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# Lexical processing of children with dyslexia: An eye-tracking adaptation of the Reicher-Wheeler task

## Summary

The aim of the study is to determine the relative influence of phonological and lexical knowledge on lexical processing of children with dyslexia. It is part of research of the role of phonotactics in lexical knowledge and dyslexia. The Reicher-Wheeler paradigm (Reicher, 1969; Wheeler, 1970) was adapted, and phonotactic probabilities in words (W), pseudowords (PW) and non-words (NW) were manipulated in a lexical superiority task. Both offline measures and online eye movements were recorded and analysed. The findings are discussed within the Dual-Route Model framework. The results suggest that: 1) predictably, unimpaired readers outperform children with dyslexia; 2) both groups appear not to predominately rely on lexical knowledge, whereas phonological knowledge seems to help processing only for controls; 3) phonotactic probability manipulations seem not to affect overall performance. The preliminary findings imply that dyslexia affects reading in all orthographic contexts and add further support to the findings that PW processing is particularly impeded in dyslexia (e.g.

Rack, Snowling, & Olson, 1992), despite the transparent orthography of the Croatian language. The study additionally highlights the importance of obtaining online measures in psycholinguistic studies with atypical population.

**Key words:** dyslexia, lexical processing, Reicher-Wheeler task, Dual-Route Model, eye movements

# 1. INTRODUCTION

Dyslexia is a learning difficulty with multiple facets, each of which depends on the properties of languages and their respective orthographic systems and on the inner strategies a person develops over time in order to cope with everyday situations. This combination of general, linguistic and individual factors makes it an impairment difficult to study and understand, resulting in a profusion of definitions and subcategories of dyslexia. It might arise from brain-related and genetic factors and a whole range of symptoms can be associated with it including, among others: impairments in processing speed, automatisation deficits, working memory difficulties, phonological deficits, comorbidities with other learning difficulties (Reid, 2016).

Studies on dyslexia have contributed to shaping theoretical models aiming at accounting for reading processes not only in impaired readers, but in typically developing population as well (e.g. Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001; McClelland & Rumelhart, 1981). The present work will mainly focus on the applications of the Dual-Route Model of reading (Coltheart et al., 2001) in understanding the pattern of impairments underlying word reading in children with dyslexia. It will focus on the comparison of impaired and typical readers, as well as on identifying the patterns of processing differences in terms of the type of information the two groups mainly rely on during lexical processing.

## 1.1. Lexical processing in unimpaired and impaired readers

Research on word processing has established the existence of word superiority effects in unimpaired readers. In other words, in this population, letters are easier to identify when presented in words (W) (Adams, 1979; Cattell, 1886; Ferraro & Chastain, 1997; Grainger & Jacobs, 1994) than in pseudowords (PW) and non-words (NW). The most widely used methodological approach to investigate this phenomenon remains the so-called *Reicher-Wheeler (R-W) paradigm* (Reicher, 1969; Wheeler, 1970). It assumes a forced choice task in which participants are asked to identify which of the two letters was present at a specific position in the previously presented stimulus. Subsequent studies proved that a pseudoword superiority effect could emerge in typically developing readers. In that case, participants are able to more easily identify letters presented in a pseudoword respecting the orthotactic constraints of the tested language than in non-words. Crucially, these effects are more limited than those of the word superiority effect (see Carr, Davidson, & Hawkins, 1978; Coch & Mitra, 2010; Jacobs & Grainger, 2005; McClelland & Johnston, 1977).

Studies including impaired readers have led to more controversial findings. Chase and Tallal (1990), for instance, found neither word nor pseudoword superiority effects in children with dyslexia. However, more recently, word superiority effects were observed in their reading behaviour. Grainger, Bouttevin, Truc, Bastien, and Ziegler (2003) tested children diagnosed as dyslexic that were identical to control children in terms of both reading and chronological age, as well as to a group of adult participants using the Reicher-Wheeler paradigm. Their results showed that all participants displayed the classic word superiority effect over non-words. Ziegler et al. (2008), working with the same paradigm, observed the same effect in response times, but not in accuracy.

As for pseudowords, much of the literature tends to prove that readers with dyslexia exhibit substantial difficulties processing them. For instance, Rack at al. (1992), in a review of studies using a reading level match design in investigating the pseudoword reading deficit in the dyslexic population, concluded that they suffer from significant impediments in reading pseudowords. Nevertheless, Grainger et al. (2003) observed a pseudoword superiority effect in impaired readers which paralleled that of unimpaired readers, even though the former, as expected, displayed difficulties pronouncing them.

Interestingly, Grainger et al. (2003) and Reilhac, Jucla, Iannuzzi, Valdois, and Démonet (2012) found that words and pseudowords led to the advantage of the same magnitude over non-words in the two groups of children, i.e. there was no word superiority effect as compared to pseudowords. In the group of adults (Grainger et al., 2003), on the contrary, both word and pseudoword superiority effects were found. The authors attributed this finding to the fact that children did not master a fully developed semantic lexicon at the time of testing. Thus, the advantage displayed on words and pseudowords over non-words was probably rooted in the phonological knowledge the children had of the orthotactic constraints of the tested language, i.e. words and pseudowords contained letter combinations of higher frequency than non-words.

## 1.2. Eye movement patterns and dyslexia

Online measurements might constitute a fertile tool in identifying less fluent and less automatic reading patterns impaired readers most likely suffer from. One could then expect other patterns of between-group differences to surface in online measurements such as eye-tracking.

Eye movement research on dyslexia has indeed proven useful in reflecting participants' processing problems in reading. Since 1970s, it has been repeatedly found that their fixations and regressions are longer and more frequent, while their saccades are shorter than in typically developing readers (e.g. Biscaldi, Fischer, & Aiple, 1994: but for a review see Rayner, 1998). These patterns are also observed in developing readers. However, with increasing age and with the automatisation of reading, their fixation durations decrease and their saccade length increases. On the contrary, readers with dyslexia continue to struggle (e.g. Lefton, Nagle, Johnson, & Fisher, 1979). Significant differences in eye movements between typical and atypical readers have also been detected in other languages (e.g. Italian – DeLuca, Borrelli, Judica, Spinelli, & Zoccolotti, 2002; German – Hutzler & Wimmer, 2004), where eye movement patterns seem somewhat different than those reported for English. It is also rather important to mention that differences are observed in relation to the type of stimuli (words vs. pseudowords; e.g. DeLuca et al., 2002), which clearly reflects differences in lexical processing. Essentially, it has been proven multiple times that eye movements are a mere reflection of the underlying processing problems of dyslexia, and not the cause of disturbances.

The properties of the investigated language and its orthography influence the processing deficits which can be detectable in eye movements. The transparent orthography and fine granularity of the Croatian language (phoneme-grapheme ratio is nearly 1:1) should suffice to read any phonotactically legitimate string of letters. In the case of words, no knowledge of a word is necessary in order to read it. In addition, the R-W task itself does not require any overt word knowledge; therefore, an opportunity was open to manipulate the phonological (phonotactic) information in the Reicher-Wheeler paradigm in order to obtain a clearer picture of the phonological nature of dyslexia as a learning difficulty.

## 1.3. Theoretical background and previous findings

Several interpretations of the *word* and *pseudoword superiority effects* have been proposed. One of them, for instance, hypothesises that the pseudoword superiority effect arises from participants' misperception of pseudowords as words (Jacobs & Grainger, 2005). This could be a consequence of top-down influences, such as the ones described by McClelland and Rumelhart (1981) in the Interactive Activation

Model. Within this framework, lexical item activation at a high processing level alternatively favours or inhibits the low-level activation of individual letters. Thus, misperception of an entire pseudoword can trigger the activation of a close word and thereby strengthen the letters composing this inadequate lexical item. Based on this model, the absence of a word superiority effect in Chase and Tallal's study (1990) was explained by the fact that children with dyslexia probably had not developed top-down processes at the time of testing.

Another approach to dyslexia relies on the postulates of the Dual-Route Model of reading (Coltheart et al., 2001) in order to account for some of the dyslexic symptoms, such as difficulties processing regular or irregular words. According to this model, reading of an item proceeds along one of two alternative processing routes: the lexical route or the non-lexical route (Hawelka, Gagl, & Wimmer, 2010). The first one holds responsibility for the processing of irregular or, in languages with transparent orthography such as Croatian, familiar words. These items can then be processed either by the direct route from the orthographic input lexicon to the phonological output lexicon or by passing through the semantic lexicon. The second route is in charge of regular or unfamiliar words processing which rests on a grapheme-to-phoneme conversion. The two routes converge onto the phonological output buffer.

The Dual-Route Model has led to several accounts of dyslexic symptoms. On one hand, subjects with impairments in the lexical route – i.e. surface dyslexia – are not able to accurately read irregular or familiar words (Coltheart, Masterson, Byng, Prior, & Riddoch, 1983). On the other hand, phonological dyslexia, which ensues from deficiencies in the non-lexical route, leads to defective reading of pseudowords and non-words (Sartori, Barry, & Job, 1984; Temple & Marshall, 1983). An important prediction in a language with transparent orthography is that, among a population of impaired readers, processing of familiar items such as words should not have to endure consequences from impairments in the lexical route: words can in that case be straightforwardly decoded via the grapheme-to-phoneme conversion pathway. Reading of pseudowords, by contrast, should be defective if dyslexia arising from impairments in the non-lexical route because accurate deciphering of these items requires reliable knowledge of grapheme-to-phoneme correspondence rules. Finally, pseudowords should be processed more easily than non-words, i.e. there should be a pseudoword superiority effect (McClelland & Johnston, 1977), if orthotactic constraints, and thus phonological knowledge, play a role in atypical readers.

In this framework, the data obtained by Grainger and colleagues (2003) can be interpreted as follows. The absence of word superiority effect in both groups of children (vs. adults) suggests that none of these participants could rely on top-down processes typically arising in the lexical route. The authors explain this with the limited extent of children's lexical semantic knowledge as compared to adults, thereby refuting the possibility of a damaged lexical route. The existence of a pseudoword superiority effect, however, combined with the fact that the magnitudes of the word and pseudoword superiority effects over non-words were the same, shows the sensitivity of both groups of children to orthotactic constraints of the language in use. This supports the idea that the non-lexical route could be successfully exploited. In sum, this pattern of results does not allow to draw any firm conclusion about the impairment of one or the other route of lexical processing. Yet, the differences in lexical processing between individuals with dyslexia and unimpaired readers might be subtler, so that delayed behavioural measurements may not be sensitive enough to enable researchers to detect individual differences. These potential methodological drawbacks and inconsistencies shaped our decisions to design a similar study with the addition of eye movement recordings.

Additionally, a considerable amount of psycholinguistic studies tries to identify which linguistic variables affect cognitive processes such as lexical decisions and how they exert their influence. Phonotactic probability is one of them. Nevertheless, findings regarding its effect on reading performance have been inconclusive. The results of the study by Chetail, Balota, Treiman, and Content (2015) generally corroborate the hypothesis that the configuration of consonant and vowel letters influence polysyllabic words processing in English; on the other hand, Schmalz and Mulatti (2017) did not find any effect of phonotactic probability on lexical decisions. We therefore decided to address this question in the present study. We also manipulated the phonotactic probability information during stimuli construction.

## 2. THE PRESENT STUDY

### 2.1. Aims and objectives

The aims of this study are to test whether typical and impaired readers differ in lexical processing and to inspect the relative influence of phonological and lexical knowledge on lexical processing of these children in Croatian in terms of accuracy, reaction time and eye movement measures. Therefore, the objective is to examine whether participants would rely more on phonological, and thus abide to the orthotactic constraints of their mother tongue, or on lexical path or knowledge, in order to solve the experimental task.

This study represents also the first step towards a more comprehensive research into the role of phonotactics in language processing, typical and impaired. General human sensitivity to the statistical properties of the input strings of sounds can explain the properties of early child's vocabulary in terms of neighbourhood density and phonotactic probabilities within a single mechanism of statistical learning (see e.g. Takač, Knott, & Stokes, 2016). In this sense, phonotactic information becomes an important topic for studying dyslexia, an impairment defined as a *learning* difficulty. If phonotactic information could explain the differences between typical and impaired readers, independently of the connectionist approach in the study by Takač and colleagues (2016), in subsequent steps a claim about the single impaired mechanism in dyslexia, i.e. statistical learning mechanism, could be made. This would, in turn, provide an explanation of the background impairment in dyslexia independently of the orthographic system of a particular language. However, since dyslexia is defined as a learning difficulty, and since the connectionist approach assumes the single mechanism of statistical learning for all processes in language development, the present study has not been conducted within the connectionist model to avoid circularity.[1] This study thus relies on the principles of the Dual-Route Model.

It is, thus, important to dissociate participants with dyslexia on the lexical superiority task (Reicher, 1969; Wheeler, 1970) in order to establish whether the task is suitable for such a dissociation at all and, if possible, to see what explains the difference between participants with dyslexia and unimpaired readers in the Croatian language, i.e. in an orthographic system that allows for clear predictions based on lexical semantic knowledge and phonological information for both groups within the Dual-Route Model, as shown in the Introduction.

We also adapted the methodology for two main reasons: 1) it has been found that monitoring fixation location is extremely important in experiments testing atypical populations (Patching & Jordan, 1998), and 2) naming times and lexical decision times seem to be less valid estimates of word processing than eye movements (Kuperman, Drieghe, Keuleers, & Brysbaert, 2013). These observations constituted a rationale for building up an experiment using eye-tracking methodology and for including and analysing online eye movement measures on top of pure accuracy and reaction time.

[1] N.b. The claim about only one learning mechanism responsible for the language development and difficulties would follow from the model itself, and not from the empirical data.

## 2.2. Predictions

To this end, we make the following predictions based on the Dual-Route Model:

1. If both groups of readers rely on phonological and lexical knowledge to solve the task, they should perform better on words than on pseudowords and better on pseudowords than on non-words (W>PW>NW);
2. If they rely only on phonological knowledge, they should perform equally on words and pseudowords, and better on both than on non-words (W=PW>NW);
3. If they rely neither on phonological, nor on lexical knowledge, the same performance should be observable across all three types of stimuli (W=PW=NW);
4. If they rely solely on general lexical knowledge, they should perform better on words than on both pseudowords and non-words, while performance on the latter two should be the same (W>PW=NW);
5. The strongest prediction is that participants with dyslexia and typically developing children will differ in the pattern of results: if participants with dyslexia have phonological deficits, then they should exhibit pattern 4, while the control group should exhibit pattern 1 or 2; i.e. D (W>PW=NW) < C (W≥PW>NW), where the difference between group means overall lower scores in the D group.

We expected that difficulties in reading pseudowords in children with dyslexia (as reported in e.g. Rack et al., 1992) would be reflected in eye movements, mostly in the sense of longer gaze durations (DeLuca et al., 2002). Nevertheless, due to inconsistent previous findings, we were unsure as to whether this would surface in accuracy and reaction time. Moreover, based on the recent discoveries about the influence of letter combinations on processing (see Chetail et al., 2015), we assumed that phonotactic probability would foster lexical processing, at least in the control group.

## 3. METHODOLOGY

## 3.1. Participants

In total, 13 school-age children participated in this study, 7 children with dyslexia (4 F, 3 M) and 6 control children (4 F, 2 M), with their ages ranging from 9;1 to 10;6 (Table 1). They all attended elementary school and their participation was previously agreed upon with the school speech and language pathologist (SLP). Parents and teachers were first introduced to the study design and research questions, and the consent forms were sent out afterwards. The final decision on the participants' inclusion in the study was made with the SLP. All children with dyslexia underwent the standard diagnostic procedures and were diagnosed by SLP experts. Parents signed the consent forms and we were informed by the school SLP that most of the children were either already educated within the individual approach to teaching or were currently in the process of finalising the standard legal procedures in order to be assigned one. We did not perform any pre-tests for the two following reasons: parents agreed for their children only to participate in the experiment, and most of the children were tested less than 6 months before the study, so too little time had passed for the re-testing to be performed. As is the case with most standardised diagnostic tests, two assessments using identical materials should be at least 6 or 9 months apart to avoid the learning effect.

**Table 1.** Characteristics of both groups of participants; control group (Cs) and dyslexic group (Ds)

**Tablica 1.** Podaci o dvjema skupinama ispitanika; kontrolna skupina (Cs) i djeca s disleksijom (Ds)

| Participants (groups) / Sudionici (skupine) | N | Gender / Spol | | Age / Dob | | | |
|---|---|---|---|---|---|---|---|
| | | M | F | M | SD | Min | Max |
| Ds | 7 | 3 | 4 | 9,9 | 0,4 | 9,1 | 10,6 |
| Cs | 6 | 2 | 4 | 9,4 | 0,5 | 9,1 | 10,5 |

## 3.2. Materials and procedure

We adapted the Reicher-Wheeler task (Reicher, 1969; Wheeler, 1970) to the Croatian language and the frequently of letter combinations was carefully controlled for. This was important because the effect of phonotactic probability was taken into account in subsequent analyses. The list of stimuli consisted of 30 words (15 three-syllable frequent W with high phonotactic probability and 15 non-frequent W with low phonotactic probability); 30 pseudowords containing letters matching a word counterpart (15 three-syllable PW with high phonotactic probability and 15 three-syllable PW with low phonotactic probability); and 30 non-words with illegal phoneme combinations. The stimuli in the word condition varied in terms of word classes (i.e. 5 nouns, 9 verbs and

1 pronoun for the frequent condition, and 6 nouns, 3 verbs, 3 adjectives and 3 adverbs for the infrequent condition). This was not controlled for since the main focus was to specifically pay attention to the frequency and length of the stimuli and, even more important, to make sure that the letter in the middle of the word could be replaced with another letter and still constitute another existing word. The entire list of stimuli is provided in the Appendix at the end of the paper.

For the purpose of conducting the study, an eye-tracker with chin rest was used (SMI Hi-Speed View 500), with sampling frequency of 500 Hz. The task was pre-programmed within the SMI Experiment Centre programme. Each participant was tested individually. After the calibration procedure, where children had to fixate a small moving circle, and a short familiarisation phase, randomised stimuli appeared on the screen. Participants were exposed to an item from one of the three conditions (W, PW or NW) for 500 ms and were subsequently required to select, out of two presented letters, the one that had been seen in a specific position in the previously shown item, making the test a two-alternative forced choice (by clicking on it with the mouse). They were previously instructed to look at the correct letter in the middle of the screen and press the button. After that, the next item appeared on the screen. Only one participant looked away from the screen, but since this happened at the very beginning of the trial, the entire procedure was immediately stopped and repeated. Each trial lasted around 15 minutes and all participants were provided with refreshments. A few weeks after the experiment, one of the authors awarded the participants with a diploma for the participation.

**Accuracy**, **reaction time** and **dwell time** were recorded and analysed in IBM SPSS 20 using non-parametric statistics. **Accuracy (Acc)** was measured as the percentage of correctly chosen letters within each condition; **reaction time (RT)** was measured as the time extending from the appearance of the question phase (choosing the correct letter) until the mouse click (in ms); **dwell time (DT)** was measured as the gaze duration or the total duration of fixations on the correct letter (in ms).

## 4. RESULTS

### 4.1. Descriptive statistics

Table 2 summarises the average performance of both groups of participants across conditions (W, PW and NW).

**Table 2.** Descriptive statistics: average performance in accuracy (Acc), reaction time (RT) and dwell time (DT) for both groups of participants across all three conditions (W, PW and NW; high and low phonotactic probability)

**Tablica 2.** Deskriptivna statistika: srednja vrijednost za varijable točnost (Acc), vrijeme reakcije (RT) i trajanje fiksacije (DT) za obje skupine ispitanika u sva tri uvjeta (riječ, pseudoriječ i neriječ; visoka i niska fonotaktička vjerojatnost)

| Measures; conditions / Mjere; uvjeti | Acc; W prop. M (SD) | Acc; PW prop. M (SD) | Acc; NW prop. M (SD) | RT; W ms M (SD) | RT; PW ms M (SD) | RT; NW ms M (SD) | DT; W ms M (SD) | DT; PW ms M (SD) | DT; NW ms M (SD) |
|---|---|---|---|---|---|---|---|---|---|
| Ds (7) | 0.86 (0.07) | 0.83 (0.19) | 0.68 (0.13) | 4022.38 (484.82) | 4043.81 (739.63) | 4280.46 (1342.10) | 54.76 (49.83) | 64.98 (61.39) | 76.64 (55.19) |
| Cs (6) | 0.96 (0.04) | 0.97 (0.03) | 0.87 (0.04) | 4327.98 (993.75) | 4606.59 (1034.65) | 4445.46 (1198.33) | 206.23 (102.54) | 193.95 (99.80) | 206.24 (124.12) |

The descriptive statistics suggest that mean scores in accuracy, reaction time and dwell time differ between groups. As shown in Table 2, in terms of accuracy, the group of children with dyslexia responded less accurately and their results varied more than those of the control group. Mean scores of reaction time were similar across groups and conditions. Larger differences between the two groups can be observed in dwell time since the control group fixated the correct letter for up to four times longer than children with dyslexia. Even though longer dwell time in some research situations may reflect higher processing costs and an increased cognitive load (e.g. uncertainty or difficulty in extracting information), similarly, when participants are asked to search for a certain item, their dwell time increases up to the point of final selection thereby indicating the level of certainty of their choice (for the entire discussion on the matter see Holmqvist et al., 2011, pp. 386–389). Since in this particular testing situation children were instructed to choose the correct letter, longer dwell time was interpreted as an indicator of certainty of an upcoming conscious choice. Therefore, as the control group tends to fixate the correct letter longer, it implies that its members recognized it with more confidence.

The normality of results distributions was assessed using a Shapiro-Wilk Test and, additionally, in terms of skewness and kurtosis, where values between -2 and +2 were considered indicative of a normal univariate distribution (George & Mallery, 2010). According to these parameters, some of the variables were normally or approximately normally distributed (i.e. Acc for W and NW; RT for W and NW; DT for W and PW) and some were not (i.e. Acc for PW; RT for PW; DW for NW). Despite the normality of distribution of some variables, due to general inconsistency and especially due to the small number of participants, non-parametric statistical methods were used in all the subsequent analyses.

## 4.2. Between-group comparison across conditions and measures

Eye-tracking results show the main difference obtained in this study, i.e. the difference between the participants with dyslexia and unimpaired readers. This difference in performance across conditions between the two groups of participants is illustrated in Figure 1.

However, the complex design and a small number of participants complicate the statistical analyses of the results. It is due to the experimental design that all three factors (group, condition, phonotactic probability) could not be taken into a single analysis (words and pseudowords were manipulated for phonotactic probabilities, but all non-words consist of only illegal letter combinations). As previously stated, a small number of participants and the inconsistent normality of distribution call for a non-parametric version of the repeated measure ANOVA. We followed the procedure suggested by Wobbrock, Findlater, Gergle, and Higgins (2011) which consists of ranking the variables and performing a regular ANOVA on the ranked data.

The results indicate that the main effect of group (dyslexia vs. control) was obtained for accuracy ($F(1,11) = 15.362$; $p = 0.002$) and dwell time ($F(1,11) = 14.401$; $p = 0.003$), while no difference was found for the reaction time ($F(1,11) = 0.328$; $p = 0.578$). The main effect of condition (W, PW, NW) was not statistically significant, neither the interaction between the factors.

Further comparison (non-parametric version of one-way ANOVA, i.e. the Kruskal-Wallis Test) reveals that the difference between groups was obtained for W and NW condition on accuracy (W: $H(1) = 5.602$; $p = 0.018$; NW: $H(1) = 9.05$; $p = 0.003$) and for W, PW and NW condition on dwell time (W: $H(1) = 8.163$; $p = 0.004$; PW: $H(1) = 4.592$; $p = 0.032$; NW: $H(1) = 5.224$; $p = 0.022$). No statistically significant differences were obtained for reaction time (W: $H(1) = 0.082$; $p = 0.775$; PW: $H(1) = 0.735$; $p = 0.391$; NW: $H(1) = 0.184$; $p = 0.668$). For mean values see Descriptive statistics provided in Table 2.

Figure 2 additionally shows the mean standard error (MSE) for dwell time for both groups across all three conditions. Relatively small MSE indicates that one might expect similar distribution of results in the population. Therefore, although this study is preliminary and includes a rather small number of participants, one could expect similar results to be replicated in larger studies.

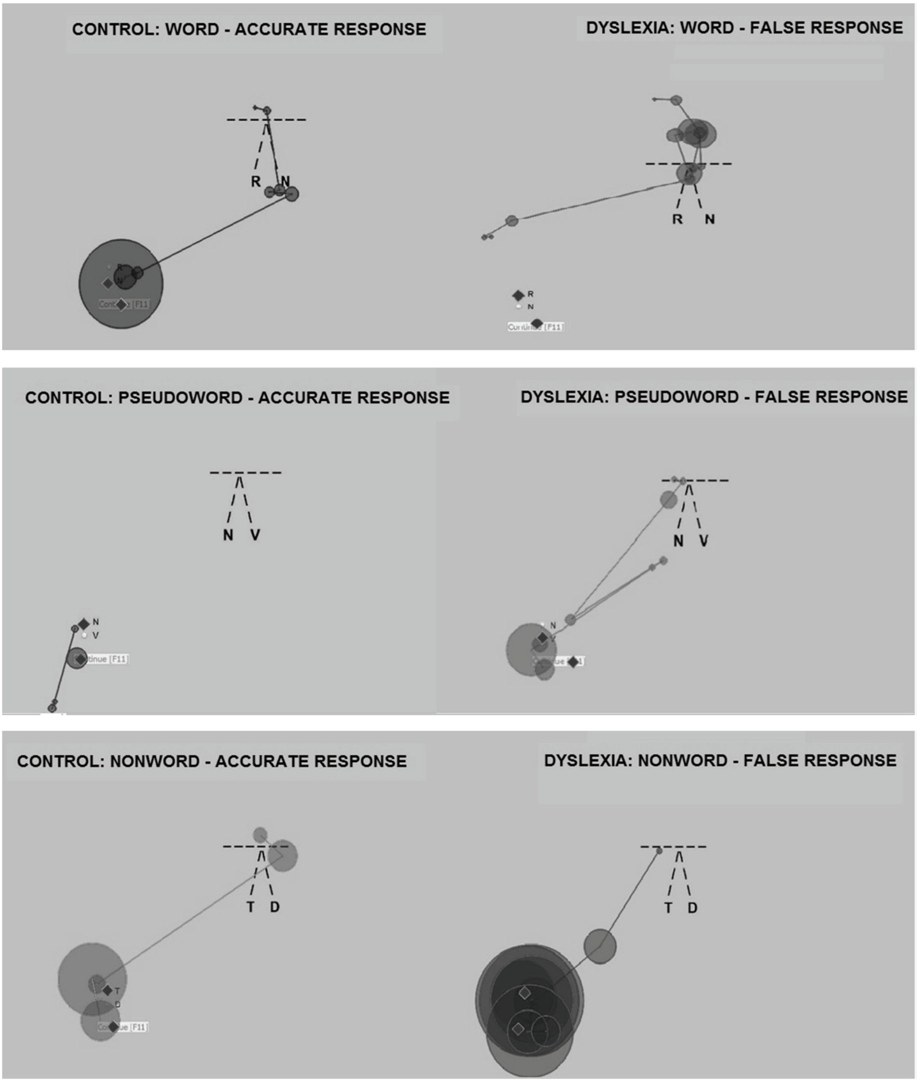


**Figure 1.** The comparison of performance of two randomly chosen participants from both groups, across all three conditions: a) words, b) pseudowords, c) non-words (each circle represents one fixation, and its size reflects its duration, while the red rhomb represents the mouse click)

**Slika 1.** Usporedba izvedbe dvaju nasumično odabranih ispitanika iz obje skupine u sva tri uvjeta: a) riječ, b) pseudoriječ, c) neriječ (svaki krug predstavlja jednu fiksaciju, pri čemu veličina kruga predstavlja trajanje fiksacije, dok crveni romb označava pritisak miša)

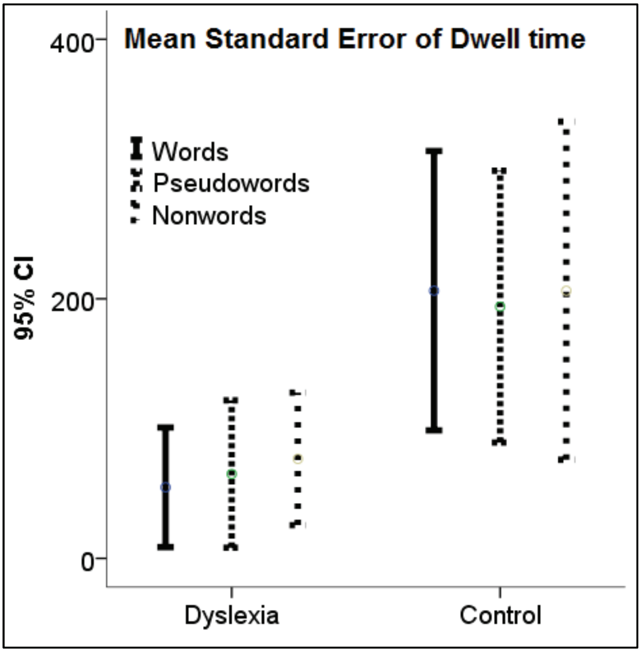


**Figure 2.** Mean standard error (MSE) for dwell time for both groups across all conditions

**Slika 2.** Srednja standardna pogreška (MSE) za varijablu trajanje fiksacije (DT – engl. *dwell time*) za obje skupine ispitanika u svim uvjetima

Overall, it can be observed that the pattern not visible in off-line measures (i.e. reaction time) did become evident in online eye movement measures. This is further discussed in the Discussion.

## 4.3. Within-group performance patterns

The next step of the study was to observe and then compare the task solving patterns within each group across the three conditions. This was important in order to understand the relative influence that each type of knowledge (phonological vs. lexical) may play in these two groups. In other words, we wanted to investigate whether the groups differ in the type of information they tend to rely on when presented with different stimuli. To this end, a Friedman Test has been performed within each group of participants. The statistically significant difference between conditions (W, PW, NW) was obtained for both groups only for accuracy (ACC; D: $\chi^2 = 8.0$; $p = 0.018$; C: $\chi^2 = 8.3$; $p = 0.016$, as opposed to non-significant *p* values for the other two variables: RT; D: $\chi^2 = 2.0$; $p = 0.368$; C: $\chi^2 = 0.3$; $p = 0.333$ and DT; D: $\chi^2 = 3.4$; $p = 0.180$; C: $\chi^2 = 1.0$; $p = 0.607$). Since Friedman Test does not allow for pairwise comparisons, Table 3 reports the tendencies based upon the mean ranks.

**Table 3.** Tendencies in task solving patterns based upon the mean ranks (Friedman Test) which parallel the initial predictions
**Tablica 3.** Tendencije u obrascima izvedbe temeljene na srednje rangiranim vrijednostima (Friedmanov test) koje odgovaraju inicijalnim pretpostavkama

| Measures / Mjere | Accuracy / Točnost | Reaction time* / Vrijeme reakcije | Dwell time / Trajanje fiksacije |
|---|---|---|---|
| Ds (7) | W>PW>NW** | W>PW>NW | W<(PW=NW) |
| Cs (6) | W≈PW>NW** | W>PW>NW | (W=NW)>PW |

* Better performance presented here corresponds to shorter RTs. / Bolji rezultat odgovara kraćem vremenu reakcije (RT).
** Statistically significant differences (Friedman Test) / Statistički značajne razlike (Friedmanov test)

Finally, in order to test whether phonotactic probability affected overall performance, each group's mean performance in accuracy, reaction time and dwell time was compared for high (15) versus low phonotactic probability (15) stimuli in the W and PW condition (NWs were not analysed since they consist of impossible letter combinations by default). For this purpose, a two related samples t-test (Wilcoxon Signed Ranks Test) was conducted. No significant differences between frequent and infrequent conditions were found. In other words, manipulations of phonotactic probability did not affect accuracy, reaction time and dwell time in neither group of participants.

## 5. DISCUSSION

The overall results of this pilot study show a clear difference in lexical processing between participants with dyslexia and typically developing readers. In addition, they show different lexical processing patterns regarding their reliance on the type of information used (lexical vs. phonological). These differences were salient enough to be detected both in accuracy (to some extent) and online measures (eye movements). The task seems to be easier to perform for the unimpaired than for the impaired readers in all conditions (visible in dwell time); and in words and non-words (visible in accuracy). That is to say, the control group was more accurate, made fewer errors (but was not faster, as opposed to Ziegler et al., 2008) and fixated the correct letter for a longer amount of time. Although we could not perform a more robust and detailed analysis, these findings corroborate our last prediction that the two groups will show different patterns of results (see prediction No. 5 in the section 2.2. Predictions).

Within groups, behavioural differences between conditions were detectable only in accuracy. On one hand, our pattern of results shows that for both groups, words are significantly easier to process than non-words. In line with the previous research, there was a word superiority effect in both groups of children (Grainger et al., 2003; Reilhac et al., 2012; Ziegler et al., 2008). The status of pseudowords remains less clear as the processing pattern is not consistent across variables. This allows us only to make assumptions based on the performance tendencies. If the performance of impaired readers with this kind of item is reminiscent of previous research highlighting their difficulties in pseudowords processing (Rack et al., 1992), the performance of the control group of children somewhat indorses the existence of a pseudoword superiority effect in unimpaired readers (Carr et al., 1978; Coch & Mitra, 2010; McClelland & Johnston, 1977). This might be explained by the familiarity of letter combinations in pseudowords that was sufficient to facilitate their processing (Hooper & Paap, 1997; Ziegler & Jacobs, 1995), i.e. their reliance on phonotactic information. The absence of clear significant difference between pseudowords and non-words processing in impaired readers (Table 3 shows only potential tendencies) in a way contradicts the findings by Grainger et al. (2003) and Reilhac et al. (2012), who observed the emergence of a clear pseudoword superiority effect in participants with dyslexia, as well. This pattern of results could potentially be imputed either to a knowledge of orthotactic rules still in development (they would in that case be significantly delayed as compared to control children) or to impairments in letter-position encoding, a symptom characteristic for dyslexia (Lachmann & van Leeuwen, 2007; Reilhac et al., 2012; Salmelin, Kiesilä, Uutela, Service, & Salonen, 1996; Vidyasagar & Pammer, 2010).

Within the Dual-Route Model framework, we could interpret our preliminary results as evidence that the control group of children rather relied on the non-lexical route, potentially because their semantic lexicon was not fully developed at the time of testing (Grainger et al., 2003), or due to the transparent orthography of the language and a phonological nature of the task.

It is interesting to note that phonotactic probability manipulations affected word processing neither for dyslexic nor for the control group of children in the study. This might be surprising, as we would expect more frequent combinations of letters to be more easily recognised by unimpaired participants. For the impaired readers, the results indicate potential difficulties in relying on phonological knowledge.

Finally, if we did anticipate that control children's performance on pseudowords would surpass that of participants with dyslexia, the fact that the latter group performed poorer than the former on words and non-words reading as well (detected in eye movements) suggests that they suffer from a more general impairment affecting their lexical processing resources in all three orthographic contexts. It is thus important to reiterate here the importance of using online measurements in investigating dyslexia, as it allowed us to identify a general impairment that was not systematically detectable in accuracy and reaction time measures.

## 6. CONCLUSIONS

The present study entitles us to characterise dyslexia as an impairment affecting reading of items in all lexical conditions. However, its exact nature and the loci of impairments responsible for the symptoms, based on our sole findings, remain underspecified. In line with the previous research, the eye-tracking data, as an added value of this study, further corroborate the fact that pseudoword processing is particularly impeded in individuals with dyslexia. This is somewhat puzzling since the transparency of the Croatian language might have facilitated pseudoword processing. Despite the limitation of the study that stem from the small number of participants, general tendencies seem to show that unimpaired readers were more able to rely on the phonological knowledge than the impaired readers, who seem not to be able to exploit either lexical or phonological information in order to complete the task.

The lexical superiority task proved to be sensitive enough – especially with the application of the eye-tracking technique – to detect differences between the impaired and unimpaired readers, and to observe differences in processing patterns. In this sense, current study serves as a basis for upcoming research with similar design. Still, to allow more robust statistical analyses, future studies should certainly include more participants.

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**Appendix** The entire list of stimuli used in the study
**Prilog** Lista podražaja korištenih u istraživanju

| Words (W) / Riječi | | Pseudowords (PW) / Pseudoriječi | | Non-words (NW) / Neriječi | |
|---|---|---|---|---|---|
| High phont. prob. / Visoka fonotakt. vjer. | Low phont. prob. / Niska fonotakt. vjer. | High phont. prob. / Visoka fonotakt. vjer. | Low phont. prob. / Niska fonotakt. vjer. | Illegal phoneme combinations / Nemogući nizovi fonema | |
| PUNICA (PURICA) | KUHALO (KUHANO) | PUDAKA | NUĐILO | DKAPUA | UĐLNIO |
| SJEDITI (SLEDITI) | MOŽDINA (MOŽDANA) | CJEMATI | SOGZANA | MEAITJC | OASGZNA |
| OSTAJE (OSTARE) | MUDRICA (MODRICA) | OSNITE | ZUDREGA | NTSIOE | RDGEAZU |
| IMATI (IMALI) | MULJATI (MUKATI) | USITI | TUZVAVI | STUII | TZVAVIU |
| OGRADA (OBRADA) | KLECNUTI (KLEKNUTI) | OSANDA | PLETŠUVI | NDAAOS | TŠLPUVIE |
| CIJENITI (CIJEDITI) | KLAUZULA (KLAUZURA) | FRAMNITI | KLEHĆULA | AMNTFRII | HĆKULLAE |
| PROLITI (PROBITI) | TURŠIJOM (TURPIJOM) | PRESATI | TOVZIJOM | ESPTRAI | VZIJTOMO |
| STANICA (STARICA) | SROZALE (SREZALE) | STADAKA | BROŽILE | AASKTDA | OIŽBLRE |
| VODITI (VOZITI) | UGASLI (URASLI) | VAPATI | USIGDI | IAPVTA | IGSDIU |
| KAMATA (KARATA) | OTKOČEN (OTKOŠEN) | KASIVA | OŠKODAN | SVKAII | OŠKDNAO |
| RANITI (RADITI) | NESTALNI (NESTAŠNI) | REJATI | SESTRVNI | AJRTIE | ESTNSVRI |

| Words (W) / Riječi | | Pseudowords (PW) / Pseudoriječi | | Non-words (NW) / Neriječi | |
|---|---|---|---|---|---|
| High phont. prob. / Visoka fonotakt. vjer. | Low phont. prob. / Niska fonotakt. vjer. | High phont. prob. / Visoka fonotakt. vjer. | Low phont. prob. / Niska fonotakt. vjer. | Illegal phoneme combinations / Nemogući nizovi fonema | |
| KOSITI (KORITI) | UMJETNO (UVJETNO) | KAMATI | ITŠEFNO | IAKMTA | EITŠFNO |
| PORUKA (PODUKA) | VRUĆICA (VREĆICA) | PORITE | VAJFICA | PTIEOR | VJFIACA |
| MORATI (MORITI) | UKUSNO (UKUPNO) | TARITI | IVUGNO | IIRTTA | OVGNUI |
| KOJIMA (KOLIMA) | LUŽINA (LUPINA) | KASAMA | GUHANA | AAMKSA | UAHGNA |

*Note.* Word list was obtained from the Croatian web corpus hrWac (Ljubešić & Klubička, 2016). The words in brackets represent the words that differ from the target word in one letter, which is the manipulation within condition that characterises the original R-W paradigm.

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# Leksička obrada djece s disleksijom: adaptacija Reicher-Wheelerovog zadatka mjerenjem pokreta oka

## Sažetak

U ovome se radu nastoji utvrditi utjecaj fonološkog i leksičkog (semantičkog) znanja na leksičku obradu kod djece s disleksijom. Istraživanje je pilot veće studije utjecaja fonotaktičkih obavijesti u jezičnoj obradi. Upotrijebljena je Reicher-Wheelerova paradigma, poznatija kao zadatak leksičke superiornosti. Zadatak se sastoji od kratkog prikaza riječi, nakon čega na zaslonu ostaju samo oznake položaja pojedinih grafema. Od sudionika se traži da odaberu grafem za koji misle da je bio na nekom položaju u riječi (nakon prikazivanja riječi *punica* prikaže se _ _ _ _ _ _, pri čemu se za treći grafem daje izbor n/r). Reicher i Wheeler su primijetili da su sudionici uspješniji ako su podražaji riječi (R), a ne pseudoriječi (PR) ili slučajni nizovi grafema, neriječi (NR). Za ovo je istraživanje zadatak leksičke superiornosti modificiran tako da uključuje R, PR i NR, a u R i PR dodatno se manipuliralo fonotaktičkim obavijestima, tj. ovi su podražaji dodatno podijeljeni u dvije skupine; one s visokom i one s niskom fonotaktičkom vjerojatnošću. Mjerila se točnost i analizirali su se pokreti oka.

Predviđanja su se temeljila na modelu dvostrukog puta prema kojem se leksička obrada sastoji od izravnoga leksičkog (semantičkog) i neizravnog (fonološkog) puta; ako ispitanik ne zna ili ne prepoznaje riječi, neizravni mu put omogućuje preslikavanje grafema u fonem, što

rezultira prepoznavanjem riječi "odozdo". Budući da u većini slučajeva disleksija podrazumijeva neki oblik fonološkog poremećaja i budući da se ona definira i kao poremećaj učenja (a fonotaktičke se obavijesti uče mehanizmom statističkog učenja), ovo je istraživanje sasvim opravdano.

Rezultati pokazuju jasnu razliku između djece s disleksijom i djece urednoga jezičnog razvoja. Sudeći prema rezultatima obje se skupine više oslanjaju na opće leksičko znanje, dok fonološko pomaže u leksičkoj obradi samo kontrolnoj skupini djece. Potvrđeni su brojni prethodni nalazi posebnih teškoća djece s disleksijom u obradi PR, bez obzira na transparentnu ortografiju hrvatskog jezika. Fonotaktičke se vjerojatnosti nisu pokazale značajnima za leksičku obradu. Moguće je da su razlike previše suptilne za mali broj ispitanika. Veličina uzorka ograničenje je ovog istraživanja pa su se istaknuli samo najveći efekti. No, s obzirom da narav zadatka ne traži eksplicitno prepoznavanje riječi pa oba leksička puta imaju ravnopravnu ulogu u njegovu rješavanju (za razliku od zadatka leksičke odluke), može se potvrditi da je uzorak ipak prikladan za istraživanje fonološke i leksičke strane mentalnog leksikona. Iako je uzorak malen, mala srednja standardna pogreška – posebno u skupini djece s disleksijom – naznaka je da bi slični nalazi bili dobiveni i slučajnim odabirom drugog uzorka.

**Ključne riječi:** disleksija, leksička obrada, Reicher-Wheelerov zadatak, model dvostrukog puta, pokreti oka