A comprehensive evaluation of lexical reading in Italian developmental dyslexics

Despina Paizi
Institute of Cognitive Sciences and Technologies (ISTC-CNR), Rome, Italy

Maria De Luca
Neuropsychology Unit, IRCCS Fondazione Santa Lucia, Rome, Italy

Pierluigi Zoccolotti
Department of Psychology, Sapienza University of Rome, Italy

Cristina Burani
Institute of Cognitive Sciences and Technologies (ISTC-CNR), Rome, Italy

Italian developmental dyslexic readers show a striking length effect and have been hypothesised to rely mostly on nonlexical reading. Our experiments tested this hypothesis by assessing whether or not the deficit underlying dyslexia is specific to lexical reading. The effects of lexicality, word frequency and length were investigated in the same group of children in four separate experiments. Although dyslexics were slower and less accurate than skilled readers and had large length effects, they showed lexicality and word frequency effects in both reading aloud and lexical decision. In a cross-experiment comparison, we show that a single global factor explains a large proportion of the difference in reading performance between dyslexic and skilled readers. This factor may indicate a deficit at a prelexical level of analysis. Lexical activation seemed spared in the dyslexic children based on the effects of lexicality and frequency. These findings contrast the hypothesis that Italian dyslexics primarily engage in nonlexical reading.

Most studies of reading development and its impairments focus on English, and extension of the results to transparent scripts, such as German or Italian, is not straightforward (Share, 2008). The present study focuses on Italian and aims to provide an assessment of lexical reading in skilled and dyslexic children.

It has been hypothesised that Italian dyslexic children rely predominantly on nonlexical grapheme-to-phoneme correspondences and are, thus, surface dyslexics (Zoccolotti et al., 1999). Surface dyslexia is a deficit of one or more components of the lexical route (or lexical reading), which is compensated by reliance on the grapheme-to-phoneme conversion route (Castles & Coltheart, 1993; Coltheart, Masterson, Byng, Prior & Riddoch, 1983).
Empirical evidence seems to support the characterisation in terms of surface dyslexia. Italian dyslexics’ reading is slow (Tressoldi, Stella & Faggella, 2001; Zoccolotti et al., 1999) and markedly affected by stimulus length (Judica, De Luca, Spinelli & Zoccolotti, 2002; Spinelli et al., 2005; Zoccolotti et al., 2005) for both words and nonwords (Brizzolara et al., 2006; Judica et al., 2002; Zoccolotti, De Luca, Judica & Spinelli, 2008). Similar results have been reported for other transparent scripts, such as German (Ziegler, Perry, Ma-Wyatt, Ladner & Schulte-Korne, 2003). Italian dyslexics are also impaired in pseudohomophonic contrasts, that is, in discriminating the meaning of word strings such as ‘lago’ (‘lake’) and ‘l’ago’ (‘the needle’) (Judica et al., 2002; Zoccolotti et al., 1999). Eye-movement studies have yielded consistent results: compared to typically developing readers, developmental dyslexics have a slow reading pattern with numerous and long-lasting fixations that increase as a function of word length during the reading of passages (De Luca, Di Pace, Judica, Spinelli & Zoccolotti, 1999) and lists of words and nonwords (De Luca, Borelli, Judica, Spinelli & Zoccolotti, 2002).

The idea that Italian dyslexic children rely predominantly on nonlexical grapheme-to-phoneme correspondences has received partial support, but a thorough account of lexical activation is lacking. The purpose of this study was to challenge the hypothesis that the main deficit underlying developmental dyslexia in Italian is specific to lexical reading and results in predominant reliance on nonlexical reading. To this end, the effects of lexicality (i.e. the advantage of words over nonwords) and word frequency (i.e. the advantage of high-frequency [HF] words over low-frequency [LF] words) were investigated for the first time in both reading aloud and lexical decision in the same population of dyslexic and skilled children.

A visual–lexical decision task (i.e. in which participants had to decide whether the presented stimulus was a word) was used to assess lexical knowledge and organisation of the lexicon in both skilled and dyslexic readers. If Italian dyslexics are selectively impaired in accessing the orthographic lexicon, they should be impaired in lexical decision.

With respect to the lexicality effect, Zoccolotti et al. (2008) found that dyslexics’ naming times (reaction time, RTs) were affected more than those of controls by both lexicality and stimulus length. However, Faust, Balota, Spieler and Ferraro (1999) noted that differences in condition effects between two groups varying for general processing ability are influenced by an over-additive effect, that is, larger differences are present in slower individuals over and above the specific effect of the experimental manipulations. Faust et al. (1999) proposed the rate-amount model (RAM) to assess global and specific components of group differences in performance. Using this model, the appropriate data transformations can be performed to control for the over-additive effect. In fact, when this model was used, dyslexics’ greater lexicality effect vanished, indicating that it was due to their overall slowness (Zoccolotti et al., 2008). By contrast, the length effect remained more marked in dyslexics than controls.

In the present study (Experiment 1: reading aloud), lexicality was varied with word frequency to investigate whether nonwords are read slower and less accurately not only than HF but also than LF words. This issue has never been investigated in Italian skilled and dyslexic readers. Skilled readers, similar to adult Italian readers (see Pagliuca, Arduino, Barca & Burani, 2008), are expected to show the lexicality effect for both HF and LF words if their main reading strategy is lexical and not serial decoding based on grapheme-to-phoneme correspondences. If dyslexics rely heavily on nonlexical reading, they should read words and nonwords in a similar fashion with smaller differences between words and nonwords compared with skilled readers. Possibly, and also considering that the nonwords
employed in our study were matched with words according to several psycholinguistic
variables and were quite word-like, dyslexics, because of their limited lexical knowledge
with respect to skilled readers, may show a processing advantage only for HF words, for
which lexical representations may not be readily available.

The advantage of words over nonwords was investigated in lexical decision (Experiment
2: lexical decision) – as well as in reading aloud – in the same group of dyslexic
and skilled children. We focused on the effect of stimulus type (word or nonword) on the
performance (decision times) of dyslexic and skilled readers as a function of frequen-
cy (high or low). In previous research, the difference in decision times between words
and nonwords and the length effect were larger for dyslexics than controls (Di Filippo,
De Luca, Judica, Spinelli & Zoccolotti, 2006). However, when the over-additive effect
(Faust et al., 1999) was partialled out, only the length effect was critical and differenti-
ated the performance of dyslexics and controls (Di Filippo et al., 2006). Therefore, dyslexics,
similar to skilled readers, should make faster decisions on words (at least HF ones) than
nonwords.

The word frequency effect on reading aloud has been reported for Italian adult (Barca,
Burani & Arduino, 2002; Bates, Burani, D’Amico & Barca, 2001; Burani, Arduino &
Burani, 2007; Burani, Barca & Ellis, 2006; Colombo, 1992; Colombo, Pasini & Balota,
2006), typically developing (Barca, Ellis & Burani, 2007; Burani, Marcolini & Stella,
2002) and developmental dyslexic readers (Barca, Burani, Di Filippo & Zoccolotti, 2006;
Paizi, Zoccolotti & Burani, 2011). When Barca et al. (2006) studied the interaction be-
tween the word frequency and the rule contextuality effect (i.e. words with simple graph-
emes are read better than words with context-dependent graphemes) a greater frequency
effect was found for dyslexics than controls (see also Ziegler, Perry, Ma-Wyatt, Ladner &
Schulte-Korne, 2003), possibly due to an over-additive effect.

In Experiments 3 and 4 of the present study, length was varied orthogonally with word
frequency, a novel manipulation for studying Italian dyslexic children. Word frequency
was expected to affect both typically developing and dyslexic readers, with HF words read
faster and more accurately than LF words. Regarding the possible interaction between
length and frequency, skilled young readers may be expected to show the usual length ×
frequency interaction, with greater length effect in the case of lower-frequency words
(Coltheart, Rastle, Perry, Langdon & Ziegler, 2001). By contrast, if developmental dyslex-
ics rely predominantly on nonlexical reading, they should show a marked length effect
irrespective of word frequency.

The effects of frequency and length were also investigated in lexical decision in Italian
typically developing and – for the first time – dyslexic readers. Effects of word frequency
on lexical decision have been demonstrated in Italian children in third through fifth grade
(Burani et al., 2002). Thus, in the present study, similar results were expected for typi-
cally developing readers. The presence of the word-frequency effect in the dyslexic group
should indicate similar activation of the input orthographic lexicon in dyslexics and unim-
paired readers. Regarding the length effect, reports indicate that developmental dyslexics
are more likely than skilled readers to show length effects in lexical decision and that this
could be associated with difficulties in visual–attentional processing (Juphard, Carbonnel
& Valdois, 2004). According to the latter authors, dyslexic readers have a limited visual–
attention span with respect to unimpaired readers. That is, dyslexic readers are limited in
the number of distinct visual elements they can process simultaneously in a multi-element
array. This view is supported by the predictions of the connectionist multitrace memory
model for reading aloud and visual word recognition (Ans, Carbonnel & Valdois, 1998).
Word frequency and length effects have been reported separately on lexical decision times for skilled readers (Burani et al., 2002). Skilled children should show both frequency and length effects, possibly with greater length effect in the case of lower-frequency words. In lexical decision, dyslexics seem to be greatly affected by length (Di Filippo et al., 2006). Consequently, the effect of length may be present independently of word frequency. The effect of frequency in dyslexic children should indicate similar lexical activation in both dyslexic and skilled children.

Four experiments with timed presentation of singly displayed stimuli are reported. Experiments 1 (reading aloud) and 2 (lexical decision) tested the effects of lexicality and word frequency. Experiments 3 (reading aloud) and 4 (lexical decision) examined the interaction between word frequency and stimulus length. To compare the influence of these factors, we examined the same group of dyslexics and typically developing readers across all experiments. Because of this general design and the need to control the stimuli for a series of psycholinguistic variables (see Materials), we had to repeatedly present some of the word stimuli. The effect of stimulus repetition was controlled by counterbalancing across subjects the sequence of the two pairs of experiments (1 and 2; 3 and 4) that shared some of the word stimuli. In the statistical analyses, we were particularly interested in the interactions of the lexical effects (lexicality and frequency) with the group factor; therefore, the over-additive effect was taken into account using data transformations, as proposed by Faust et al. (1999). Finally, according to the framework of the RAM (Faust et al., 1999), all data were analysed in a cross-experiment comparison to detect the presence of global components contributing to group differences in performance between dyslexic and skilled readers.

Experiment 1: Lexicality in reading aloud

The purpose of this experiment was to investigate the lexicality effect in dyslexic and typically developing readers. We also assessed the effect of word frequency and its interaction with lexicality.

Method

Participants

We recruited 17 dyslexics (8 girls and 9 boys) with a mean age of 11.7 (standard deviation $[SD] \ 0.3$) and 17 typically developing readers (8 girls and 9 boys) with a mean of 11.6 years, $SD \ 0.4$) to participate in all four experiments.

Criteria for inclusion in the dyslexic group were scores at least two $SD$s below the norm for either speed or accuracy on a standardised reading test (MT Reading test, Cornoldi & Colpo, 1995). This disjunctive criterion was adopted because it has been shown that children with reading disabilities may strategically modify their ability to read faster (at the expense of accuracy) or more accurately (at the expense of speed; Hendriks & Kolk, 1997). In this test, the child reads aloud a passage of text with a 4-minute time limit; speed (s per syllable) and accuracy (number of errors, adjusted for the amount of text read) are scored. A comprehension subtest was also given (but not used as part of the selection criteria) in which the participant read a second passage silently, with no time limit, and then responded to 10 multiple-choice questions. Mean scores for the two groups of participants for reading
speed, accuracy and comprehension are presented in Table 1 both as absolute values and $z$ scores compared with normative values (Cornoldi & Colpo, 1995).

Of the 17 dyslexic children, three were below the cut-off for both speed and accuracy and 14 for accuracy only. Reading accuracy was generally more compromised than reading speed. Nevertheless, the dyslexics’ mean impairment in reading speed was substantial, indicating they were about 80% slower than typically developing readers. This difference in speed was comparable to that reported in previous studies (e.g. the delay was 80% in both De Luca, Barca, Burani & Zoccolotti, 2008, and De Luca, Paizi, Burani, Spinelli & Zoccolotti, 2009). Comprehension was poorer in dyslexic than skilled readers; notably, the effect was smaller than for accuracy and speed, a common finding in Italian dyslexic children (Judica et al., 2002).

Nonverbal IQ levels were assessed on the basis of the participants’ scores on Raven’s Coloured Progressive Matrices. The performance of all children was well within the normal range, according to Italian normative data (Pruneti, 1985). All participants had normal or corrected to normal visual acuity. The two groups were matched for chronological age, sex and nonverbal IQ levels. Summary statistics for the two groups of participants are presented in Table 1.

### Materials

The experimental list consisted of 48 words and 48 nonwords (a total of 96 items). The word list was composed of 24 HF and 24 LF words, all of which were stressed on the first syllable. They were selected from the LEXVAR database (Barca et al., 2002), available at http://www.istc.cnr.it/material/database. The nonword list was composed of 24 items derived from the HF words and 24 items derived from the LF words by changing one (or two) letter(s). All stimuli were disyllabic and four to six letters long. The four types of stimuli were matched for length in letters, bigram frequency, number of orthographic (word) neighbours ($N$-size), summed neighbours’ frequency, number of geminates and diphthongs and two initial phonemes. All stimuli were orthographically simple and contained letters with one-to-one grapheme-to-phoneme correspondence (i.e. stimuli did not include the letters $c$ and $g$, whose pronunciation is complex because it depends on the following letters; Burani et al., 2006). The list of words and nonwords was adopted from Pagliuca et al. (2008). The characteristics of the stimuli are reported in Table 2.
Procedure

The stimuli appeared on the computer screen after the appearance of a fixation point, which was displayed for 500 ms and disappeared at the onset of the stimulus pronunciation or after a maximum of 6,000 ms. The inter-stimulus interval was 1,000 ms.

The 96 experimental items were presented in four blocks of 24 trials each. Within each block, words were interspersed with nonwords in randomised order. Presentation order was randomised both within and between blocks. A short pause followed each block. There was a practice block of 10 trials: five words and five nonwords, other than the experimental items. The practice items had the same characteristics as the experimental items. They were presented in random order.

The children were tested individually in a quiet room at their school. They were instructed to read aloud the letter strings that appeared on the computer screen as fast and accurately as possible. Responses were recorded by a microphone connected to a voice-key. Naming RTs were measured in milliseconds (ms) using the E-Prime software. There was an interval of at least 10 days between the experimental sessions of Experiments 1 and 2 that shared the same stimuli. Half of the participants were first tested on reading aloud and half on lexical decision.

Data analysis

It has been established that standard parametric analyses based on raw scores of groups that vary greatly for general levels of performance (such as young people vs elderly) may yield spurious interactions between group and experimental factors (Faust et al., 1999). In particular, there may be over-additive interactions, that is, larger effects for the group showing larger values. In the case of RTs, this indicates that the slower group will show larger effects for more difficult conditions independently of the characteristics of the experimental manipulations. Various models have been proposed to interpret and control for these effects; here we refer to the RAM model (Faust et al., 1999).

We found that the dyslexic group was much slower across all conditions of all four experiments than the control group. Consequently, it seemed appropriate to introduce one of the data transformations proposed by Faust et al. (1999) to control for over-additive effects in the presence of large intergroup differences: individually based z-score transformation.

Table 2. Descriptive statistics for high- and low-frequency words and nonwords used in Experiments 1 and 2 (mean values and standard deviations in parenthesis) (see Pagliuca et al., 2008).

<table>
<thead>
<tr>
<th></th>
<th>Words</th>
<th>Nonwords</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
</tr>
<tr>
<td>Length (in letters)</td>
<td>4.66 (0.63)</td>
<td>4.75 (0.52)</td>
</tr>
<tr>
<td>Written word frequency</td>
<td>2.40 (0.31)</td>
<td>1.05 (0.35)</td>
</tr>
<tr>
<td>Bigram frequency</td>
<td>11.01 (0.41)</td>
<td>10.88 (0.52)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N-size</td>
<td>2.83 (1.67)</td>
<td>2.33 (1.64)</td>
</tr>
<tr>
<td></td>
<td>(0.72)</td>
<td>(0.67)</td>
</tr>
<tr>
<td>Summed neighbourhood frequency</td>
<td>2.10 (1.09)</td>
<td>1.81 (1.18)</td>
</tr>
<tr>
<td></td>
<td>(1.18)</td>
<td>(0.87)</td>
</tr>
</tbody>
</table>

Note: HF = high frequency; LF = low frequency. Written word frequency and summed neighbourhood frequency are log transformed (base 10). Bigram frequency values are also log transformed (natural logarithm).
We obtained $z$ scores by taking each individual’s RTs (only on correct responses), subtracting the overall mean averaged across all trials and dividing it by their $SD$. To obtain more reliable estimates of general individual performance (and therefore of the $z$ scores), we carried out a single data transformation spanning all dependent measures derived from the four experiments. $Z$ scores indicate an individual participant’s performance on a given trial relative to all of his/her other trials. Since the grand average of each participant (and therefore of each group) is zero, in all $z$-score analyses the main effect of group tends to be negligible. However, it is not necessarily zero because the analysis of each experiment is based on the subset of the data used for the normalisation (these residual group effects will be presented in the cross-experiment comparison at the end of the paper).

To examine the effect of the experimental variables (frequency and lexicality), the $z$-transformed values were submitted to the Linear Mixed Effects Model, which is a robust analysis that allows controlling for the variability of items and subjects (Baayen, Tweedie & Schreuder, 2002). This analysis prevents the potential lack of power of the by-subject and by-item analyses and limits the loss of information due to the prior averaging of the by-item and by-subject analyses (Baayen et al., 2002; Brysbaert, 2007). Analyses were carried out using the SPSS package (see Brysbaert, 2007). Participants and items were crossed independent random effects. Fixed effects varied in different analyses. Two analyses were conducted with group (dyslexics vs controls) and lexicality (words vs nonwords) as fixed factors, separately for HF words (and corresponding nonwords) and LF words (and corresponding nonwords). A separate analysis was carried out with group (dyslexics vs controls) and frequency (HF vs LF words) as fixed effect. As Experiments 1 and 2 (which used the same stimulus set) were randomised across participants, children might have seen a given word first in reading and second in lexical decision (or vice versa). To control for the effect of repetition, the number of stimulus presentations was entered as a covariate in all analyses. Bonferroni post hoc comparisons were used to decompose significant interactions.

Note that the RAM applies to open scales (such as time), not to closed scales (such as accuracy). Consequently, $z$-scores analyses were carried out on RTs only. Both $z$-scores and raw RTs are illustrated in the Figures to allow for an inspective grasp of the main results.

Accuracy on each item (in binary form: 0 = error; 1 = correct response) was analysed through a generalised linear mixed model fit by the Laplace approximation (see Wolfinger, 1993). Random and fixed factors were the same as those for the analyses on $z$-transformed RTs. Stimulus repetition was also entered as a random effect in these analyses. Note that these analyses are effective in controlling for the variability of items and participants; however, they do not compensate for absolute differences in performance between the two groups and, therefore, are sensitive to over-additive effects. Therefore, the group by condition interactions must be interpreted with caution. Nevertheless, these analyses can be informative about the possible presence of trade-off effects in performance between speed and accuracy.

This general model of data analysis was maintained across the four experiments. We will, however, specify each time which fixed factors were considered in the analyses.

Results

Invalid trials due to technical failures or responses that exceeded the time limit accounted for 3.3% and 4.9% of responses of proficient readers and dyslexics, respectively, and were discarded from the analyses. Main results are presented in Figures 1a (raw RTs), 1b ($z$ scores) and 1c (percentages of errors).
Figure 1. Lexicality: reading aloud task (Experiment 1). (a) Mean naming times, (b) mean $z$-transformed RTs and (c) percentages of errors as a function of lexicality and frequency for both proficient and dyslexic participants. As to $z$ scores, negative values indicate slower RTs; the ordinate in the central panel (in this and the following three figures) has been arranged with negative values above so as to visually maintain the general direction of the effects. Error bars represent 95% confidence interval of the mean.
Reaction times

The Mixed Effects Model analysis on z-transformed RTs for HF words showed a main significant effect of lexicality, $F(1, 51) = 12.05$, $p < .001$. The effect of group was marginally significant, $F(1, 32) = 3.83$, $p = .057$. The group by lexicality interaction was not significant, $F(1, 1416) < 1$, $p = .35$. The effect of stimulus repetition was significant, $F(1, 173) = 5.15$, $p < .05$.

The Mixed Effect Model analysis on LF words showed a marginally significant main effect of lexicality, $F(1, 48) = 3.80$, $p = .057$. The effect of group, $F(1, 31) = 1.71$, $p = .22$ and the group by lexicality interaction, $F(1, 1362) < 1$, $p = .71$ were not significant. The effect of stimulus repetition was not significant, $F(1, 166) = 1.92$, $p = .16$.

The analysis comparing HF and LF words showed a main effect of frequency, $F(1, 44) = 14.79$, $p < .001$. The effect of group, $F(1, 32) = 3.22$, $p = .08$ and the group by frequency interaction were not significant, $F(1, 1452) = 1.23$, $p = .26$. The effect of stimulus repetition was significant, $F(1, 115) = 4.75$, $p < .05$.

Errors

The Mixed Effects Model on HF words (and derived nonwords) showed the effect of group ($z = -4.51$, $p < .0001$). The effect of lexicality fell short of significance ($z = 1.75$, $p = .08$). The interaction between group and lexicality was not significant ($z = 1.49$, $p = .14$).

The analysis of LF words (and derived nonwords) showed main effects of lexicality ($z = 2.51$, $p = .01$) and group ($z = -4.20$, $p < .0001$). The interaction between group and lexicality was not significant ($z = 0.56$, $p = .57$).

The analysis comparing HF and LF words showed no effect of frequency ($z = -0.89$, $p = .37$) or group ($z = -0.37$, $p = .71$). The interaction between group and frequency was not significant ($z = -0.86$, $p = .39$).

Summary of results

Both groups read HF words faster than nonwords, in agreement with previous findings in proficient adult readers (Pagliuca et al., 2008). The effect of word frequency affected both dyslexics’ and skilled readers’ naming latencies but not accuracy. Notably, the effects of lexicality and frequency did not interact with the group factor, indicating similar effects in the two groups of children.

Experiment 2: The advantage of words over nonwords in lexical decision

The aim of this experiment was to investigate the advantage of words over nonwords in terms of decision times. It has been shown that dyslexics make faster decisions on words than nonwords (Di Filippo et al., 2006). Nevertheless, whether this difference holds for both HF and LF words has never been investigated in young readers. Both HF and LF words should be decided on faster and more accurately than (word-like) nonwords by skilled and dyslexic readers, if both groups of readers have unimpaired access to a sufficiently large orthographic lexicon. Comparisons between decisions on HF and LF words are also reported.
Method

Materials
The materials were the same as in Experiment 1.

Procedure
The stimuli appeared after participants had fixated a point in the centre of the screen for 500 ms. The stimuli remained on the screen until the participant pressed one of the two keys or after a maximum of 6,000 ms. The inter-stimulus interval was 1,000 ms. The stimuli were presented in four blocks of 24 trials each. A practice block consisted of 10 stimuli (different from the experimental items): five words and five nonwords. The order of both trials and blocks was random. Each block was followed by a short pause.

Participants had to decide whether or not the letter string was a word. They had to press the yes-key for words and the no-key for nonwords. They were instructed to respond as fast and accurately as possible. A serial response box collected the participants’ responses.

The design of the statistical analyses was the same as in Experiment 1. As stated above, half of the participants were first tested on reading aloud (Experiment 1) and half on lexical decision (Experiment 2). There was a minimum interval of 10 days between the two experimental sessions.

Results
Invalid trials accounted for 0.2% of the data points for the dyslexics. There were no missing data for the control participants. Main results are presented in Figure 2a (raw RTs), 2b (z-transformed RTs) and 2c (percentages of errors).

Reaction times
The Mixed Effects Model analysis on z-transformed RTs for HF words showed a main effect of stimulus type, $F(1, 50) = 96.46, p < .0001$. The effect of group, $F(1, 33) < 1, p = .71$ and the stimulus type by group interaction, $F(1, 1468) = 2.47, p = .11$ were not significant. The effect of stimulus repetition was not significant, $F(1, 106) = 1.16, p = .28$.

The analysis of LF words showed a main effect of stimulus type, $F(1, 47) = 16.93, p < .001$. The effect of group was not significant, $F(1, 32) = 1.19, p = .28$. The group by stimulus type interaction was significant, $F(1, 1368) = 17.94, p < .0001$: LF words were responded to faster than nonwords by both groups, but the effect was significant for dyslexics (z-score difference: 0.95, $p < .0001$) while it fell short of significance in controls (z-score difference: 0.56, $p = .08$). The effect of stimulus repetition was not significant, $F(1, 94) = 2.14, p = .15$.

The analysis comparing HF and LF words showed a main effect of frequency, $F(1, 25) = 25.09, p < .0001$. The effect of group, $F(1, 29) < 1, p = .43$ and the frequency by group interaction, $F(1, 1402) < 1, p = .75$ were not significant. The effect of stimulus repetition was not significant, $F(1, 108) < 1, p = .99$.

Errors
The Mixed Effects Model on HF words showed a main effect of group ($z = -2.45, p = .01$). The effect of stimulus type tended towards significance ($z = 1.84, p = .066$) as did the group by stimulus-type interaction ($z = 1.65, p = .10$).
Figure 2. Superiority of words over nonwords: lexical decision task (Experiment 2). (a) Mean RTs, (b) mean $z$-transformed RTs (negative values indicate slower RTs) and (c) percentages of errors as a function of lexicality and frequency for both proficient and dyslexic participants. Error bars represent 95% confidence interval of the mean.
The same analysis of LF words showed a main effect of stimulus type (z = −2.90, p < .01) with more errors on LF words than nonwords. The group effect was significant (z = −2.29, p < .05). The group by stimulus-type interaction was not significant (z = 1.37, p = .17).

The analysis comparing errors on HF and LF words showed a main effect of frequency (z = −4.09, p < .0001). The effect of group (z < 1, p = .83) and the group by frequency interaction (z < 1, p = .72) were not significant.

Summary of results
With respect to latencies, dyslexics showed a larger difference between words and nonwords than controls, which was limited to the comparison of LF words. As for accuracy, both groups made more errors in judging LF words than corresponding nonwords.

Experiment 3: Frequency and length effects in reading aloud

In Experiment 3, length and frequency were manipulated in an orthogonal design to systematically investigate the effects of these variables in word reading aloud. This design allowed specific examination of frequency effects on various word lengths (four–seven letters).

Word frequency and length were expected to affect the reading of skilled readers, with a possibly greater length effect for LF than HF words because LF words are less familiar and more likely than HF words to be processed sub-lexically (Coltheart et al., 2001). If dyslexics over-rely on nonlexical processing, as previous research suggests, they should be affected by length, irrespective of word frequency.

Method

Materials
A list of HF and LF words was used. Frequency was based on child-printed frequency counts (Marconi, Ott, Pesenti, Ratti & Tavella, 1993). The two frequency conditions (HF and LF words) were varied orthogonally with four length conditions: four-, five-, six- and seven-letter words. There were 15 words per condition (a total of 120 words). All words were regularly stressed and morphologically simple (no compound words or derivational affixes were included). An attempt was made to select words different from those in the set used in Experiments 1 and 2. However, some overlap (c. 30%) was necessary to counterbalance all critical psycholinguistic factors (see below). This was another reason why we covaried stimulus repetition in the statistical analyses.

The 4 length × 2 frequency conditions were matched for bigram frequency. Initial phonemes in the four sets were matched for the voiced versus voiceless features and manner of articulation. Word familiarity, that is, estimated frequency of occurrence of the word in daily life, and age of acquisition (Juhasz, 2005) were matched across different lengths within the two sets (HF set–LF set). N-size was matched between corresponding length sets in the HF and LF conditions (i.e. four-letter HF words vs four-letter LF words, five-letter HF words vs five-letter LF words, and so on). Orthographic complexity (i.e. the number of letters c and g, which require complex grapheme-to-phoneme conversion rules
because their pronunciation depends on the following letters; see Burani et al., 2006) was also matched between corresponding length sets in the HF and LF conditions. Age of acquisition was controlled so as not to exceed mean participants’ age (11.7 years). Materials were selected from the LEXVAR database (Barca et al., 2002) (see Table 3 for descriptive statistics on the characteristics of the words).

**Procedure**

The general procedure was the same as that in Experiment 1. The 120 words were presented in five blocks of 24 words each. The presentation order of the blocks, as well as the order of the stimuli within each block, was fully randomised in each experimental session. There was a short pause after each block. Prior to the first block, a practice block was administered; it consisted of 10 words different from the experimental items, but with the same characteristics.

Testing started at least 10 days after completion of the first two experiments. There was also an interval of at least 10 days between the two experimental sessions (Experiment 3 and 4) that shared part of the experimental items. Half of the participants were first administered reading aloud, and half lexical decision.

The general design of the statistical analyses was similar to that described for Experiment 1. Participants and items were crossed independent random effects. Fixed effects were group (dyslexics vs controls), frequency (high vs low) and length (four, five, six and seven letters). To control for the effect of repetition, number of stimulus presentations was entered as a covariate.

---

**Table 3. Descriptive statistics for the four-, five-, six- and seven-letter high- and low-frequency words used in Experiments 3 and 4 (mean values).**

<table>
<thead>
<tr>
<th>Length</th>
<th>Four letters</th>
<th>Five letters</th>
<th>Six letters</th>
<th>Seven letters</th>
<th>Frequency</th>
<th>Length</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>HF</td>
<td>LF</td>
<td>HF</td>
<td>LF</td>
<td>HF</td>
<td>LF</td>
<td>HF</td>
</tr>
<tr>
<td>Written word frequency</td>
<td>458.7</td>
<td>14.7</td>
<td>225.5</td>
<td>12</td>
<td>224.8</td>
<td>9.6</td>
<td>253.7</td>
</tr>
<tr>
<td>SD</td>
<td>921</td>
<td>10.7</td>
<td>269</td>
<td>6.8</td>
<td>228</td>
<td>9.1</td>
<td>295</td>
</tr>
<tr>
<td>Age of acquisition</td>
<td>2.6</td>
<td>4</td>
<td>2.7</td>
<td>4.3</td>
<td>2.8</td>
<td>3.8</td>
<td>3</td>
</tr>
<tr>
<td>SD</td>
<td>0.78</td>
<td>0.86</td>
<td>0.79</td>
<td>0.76</td>
<td>0.51</td>
<td>0.98</td>
<td>0.80</td>
</tr>
<tr>
<td>Familiarity</td>
<td>6.6</td>
<td>5.9</td>
<td>6.6</td>
<td>5.8</td>
<td>6.6</td>
<td>5.7</td>
<td>6.6</td>
</tr>
<tr>
<td>SD</td>
<td>0.4</td>
<td>0.5</td>
<td>0.31</td>
<td>0.79</td>
<td>0.23</td>
<td>0.67</td>
<td>0.43</td>
</tr>
<tr>
<td>Bigram frequency</td>
<td>11.1</td>
<td>10.9</td>
<td>10.9</td>
<td>10.8</td>
<td>10.9</td>
<td>10.9</td>
<td>10.8</td>
</tr>
<tr>
<td>SD</td>
<td>0.23</td>
<td>0.50</td>
<td>0.35</td>
<td>0.41</td>
<td>0.40</td>
<td>0.40</td>
<td>0.41</td>
</tr>
<tr>
<td>Orthographic complexity</td>
<td>0.27</td>
<td>0.27</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.33</td>
<td>0.93</td>
</tr>
<tr>
<td>SD</td>
<td>0.46</td>
<td>0.46</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.62</td>
<td>0.68</td>
</tr>
</tbody>
</table>

**Notes:** HF = high-frequency words; LF = low-frequency words.

Printed word frequency corresponds to child frequency counts of 1.000.000 occurrences. Bigram frequency values are log transformed (natural logarithm). Age of acquisition and familiarity are on a seven-point scale. All measures were taken from the LEXVAR database (Barca et al., 2002), available at http://www.istc.cnr.it/material/database.
Results

Invalid trials accounted for 2.8% of the data points for controls and 4.2% for dyslexics. Main results are presented in Figure 3a (raw RTs), 3b (z values) and 3c (percentages of errors).
Reaction times

The Mixed Effects Model analysis on z-transformed RTs showed main effects of frequency, $F(1, 108) = 52.15, p < .0001$ and length, $F(3, 108) = 16.46, p < .0001$. The group by length interaction was significant, $F(3, 3540) = 8.55, p < .0001$, indicating a greater effect of length in dyslexics than controls. For the control group, only four-letter words were significantly different from all other word lengths (at least $p < .05$); no other comparisons between length conditions were significant. On average, there was a 0.01 z-score average increase per letter. For dyslexics, four-letter words were significantly different from all other word lengths (at least $p < .05$); and five-letter words were significantly different from seven-letter words ($p < .01$). On average, there was a 0.19 z-score average increase per letter. Dyslexics were slower than controls only on seven-letter words ($p < .01$). On average, there was a 0.19 z-score average increase per letter. Dyslexics were slower than controls only on seven-letter words ($p < .01$). The effect of group was not significant, $F(1, 32) = 1.20, p = .28$. The other interactions and the effect of the covariate were also nonsignificant. In particular, the group by frequency interaction was negligible, $F(3, 3,540) < 1, p = .38$.

Errors

The Mixed Effect Model showed no effect of group ($z = 0.15, p = .88$), frequency ($z = 0.44, p = .65$) or length ($z = -0.12, p = .89$). All interactions were nonsignificant (all $zs < 1$).

Summary of results

The results on RTs showed that dyslexics were more sensitive to stimulus length than controls, confirming previous findings (Spinelli et al., 2005; Zoccolotti et al., 2005). The group by length interaction detected in the z-scores analysis indicated that the great influence of length in dyslexics cannot be explained in terms of an over-additive effect, that is, it is not due to the generally slower performance of dyslexics. The effect of frequency reported in Experiment 1 was confirmed. Again, this effect was similar in the two groups of children (as indicated by the lack of interaction with the group factor). Notably, all interactions involving length and frequency were not significant. No effect was detected for accuracy.

Experiment 4: Frequency and length effects in lexical decision

Experiment 4 investigated word frequency and length in lexical decision. Word frequency has been reported to affect decision time in Italian skilled readers (Burani et al., 2002), but this is the first study in which it was investigated in dyslexic readers (see also Experiment 2). Length has been reported to affect decision times in both skilled (Burani et al., 2002) and dyslexic readers (Di Filippo et al., 2006). Similarly, the effect of length in lexical decision has been reported (only) for dyslexic readers of both deep, such as French (Bosse, Tainturier & Valdois, 2007; Juphard et al., 2004) and shallow scripts, such as Dutch (Martens & de Jong, 2006).

Method

Materials

A list of 120 nonwords was added to the word list used for the reading aloud task (Experiment 3). The nonwords were derived from the words by changing one or two letters. They
were matched with the words for length in letters and bigram frequency. The nonwords were excluded from the analyses (and the computation of $z$-scores across the four experiments).

**Procedure**

The general procedure was the same as that in Experiment 2. The 240 experimental items were presented in eight blocks of 30 trials each. Each block consisted of 15 words and 15 nonwords. Presentation order within and among blocks was fully randomised. Each experimental block was followed by a short pause. There was a short practice session of 10 trials consisting of five words (other than the experimental items, but with the same characteristics) and five nonwords derived from the words.

As stated above, half of the participants were first administered lexical decision (Experiment 4), and half reading aloud (Experiment 3). Overall, the testing in the four experiments took approximately 45 days. The general design of the statistical analyses was similar to that described for Experiment 1. Participants and items were crossed independent random effects. Fixed effects were group (dyslexics vs controls), frequency (high vs low) and length (four, five, six and seven letters). To control for the effect of repetition, number of stimulus presentations was entered as a covariate.

**Results**

Invalid trials accounted for 0.2% of the data points for the dyslexic group (there were no missing data for the controls). Main results are presented in Figure 4a (raw RTs), 4b ($z$ scores) and 4c (percentages of errors).

**Reaction times**

The Mixed Effects Model analysis showed main effects of frequency, $F(1, 107) = 51.15, p < .0001$ and length, $F(3, 109) = 4.08, p < .01$. The effect of group was not significant, $F(1, 32) = 1, p = .86$. The interaction between group and length was significant, $F(3, 3582) = 7.08, p = .0001$: controls were not affected by length. Dyslexics showed significant differences in the comparisons between four- and six-/seven-letter words (at least $p < .05$) as well as between five- and seven-letter words ($p < .05$); on average, there was a 0.16 z-score mean increase per letter. No other interactions were significant. The effect of stimulus repetition was marginally significant, $F(1, 1209) = 3.79, p = .051$.

**Errors**

The Mixed Effects Model showed a main effect of frequency ($z = -2.54, p = .011$), indicating more errors on LF than HF words. The effect of length fell short of significance ($z = 1.83, p = .066$); fewer errors on seven-letter words were present compared with the other length conditions. The main effect of group ($z = -0.02, p = .98$), and all interactions were nonsignificant (all $zs < 1$).

**Summary of results**

Word frequency affected the performance of both groups, indicating similar lexical access for both dyslexics and controls. Dyslexics' decision speed, as opposed to controls, showed great sensitivity to stimulus length, consistently with findings in other languages, such as
French (Bosse et al., 2007; Juphard et al., 2004) and Dutch (Martens & de Jong, 2006). Notably, the length by group interaction was not due to over-additive effects.

Both groups were relatively accurate in deciding on HF words irrespective of stimulus length. The effect of length indicated a tendency (for both groups) to make fewer errors in
lexical decision on seven-letter words compared with shorter ones. Longer LF words may be easier to respond to correctly than shorter words, possibly because their orthographic whole-form is more distinct.

Global differences in RTs: a cross-experiment comparison

Based on the framework of the RAM (Faust et al., 1999), data from all four experiments were analysed to determine whether global components were present that could have contributed to group differences in performance between dyslexic and skilled readers.

The RAM assumes that different individuals have a different rate of information processing and that experimental conditions require a certain amount of information to be processed (i.e. they have a given difficulty) before a correct response can be produced (Faust et al., 1999). The ratio of information-processing amount over rate of processing is believed to predict response latencies across a variety of experimental conditions. This ratio identifies a multiplicative principle, which allows identifying the large-scale influences that can be ascribed to global factors, as separate from the small-scale influences that indicate the effect of specific experimental manipulations. To detect the presence of a global factor, the RAM makes a number of predictions regarding the performances of two groups that differ for general performance across various conditions. The data of the four experiments presented here provide an excellent opportunity to evaluate the potential influence of this global factor for two reasons. First, the four experiments were carried out on the same children. Second, we tested the children across experimental conditions varying for type of task (naming aloud, lexical decision) and type of stimulus (words varying for frequency and length and nonwords).

The RAM predicts a linear relationship between the condition means of two groups that vary in overall information-processing rate. To check for this relationship, dyslexics' and controls' condition means were plotted against each other in Figure 5a.

Several observations emerge from the inspection of the graph. First, data points progressively diverge from the diagonal line; therefore, more difficult conditions generate generally larger group differences over and above the influence of specific condition effects (over-additive effect). Second, data points are well fit by a single regression line that accounts for a very large proportion of variance ($R^2 = .94$). Note that this relationship holds for a variety of stimulus materials (HF and LF words, nonwords, etc.) as well as different tasks (i.e. reading and lexical decision). The specific effects described in the four experiments add to (or detract from) this general baseline. For example, longer stimuli produce generally slower performance in dyslexics even after taking into account this global factor (Experiments 3 and 4). For example, in Experiment 1, the (marginally significant) group effect indicated generally better performances in dyslexics. In Figure 5a, note that the data points of Experiment 1 (open and filled circles) generally lie below the regression line, whereas the opposite trend is present for the data points of Experiment 3 (open diamonds). This indicates that naming deficits are more severe when blocks with only words are presented than when words are intermingled with nonwords. Third, the slope of the regression line (2.55) represents a synthetic marker of the severity of the reading deficit (see Kail & Salthouse, 1994); that is, dyslexics’ RTs are on average 2.5 times slower than those of control children (indicating a 150% delay).

Successively, we tested the prediction of a linear relationship between overall group means and $SD$s across individuals in the same conditions (this prediction refers to the whole group, including both dyslexics and controls). To this aim, in Figure 5b, we plotted
Figure 5. Test of RAM predictions based on results of dyslexics and skilled readers in several experimental conditions. (a) Dyslexics’ condition means are plotted as a function of skilled readers’ means. Different symbols are used to identify data from the four experiments and data based on word or nonword stimuli. The diagonal dotted line in the graph indicates the reference for identical performance between the two groups. Note that all data points lie above the diagonal dotted line indicating that dyslexics were slower than controls in all conditions. (b) Standard deviations across individuals (dyslexics and skilled readers) are plotted as a function of overall group means for the same conditions (symbols as in (a)).

the condition means of the total sample against the SDs of the same conditions. Note the general tendency for more difficult conditions to be associated with larger variability values. Data points are well fit by a single regression line that accounts for a very large proportion of variance (\(R^2 = .93\)). Finally, note that the relative position of the data points with
regard to the regression line is consistent with the results presented in Figure 5a: the data points of Experiment 1 lie below the regression line, indicating that variability tends to be lower than the general prediction when words are intermingled with nonwords; by contrast, data points of Experiment 3 lie predominantly above the regression line, indicating the opposite.

**Summary of results and comments**

These regression analyses provide strong support for the idea that large-scale influences contribute to determining group differences between dyslexics and controls. The mean performance of the group of dyslexics in a set of conditions can be predicted quite accurately by considering the regression parameters of the linear regression of the condition means of the control group. Note that this relationship holds for a variety of stimulus materials (HF and LF words, nonwords, etc.) as well as different tasks (i.e. reading and lexical decision).

Also, inter-individual variability across conditions was quite closely related to mean condition performances. This is a systematic deviation from the homogeneity assumption, on which standard analyses of variance (ANOVAs) are based and justifies our use of the z-score data analyses.

According to Kail and Salthouse (1994), the slope of the regression provides an effective estimate of individual variation on a global factor and therefore of the degree of the impairment. In the present data, dyslexics were 2.5 times slower than typically developing readers across conditions, that is, they had a rather severe deficit (c. a 150% delay). Note that reading slowness on the standard reading task (MT Test) was less pronounced; dyslexic children were 1.8 times slower than control children (indicating an 80% delay; see Table 1). RTs selectively capture the decoding part of the reading process, whereas the measure of reading time includes both the decoding and articulatory components of reading, with the latter being unimpaired in dyslexic children (e.g. Wimmer, Mayringer & Landerl, 1998). Therefore, these data are consistent with the idea that the decoding part of the reading process is most affected in dyslexia.

The results suggest that naming deficits were more severe when the stimulus list contained only words than when words were intermingled with nonwords. In a recent experiment, we systematically manipulated the effect of list context and confirmed that the dyslexics’ reading deficit was greater when only word stimuli were presented (Paizi, De Luca, Burani & Zoccolotti, 2011).

Overall, it seems that the general speed of processing words and nonwords is an important parameter in explaining the reading deficit over and above the effects of specific conditions. This finding confirms and extends similar previous observations (Di Filippo et al., 2006; Zoccolotti et al., 2008) based on a smaller set of experimental conditions. As the global factor accounts for the analysis of both words and nonwords, we tentatively proposed that it could indicate the ability to code the graphemic string; indeed, this would represent an obligatory step in proceeding to lexical–sub-lexical analysis of the word (Zoccolotti et al., 2008). Recently, we demonstrated that, unlike the case of words and nonwords, tasks requiring the naming or matching of individual letters or syllables did not contribute to the global factor (De Luca, Burani, Paizi, Spinelli & Zoccolotti, 2010). These findings further support the idea that the processing of the graphemic string underlies the global factor examined here. This proposal shares similarities with that proposed by Marsh and Hillis (2005) based on neuroimaging and lesional data. These authors proposed that creating and holding in memory a graphemic string (called ‘graphemic description’) is a necessary stage for word
recognition. The occipitotemporal areas, which are often called the visual word form area, would constitute the neural substrate for this processing.

**General discussion**

Overall, the results indicate that the deficit in Italian developmental dyslexic readers is not specific to lexical reading, because lexicality and frequency affect the reading of both typically developing and dyslexic young Italian readers. A single global factor explains a large proportion of the differences in (RTs) performance between dyslexics and controls. A residual (specific) length effect survived in dyslexics after taking into account the over-additive effect; that is, it could not be explained by their overall worse performance.

The present study shows for the first time that Italian dyslexic children read both HF and LF words faster than nonwords, consistently with previous findings in adult readers (Pagliuca et al., 2008). The importance of this finding is underscored by the fact that the words presented for reading aloud were mixed with nonwords. In a list in which words are mixed with nonwords, the regularity of Italian transparent orthography should maximally favour use of the nonlexical reading procedure by all children and particularly by dyslexics, who have been hypothesised to over-rely on the nonlexical reading procedure. However, this was not the case here. The lexicality effect of the dyslexics indicates unimpaired access to the orthographic lexicon (see also Ziegler et al., 2008).

This finding is reinforced by the results of a lexical decision task, which was carried out with the same children and the same sets of stimuli. In fact, in both dyslexics and controls decision times were faster for HF and LF words than for nonwords. Dyslexics were generally slow and inaccurate. Their slowness may reflect difficulty in processing (visually or orthographically) letter strings as whole units prior to accessing the lexicon.

The word frequency effect on reading times is reported – for the first time – on both short words (in Experiment 1) and long words (in Experiment 3) for both groups. Barca et al. (2006) reported that Italian developmental dyslexics were affected by frequency in reading aloud more than controls, presumably because of an over-additive effect. In the present study, the frequency effect was investigated in a more systematic way, because it was varied orthogonally with length and over-additive effects were controlled for according to the RAM approach (Faust et al., 1999; Zoccolotti et al., 2008). The effect of frequency on Italian developmental dyslexics’ reading aloud (and the absence of an interaction with the group factor) provides strong evidence against a deficit specific to lexical processing. The results on lexical decision in the same set of words and with the same children yielded consistent results. Both dyslexics and controls were affected by frequency and generally made more errors on LF words.

The effect of length, which is thought to be a marker of developmental dyslexia in Italian (Zoccolotti et al., 1999) as well as in other transparent orthographies, such as German (Wimmer, 1993; Ziegler et al., 2003), was confirmed very clearly here. Dyslexics, unlike controls, showed great sensitivity to stimulus length in reading aloud and lexical decision, an effect that was not explained by their overall reading slowness. Typically, developing readers show a minor effect of length (which is stronger for LF words) in reading aloud. In the present study, the effect of length was present for LF and HF words in both groups. The length effect on HF word reading is inconsistent with results on opaque scripts and demonstrates that stimulus length only affects the reading of LF words and nonwords (Ans et al., 1998; Ferrand, 2000; Juphard et al., 2004; Weekes, 1997).
A remarkable difference between the two groups was that dyslexics, but not controls, were affected by word length in lexical decision (Experiment 4). Previous findings on the length effect were inconclusive. Some studies on skilled readers reported length effects in lexical decision (Burani et al., 2002; Burani et al., 2007; Butler & Hains, 1979; Hudson & Bergman, 1985; New, Ferrand, Pallier & Brysbaert, 2006), whereas others did not (Balota, Cortese, Sergent-Marshall, Spieler & Yap, 2004; Juphard et al., 2004; Martens & de Jong, 2006).

For impaired readers, however, length effects in lexical decision have been reported in both opaque, such as French (Bosse et al., 2007; Juphard et al., 2004), and transparent scripts, such as Dutch (Martens & De Jong, 2006) and Italian (Di Filippo et al., 2006). Martens and de Jong (2006) reported length effects in Dutch developmental dyslexics’ lexical decision, which they attributed to over-reliance of the dyslexics on the sub-lexical reading procedure. However, their interpretation was based on the length effect only, as other lexical variables, such as word frequency, were not manipulated. Moreover, Di Filippo et al. (2006) found that length affected performance of Italian developmental dyslexics for both words and nonwords in lexical decision, but that the effect was limited to nonwords in typically developing readers. Consistently with the aforementioned study, we found length effects in lexical decision for dyslexics but not controls. Yet, in our study both groups were affected by word frequency. This pattern excludes interpretations of dyslexics’ reading in terms of over-reliance on nonlexical processing. It should be noted that the effect of length on decision times of dyslexic readers has been linked to underlying visual–attentional processing deficits (Ans et al., 1998). Furthermore, it has been suggested that the visual–attentional disorder may be an independent cognitive disorder that contributes to developmental dyslexia (Bosse et al., 2007; Facoetti et al., 2006; but see Hawelka & Wimmer, 2008 for an assessment of purely visual tasks with different results).

The marked length effect in both reading aloud and lexical decision in developmental dyslexics and its coexistence with the frequency effect in our data are difficult to explain in terms of surface dyslexia as it has been framed within the standard dual-route framework (e.g. Coltheart et al., 2001). The effect of length was found along with the effects of lexicality and frequency in two different tasks (reading aloud and lexical decision) in the same population. Lexicality and frequency effects advocate for lexical access of dyslexics against previous interpretations of a selective deficit in lexical processing and over-reliance on nonlexical reading (see also Burani, Marcolini, De Luca & Zoccolotti, 2008 for morpho-lexical effects in developmental dyslexics).

The cross-experiment analysis suggested that a single global factor accounts for a surprisingly large portion of variance in the speed differences between dyslexics and controls across tasks. This factor captures slowness in responding to orthographic stimuli regardless of the lexical value of the stimulus and the type of response and task (i.e. vocal RTs as in naming vs decision times in lexical decision). Consistently with previous work (Zoccolotti et al., 2008), it is suggested that this global factor marks a level of prelexical graphemic analysis that precedes further lexical or sub-lexical processing. The present data indicate that if the dyslexics’ defect in graphemic analysis is taken into consideration, their capacity for lexical activation is similar to that of skilled readers. Indeed, this is contrary to the hypothesis that their reading is primarily nonlexical.

Acknowledgements

This work was supported by the EU Sixth Framework Marie Curie Research Training Network (MRTN-CT-2004–512141): Language and Brain (RTN: LAB, http://www.hull.
ac.uk/RTN-LAB/). We are grateful to Gloria Di Filippo and Mara Trenta for their help with the data collection and Chiara Valeria Marinelli and Daniela Traficante for advice on the statistical analyses. We would also like to thank Claire Montagna for her help.

References


Appendix: High- and low-frequency words used in Experiments 3 and 4*

<table>
<thead>
<tr>
<th>High frequency</th>
<th>Low frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>ACQUA (water)</td>
<td>ABISSO (abyss)</td>
</tr>
<tr>
<td>ALBERGO (hotel)</td>
<td>ACETO (vinegar)</td>
</tr>
<tr>
<td>ALUNNO (student)</td>
<td>AGGUATO (ambush)</td>
</tr>
<tr>
<td>ARGENTO (silver)</td>
<td>AGIO (comfort)</td>
</tr>
<tr>
<td>ARTE (art)</td>
<td>ASFALTO (asphalt)</td>
</tr>
<tr>
<td>AULA (classroom)</td>
<td>ASMA (asthma)</td>
</tr>
<tr>
<td>BALCONE (balcony)</td>
<td>ATLETA (athlete)</td>
</tr>
<tr>
<td>BESTIA (beast)</td>
<td>ATRIO (foyer)</td>
</tr>
<tr>
<td>CAMINO (fireplace)</td>
<td>BAVA (froth)</td>
</tr>
<tr>
<td>CANDELA (candle)</td>
<td>BEFANA (Epiphany)</td>
</tr>
<tr>
<td>CANE (dog)</td>
<td>BELVA (wild beast)</td>
</tr>
<tr>
<td>CANZONE (song)</td>
<td>CANGURO (kangaroo)</td>
</tr>
<tr>
<td>CAPRA (goat)</td>
<td>CATINO (basin)</td>
</tr>
<tr>
<td>CASA (house)</td>
<td>CLERO (clergy)</td>
</tr>
<tr>
<td>CAVALLO (horse)</td>
<td>COMETA (comet)</td>
</tr>
<tr>
<td>COLORE (colour)</td>
<td>COMIZIO (campaign speech)</td>
</tr>
<tr>
<td>CUORE (heart)</td>
<td>CORALLO (coral)</td>
</tr>
<tr>
<td>DONNA (woman)</td>
<td>CORO (choir)</td>
</tr>
<tr>
<td>ESTATE (summer)</td>
<td>CRANIO (skull)</td>
</tr>
<tr>
<td>FAME (hunger)</td>
<td>CUBO (cube)</td>
</tr>
<tr>
<td>FATA (fairy)</td>
<td>CUOIO (leather)</td>
</tr>
<tr>
<td>FESTA (holiday)</td>
<td>DEMONIO (demon)</td>
</tr>
<tr>
<td>FIAMMA (flame)</td>
<td>FAMA (fame)</td>
</tr>
<tr>
<td>FIGLIO (son)</td>
<td>FANALE (headlight)</td>
</tr>
<tr>
<td>FORESTA (forest)</td>
<td>FIDUCIA (trust)</td>
</tr>
<tr>
<td>FRASE (phrase)</td>
<td>FLOTTA (fleet)</td>
</tr>
<tr>
<td>FRECCIA (arrow)</td>
<td>FOGNA (sewer)</td>
</tr>
<tr>
<td>GARA (race)</td>
<td>FUNE (rope)</td>
</tr>
<tr>
<td>LIBRO (book)</td>
<td>FURGONE (van)</td>
</tr>
<tr>
<td>MUCCA (cow)</td>
<td>FURTO (theft)</td>
</tr>
<tr>
<td>NEBBIA (fog)</td>
<td>LACCIO (lace)</td>
</tr>
<tr>
<td>NEGGOZIO (shop)</td>
<td>LATTUGA (lettuce)</td>
</tr>
<tr>
<td>NEVE (snow)</td>
<td>LIDO (shore)</td>
</tr>
<tr>
<td>ODORE (smell)</td>
<td>LISTA (list)</td>
</tr>
<tr>
<td>PACE (peace)</td>
<td>MUMMIA (mummy)</td>
</tr>
<tr>
<td>PALAZZO (building)</td>
<td>PACCO (parcel)</td>
</tr>
</tbody>
</table>
Despina Paizi conducted her PhD thesis in Cognitive Neuroscience at the University of Rome ‘La Sapienza’ in collaboration with the Institute of Cognitive Sciences and Technologies (ISTC-CNR) which was funded by a European Union Marie Curie studentship. Her research interests lie in the area of psycholinguistics, developmental reading disorders, orthographic transparency and its relationship with reading processing as well as stress assignment. The results of her research in the field of developmental reading disorders and especially developmental dyslexia have been presented in many scientific conferences and they have also been published in international scientific journals.

Maria De Luca is a psychologist and a researcher in Neuropsychology at Fondazione Santa Lucia (Scientific Institute for Research, Hospitalization and Health Care) in Rome, Italy. She conducts experimental and clinical research in neuropsychology, neuropsychological rehabilitation and developmental reading deficits. Her research interests also include visual function and eye movement pattern evaluation in typically developing children, children with developmental deficits and adults with acquired brain lesions. She has published her research in numerous international scientific journals.

Pierluigi Zoccolotti is Professor of General Psychology at the Sapienza University in Rome, where he gives courses on perception and on learning disabilities. He is also director of the School of Specialization in Neuropsychology. He has carried out research on various topics in cognitive psychology and neuropsychology, including space orientation, attentional disorders and neglect, and has published many scientific articles in international refereed journals. In the last decade, his research interests have been focused on developmental reading and writing deficits.
Cristina Burani is a Senior Researcher at the Institute of Cognitive Sciences and Technologies (ISTC), CNR, Rome, Italy. She conducts research in experimental psycholinguistics and neuropsychology of language, with main reference to lexical processing, reading aloud, developmental and acquired dyslexia. She is author of several publications in international refereed journals. She has taught Psycholinguistics and Neuropsychology of Language at the University of Trieste and Rome ‘La Sapienza’. She had supervising appointments in PhD programmes in Neuropsychology, Cognitive Neurosciences, Experimental Psychology, Developmental and Clinical Psychology at the Universities of Rome-La Sapienza and Trieste, in the framework of national and European Community grants.

Received date 26 July 2011; revised version received 31 March 2011.

Address for correspondence: Despina Paizi, Institute of Cognitive Sciences and Technologies (ISTC-CNR), Via San Martino della Bataglia 44, 00185 Rome, Italy. E-mail: despina.paizi@istc.cnr.it