output phonology, but no corresponding clear difference in the speed of accessing input phonology. The results suggest that input and output phonological systems are distinct, and that reading disability may be related more specifically to deficits in output phonology (cf. Griffiths and Snowling, 2001).

The children in the present study were unselected in terms of sub-type of dyslexia (Castles & Coltheart, 1993; Manis et al., 1996), but they do show clear difficulties retrieving output phonology.
Because phonological processing difficulty is a feature of phonological dyslexia, it is likely that the dyslexics in this study are representative of phonological dyslexia. It would be of interest, therefore, to compare phonological facilitation and interference between children with phonological dyslexia and those with a reading delay or surface dyslexic profile. Because not all children with specific language impairment have reading difficulty, it would also be of interest to examine phonological facilitation and interference in these children. This will provide some evidence for the extent to which impaired output phonological representations are a necessary correlate of reading difficulty in this population.

REFERENCES


