Scientific
Research
Publishing

Reading Skills in Deaf Subjects: Role of Psycholinguistic Factors and Global Influences in Affecting Reading Performance

Chiara Valeria Marinelli[1*], Francesca Vizzi[1], Pierluigi Zoccolotti[2,3]

[1]Laboratory of Applied Psychology and Intervention, Department of History, Society and Human Studies, University of Salento, Lecce, Italy
[2]Department of Psychology, Sapienza University of Rome, Rome, Italy
[3]ISTC Institute for Cognitive Sciences and Technologies, CNR, Rome, Italy
Email: *chiaravaleria.marinelli@unisalento.it

Abstract

The present study examined the role of psycholinguistic variables, as well as the presence of a global factor, in modulating reading speed and accuracy in individuals with a severe hearing impairment. Thirteen deaf and thirteen hearing young adults who completed high school and were proficient in both oral lipreading and Italian sign language were examined and compared to a group of control subjects matched for gender, age and education. A wide spectrum of psycholinguistic variables affecting reading were examined, marking visual (letter confusability), sub-lexical (length, grapheme contextuality), lexical (frequency, N-size, stress) and semantic (age of acquisition and imageability) processes. Vocal reaction times (RT) in reading aloud single words were slower in deaf participants with respect to hearing subjects but they were affected by psycholinguistic variables in a very similar way than in the case of controls. Moreover, deaf individuals did not show a multiplicative effect as a function of word difficulty in their reading slowness but only a constant delay. Overall, the deficit shown by deaf participants was relatively limited and not associated to specific cognitive processes. This finding is in keeping with the idea that at least some individuals with a severe hearing impairment may reach reasonably high levels of word decoding.

Keywords

Reading, Deaf Subjects, Global Factor, Lexical Reading, Sublexical Reading

1. Introduction

Individuals with moderate to severe deafness show various degrees of difficulty

in learning to read and write effectively. Understanding the source of these difficulties is complex as several different abilities contribute to the acquisition of literacy even in typical development.

One important foundation of literacy rests on the acquisition of oral language skills. Several studies (e.g. Perfetti & Sandak, 2000; Musselman, 2000) have shown that deaf people present several difficulties in language as consequences of a variety of factors. One of these factors is the late exposure to spoken language compared to hearing children (Bertone & Volpato, 2009). In fact, even if the diagnosis of deafness is made early, it takes some time before the child learns to read the labial and to exploit any acoustic residual through the hearing aids. This typically produces a delay in the exposition to language. The phonological deficit and language delay may have consequences on the learning of reading and writing skills. Indeed, even in hearing children the presence of a language delay reflects on the quality of written language acquisition and text comprehension (Angelelli et al., 2016; Chilosi et al., 2009). In fact, deaf subjects report less adequate written language skills compared to hearing people, matched for age and years of education (Williams & Mayer, 2015); moreover, in most cases, the difficulties are also found after some periods of rehabilitation (Bertone & Volpato, 2009). Productions of deaf subjects in writing tasks have peculiar traits (Caselli et al., 2006; Chesi, 2006): text is characterized by poor vocabulary and the formulation of short and telegraphic sentences. Importantly, the deficit in the use of syntax is not confined to production but there is evidence that deaf children are also impaired is solving visually presented syntactic contrasts (such as active-passive, single-plural etc.; Bishop, 1983). In addition, significant errors are found in the nominal domain, specifically a systematic omission of indefinite articles, while in the verbal domain, the difficulties are mainly reported in ordering the subject and verb (Franchi & Musola, 2010). Many errors and omissions are reported in the use of free morphology, especially in the use of pronouns and prepositions (Chesi, 2006). The difficulty of deaf people to understand and use these words in a proper way is mainly caused by their length (number of letters), their atonic nature, and the lack of semantic content, and by the fact that they are not essential within the discourse. These characteristics make these words difficult to identify through lip-reading.

Several studies have shown that, as a group, the reading skills of deaf children are poorer compared to those of hearing peers (Geers, 2003; Geers & Hayes, 2011; Harris & Terlektsi, 2010; Johnson & Goswami, 2010; Kyle & Harris, 2006; Moeller et al., 2007). However, it must be noted that also large inter-individual differences are reported such that a proportion of deaf individuals read at much the same level of hearing subjects (e.g. Bélanger et al., 2012a). A pioneering study, dating about forty years ago (Conrad, 1979), had already pointed out that, as a group, the reading skills of deaf subjects were considerably worse than the reading abilities of hearing subjects. Specifically, this study, conducted on a considerable number of deaf students who left school between 1974 and 1976, revealed that less than 15% of the entire sample reached an adequate level in read-

ing tasks. Also, illiteracy of deaf students is reported to be higher than that of hearing peers (Sánchez & García-Rodicio, 2006). More recent evidence indicates that the use of hearing cochlear implants has significantly enhanced the quality of reading skills in deaf children even though, as a group, they still showed lower performance in reading; notably, less improvement was noted in the case of writing (Mayer et al., 2016). In part as an effect of this, it has been noted that deafness *per se* is a poor predictor of reading efficiency (Moreno-Pérez et al., 2015).

How should the presence of impaired reading along with large inter-individual variability be interpreted? There seem to be two major lines of research. One focusses on the role of the phonological deficit connected with the hearing impairment; in this view, impairment in reading directly depends on the level of phonological skills acquired. A different line of research focuses on the possible presence of qualitative differences in strategies in the reading of deaf and hearing subjects. Below, we briefly describe the main evidence connected with these two lines of research.

In deaf subjects, the perception of phono-acoustic details of language is obviously lower with respect to hearing people (Brown & Bacon, 2010; Pisoni et al., 2008; Tomblin et al., 2015). In fact, deaf individuals are able to access phonology only using multiple compensation strategies, but notably these are not always effective in order to achieve a good result (Leybaert, 1993; Marschark & Harris, 1996). The difficulty in accessing the acoustic input leads to a consequent poor phonological competence (Lyxell et al., 2008; Pisoni et al., 2008), that in turn may affect reading (and spelling) acquisition. Potentially critical to this idea is the performance of deaf individuals in tasks specifically calling for phonological processing, often involving the presentation of pseudo-homophones. Unfortunately, evidence is mixed showing the whole spectrum of possible outcomes. Based on a masked phonological priming paradigm, Gutierrez-Sigut et al. (2018) reported that deaf individuals showed faster word identification times in the pseudo-homophone than in the control condition. Similar results were reported in a study using both behavioural and ERP measures (Gutierrez-Sigut et al., 2017) and in a study on English children by Blythe et al. (2018). Transler and Reitsma (2005) found that pseudo-homophony effects were present but smaller in deaf individuals than in hearing controls. Yet different findings were reported by Bélanger et al. (2012a) who, using a masked priming paradigm, found that orthographic codes were used independent of the hearing deficit but phonological codes were used only by skilled hearing subjects. The authors of studies obtaining evidence of pseudo-homophone effects in deaf individuals underscore the critical role of phonological processing in reading. In this vein, impaired reading is seen as a direct consequence of low phonological processing. However, there are quite different views regarding the relationship between reading skills and phonology in deaf individuals (Leybaert, 1993; Musselman, 2000; Perfetti & Sandak, 2000).

In a different line of research, several authors claim that deaf individuals can

achieve an adequate level of literacy only if they employ reading mechanisms that are not based on a phonological conversion process but on lexical processing (Mayberry et al., 2011; Strong & Prinz, 2000) or contextual information. For example, Domìnguez and Alegrìa (2010) hypothesized that the strategy used by many deaf readers in adulthood is to ignore function words and low frequency words and focus on the key words of a text to derive the global meaning of the sentence they are reading (see also Domínguez et al., 2014). In this vein, a direct comparison of the structure of the lexicon indicates that deaf people are on average quite similar to hearing subjects (McEvoy et al., 1999). Interesting evidence on this issue comes from studies of eye movements (for a review see Bélanger & Rayner 2015). In particular, it has been found that the general pattern of eye movements in reading of deaf individuals is similar to that of hearing subjects but clear differences are also present in some parameters. In particular, in reading meaningful texts deaf individuals show fewer regressions than what is typical for hearing subjects (i.e. 15% - 20% of movements) thus also making fewer word refixations. Furthermore, they skip function words more often than do hearing subjects. This pattern may indicate a tendency to focus on critical lexical items and context (Mayberry et al., 2011; Strong & Prinz, 2000). However, Bélanger and Rayner (2013) also note that the tendency for a greater use of contextual information in deaf individuals (as originally proposed by Fischler, 1985) is not a general characteristic but it is actually present only on low achieving deaf individuals. Accordingly, Bélanger and Rayner (2015) propose that the (small) proportion of deaf individuals who perform at the same level of hearing subjects actually develop a particular skill in word processing (referred to as "*word-processing efficiency hypothesis*"). Evidence on this comes from eye movement data using the so-called boundary paradigm which provides an online measure of the size of the parafoveal visual span (Bélanger et al., 2012b). Notably, profoundly deaf individuals who were skilled readers had a larger visual span than controls matched for reading ability. This finding is in keeping with the idea that some (though not all) deaf individuals are able to optimize their orthographic skills even in the presence of deficient phonological processing so as to fill the gap in reading as envisaged by the word-processing efficiency hypothesis (Bélanger & Rayner, 2015). Consistent evidence also comes from the use of the gaze-contingent boundary paradigm (Bélanger et al., 2013): hearing subjects showed the activation of both phonological and orthographic codes while deaf individuals were sensitive only to orthographic codes. Overall, some experimental data point to the presence of qualitative differences in the word-processing of deaf individuals; at least a proportion of them seem able to optimize the visual-orthographic components of reading reaching a performance level comparable to that of skilled hearing readers.

Some evidence pointing to qualitative differences between deaf and hearing subjects also comes from neurophysiological and imaging data. Based on fMRI data, Glezer et al. (2018) reported similar activation in the so-called visual word form area (VWFA) in deaf and hearing subjects but less activation in the tem-

poroparietal cortex commonly believed to subsume phonological processing. Furthermore, deaf individuals showed sensitivity to orthographic but not phonological information in the inferior frontal gyrus. Consistent findings were reported by Wang et al. (2014) who found spared activation of VWFA but also reduced resting-state connectivity between the VWFA and the auditory speech area in the left anterior superior temporal gyrus. Also consistent appears the evidence based on evoked potentials (ERP) data. Thus, deaf individuals showed spared N170 (known to be sensitive to print-tuning) in occipital sites while hearing subjects showed clear N170 responses both in temporal and occipitals areas (Emmorey et al., 2017). Overall, the ERP and MRI data are in keeping with the idea that deaf individuals may actually process information differently from hearing subjects.

To fully characterize the reading profile of individuals with hearing impairment it would be important to exploit the several well-known benchmark effects which have been established in the case of reading (e.g. Perry et al., 2007). However, only a few studies have examined which psycholinguistic characteristics of words modulate reading in deaf individuals. As described above, the main interest has been on phonological effects while only a few studies have considered the role of frequency or contextual effects (e.g. Bélanger et al., 2013). In Italian (Barca et al., 2013), the language object of the present research, one study examined the lexicality effect in deaf individuals (either using a spoken or a sign language) and in control hearing subjects using a task requiring to discriminate words from letter strings. No difference was found between deaf individuals, using spoken language, and controls while deaf individuals using sign language showed an advantage for words possibly pointing to a lexical strategy in subjects experienced in this mode of communication.

In the present study our aim was to examine which psycholinguistic variables affect the reading performance of the deaf individuals in order to observe if and how these may differ from what is observed with hearing subjects. To this purpose, we examined the role of visual, phonological, lexical and semantic and variables in modulating the vocal reaction times (RT) and accuracy in reading aloud single words. In particular, we aimed to evaluate a wide spectrum of variables including visual (letter confusability), sub-lexical (length, grapheme contextuality), lexical (frequency, N-size, stress) and semantic (age of acquisition and imageability) processes. In general, based on the reviewed literature, we expected spared lexical and semantic processing in deaf individuals while some deficits may me envisaged in the case of sub-lexical (phonological) effects such as length and grapheme contextuality. Finally, we also evaluated the possibility that deaf subjects would be particularly sensitive to visual parameters, such as visual confusability. In this vein, it should be considered that for some time it has been thought that the role of visual confusability would emerge more clearly in the reading of non-lexical items, i.e. pseudo-words. However, more recent evidence indicates that some effect of visual confusability is observed also in the case of word recognition (Marcet & Perea, 2017, 2018). In this study we focus on

deaf individuals who have reached a reasonably good level of oral (and sign) communication: in fact, we examine young adults who had completed high school and were proficient in both oral lipreading and Italian sign language and compare them to a group of control subjects matched for gender, age and education.

Note that, when two groups vary for general level of performance, differences in specific experimental conditions may depend upon the combined effect of global differences in cognitive speed and the specific influence of a given experimental manipulations. The exam of vocal RTs allowed evaluating the possible contribution of a global factor in the reading times of deaf subjects. In this vein, a deficient performance by deaf subjects does not necessarily imply a specific deficit of the subject, but may represent the result of the influence of global components on the performance across reading conditions. The presence of a general speed deficit may affect the performance across different conditions as well as affect the size of the group effect, producing larger groups differences in a "slower" group with respect to a corresponding "fast" control group (Faust et al., 1999 refer to this as the "over-additivity" effect and use it to interpret the slowing produced by aging). As the reviewed research generally pointed to sizeable group differences in the reading skills of deaf and hearing subjects, we thought it would be interesting to examine whether at least part of these differences could be explained in terms of a global factor. To this aim we referred to the rate and amount model (RAM, Faust et al., 1999) and the difference engine model (DEM, Myerson et al., 2003). These two models provide complementary predictions on the detection of global components in the data and have already be found useful when examining the reading skills of dyslexic children in comparison to typically developing peers (e.g. Zoccolotti et al., 2008; Marinelli et al., 2011, 2014; Paizi et al., 2013).

Overall, we compared deaf and hearing young adults in a single word reading aloud task with the aim to quantify their reading impairment and describe which psycholinguistic factors, if any, would characterize best their difficulty. For the first time, we also tested for the possible presence of a global factor in deaf readers. Finally, we also examined whether deaf and hearing individuals would differ in terms of text comprehension skills.

2. Method

2.1. Participants

Participants were 13 deaf young adults (7M, 6F, mean age = 36.64 years; SD = 9.91) and 13 matched control subjects. Information concerning the deaf subjects was collected through the compilation of a specifically created anamnestic report.

The following inclusion criteria were used to select the sample of deaf individuals:

- Diagnosis of deafness (hearing impairment ≥ 70 db);

- Absence of cognitive disorders (investigated by SPM test, Raven, 2008);
- Absence of other sensory, psychiatric or neurological deficits, except deafness.

Sociodemographic characteristics of participants

Table 1 reports the socio-demographic information of the sample. The whole group was resident in Puglia; most participants lived in the province of Lecce

Table 1. Socio-demographic information of deaf and control individuals.

Subject N°	Group	Age	Gender	Employment	Educational level
1	Deaf	34.02	F	worker	13
2	Deaf	34.55	M	unemployed	13
3	Deaf	35.80	M	unemployed	13
4	Deaf	36.33	M	worker	13
5	Deaf	41.20	M	employee	13
6	Deaf	38.42	F	unemployed	11
7	Deaf	33.82	F	employee	13
8	Deaf	29.89	F	unemployed	13
9	Deaf	68.55	M	pensioner	13
10	Deaf	32.14	F	free-lance	13
11	Deaf	31.40	F	unemployed	13
12	Deaf	35.54	M	unemployed	13
13	Deaf	31.47	M	employee	13
14	Control	36.15	M	employee	13
15	Control	33.64	M	employee	13
16	Control	32.03	M	employee	13
17	Control	29.98	M	salesperson	13
18	Control	35.13	F	student	13
19	Control	30.12	F	unemployed	13
20	Control	37.37	F	unemployed	13
21	Control	26.88	M	worker	13
22	Control	32.12	F	free-lance	13
23	Control	31.48	F	employee	13
24	Control	62.52	M	employee	11
25	Control	33.12	F	unemployed	13
26	Control	41.02	M	employee	13
Deaf participants	Mean	37.17			12.85
	SD	9.92			0.55
Controls participants	Mean	35.51			12.85
	SD	8.88			0.55

and only two resided in Brindisi. Note that all participants had a high educational qualification, i.e. second-level high school diploma or professional qualification.

The performance of deaf individuals was compared to that of a group of hearing control subjects, matched one by one with the deaf individuals for gender, age and educational qualifications. As an effect of the selection process, groups did not differ for gender distribution as well for age and educational level (in both cases ts about 0).

Nine individuals had hearing parents while four had both deaf parents. Participants with hearing parents used the Italian vocal language within the family context but also had good knowledge of Italian Sign Language (ISL). Participants with deaf parents early acquired ISL but also had good lipreading skills. As for type of deafness, 66% of participants had congenital deafness and 34% acquired, with an average age of the diagnosis of 21 months (SD = 15.6). As for the use of hearing aids, 50% of the sample stated that they did not use them at all due to physical discomforts of various kinds; 44% of the subjects stated that they used hearing aids assiduously; the remaining 6% stated that they used the aids sporadically. None of the subjects had had cochlear implantation.

2.2. Materials and Procedure

Text comprehension skills

The comprehension of text was examined through the Advanced 3 MT test (Cornoldi et al., 2017). The participant reads a text passage without a time limit and responds to 10 multiple-choice questions. The participant can check the text again if necessary. The MT comprehension test allows assessing the ability to make semantic inferences and the ability to catch the specific meaning of information provided in the text. Quite often the text does not explicitly offer all the information; therefore, the reader is called, at various levels, to make deductions that require the links between distant parts of the text. Moreover, the inferential process requires that the information, provided in various ways to the reader, should be correctly analysed and interpreted. The ability to comprehend the written text is evaluated in terms of the number of correct responses to the questions concerning the text.

Reading skills

Words from the Varless 2 database (Burani et al., 2015; https://www.istc.cnr.it/it/grouppage/varless) were singly presented to the subjects in a computerized reading aloud test. This database contains 626 morphologically simple Italian nouns, for which information on several psycholinguistic variables, such as age of acquisition, familiarity, imagination, concreteness, word frequency, the number of neighbours (N-size), bigram frequency, length, stress and visual confusability, is available.

Also based on previous research, words in the Varless 2 database can be organized in several different sub-lists aimed to test the effect of specific variables. In

particular, the sub-lists considered here examined the effect of stress assignment (Marinelli, 2010), length (De Luca et al., 2008), frequency (Barca et al., 2007), contextual rules (i.e. letters such as c and g, requiring analysis of subsequent letters in order to by pronounced correctly, Barca et al., 2007), age of acquisition (Mazzotta et al., 2005), word imageability and frequency (Mazzotta et al., 2005), N-size (Marinelli et al., in preparation), and visual confusability by length (Marinelli et al., in preparation). It should be noted that some words appeared in more than one experimental sub-list, even though children read it only once. As specified below, the reference to the organization in sub-lists was used to have a sufficient number of means to test global components in the data (while general analyses on the effect of psycholinguistic variables were carried on the whole Varless 2 database).

Words were presented through the SuperLab software in 5 blocks to avoid attentional drops. Words were presented in the centre of a computer screen. Each letter subtended 0.4 cm horizontally (which, at a distance of 57 cm, corresponds to 0.4 deg of visual angle) with font Verdana and size 42. Each item was preceded by a fixation point (750 ms) and disappeared after subject's response. There was a 250 ms inter-trial interval. The participants read aloud as quickly and as accurately as possible each word presented on the centre of the PC screen. A brief practice with 3 stimuli preceded the experiment.

The program recorded the onset of the vocal response, while the experimenter manually recorded errors in the subject's production with the support of an audio-recorder. Note that only errors were scored, while pronunciation defects were not penalized in deaf subjects.

The RTs corresponding to errors were not included in the analyses. Self-corrections were considered errors and the corresponding RTs were not included in the analyses. False responses and invalid trials (i.e. responses lower than 300 ms or higher than 3000 ms) were excluded from the analyses (0.12% for control and 2.25% for deaf participants, respectively; $t_{(25)} = 2.95$, $p < 0.01$).

2.3. Procedure

Testing was conducted individually in an isolated room. Test instructions were given both in Italian and in ISL. Subjects were informed about the experimental procedure and gave their written consent to participate to the study and to the recording of reading performance. The study was conducted according to the principles of the Helsinki Declaration.

2.4. Data Analysis

As to global components in the data, since RAM (Faust et al., 1999) and DEM (Myerson et al., 2003) make explicit predictions limited to open scale measures, the analyses were limited to vocal RTs and not for accuracy.

In particular, according to the DEM, the condition means were plotted against the standard deviations of the same conditions separately for the two groups of

subjects (Myerson et al., 2003). The model allows isolating, in the individual performance, a cognitive-decisional compartment (that corresponds to the central cognitive processing and might be affected in a multiplicative way by task difficulty) from a sensory-motor compartment (that adds to the individual performance the "constant" time necessary for sensory processing and motor program and may estimate thought the intercept on the x-axis). To yield a sufficient number of condition means we calculated means and SDs based on several sub-lists (as presented in the Method section) which could be derived from the whole presentation of the Varless 2 database. Note that these condition means were used only to the specific aim of detecting global components while the actual effect of the psycholinguistic variables was tested with the more powerful linear mixed effect models analyses considering the whole Varless 2 database (see description below).

Second, we examined whether the slowness of deaf individuals could be ascribed to the presence of a global factor by means of a Brinley plot. In this way, the prediction of RAM of a linear relationship between the condition means of the two groups was tested.

Next, we examined the possible role of psycholinguistic variables in influencing reading accuracy and speed in reading single words. Initial examination of data indicated a nearly flawless performance from hearing control subjects who were correct in 99.88% of times (SD = 0.97). Also, performance of deaf individuals was high (95.29%; SD = 5.43) though somewhat lower (t = 20.7, $p < 0.0001$) than that of hearing subjects. The presence of a ceiling effect in control subjects prevented from further analyses of accuracy scores. Thus, statistical analyses focussed on RT data only.

Specifically, we run linear mixed effect models analyses on the vocal RTs of the two groups. The whole set of 626 words presented was entered in the analyses. As we wanted to examine several psycholinguistic factors, for practical reasons, we chose to perform two separate analyses, distributing visual, phonological, lexical and semantic variables approximately in the two analyses. In the first one, we entered as fixed factors: word length (number of letters, range 4 - 9), contextual rules (number of contextual rules, range 0 - 4), frequency (values according to Colfis database, Bertinetto et al., 2005, but reported to one million of occurrences; range: 0 - 856) and imageability (rating according to Varless 2 database; Burani et al., 2015; range 1.89 - 6.68), as well as group (deaf and control subjects). Additionally, also the group factors in interaction with all aforesaid variables as fixed factors were added to the model in order to check if these variables affected the two groups differently. Items and participants were added as random factors. In the second model, we entered as fixed factors: letter confusability (mean values for each word; range: 1.75 - 2.73), N-size (number of neighbours according to Colfis database, Bertinetto et al., 2005, range 0 - 28), age of acquisition (rating according to Varless 2 database; Burani et al., 2015; range 1.09 - 6.77), and stress (on the penultimate vs. antepenultimate syllable), as well

as group (deaf and control subjects). Also in this case, the interaction between group and all aforesaid variables were added to the model as fixed factors, in order to check whether groups were differently modulated by these variables. Items and participants were added as random factors.

Performance in text comprehension was compared in the two groups of participants by t test analysis.

## 3. Results

3.1. Detecting Global Components in the Data

In Figure 1, condition means are plotted against the standard deviations of the same conditions separately for the two groups of subjects (as envisaged by the DEM model, Myerson et al., 2003). The fit of the linear regression is reasonably high ($r^2 = 0.83$) with an intercept on the x-axis of 496.6 and a slope of 0.59, indicating that variability increases as a function of condition's difficulty. These two values are compatible with previous reports on reading data (Zoccolotti et al., 2018); also note that reading aloud tasks tend to produce higher slopes and higher intercepts (Zoccolotti et al., 2018) than most other speeded tasks (Myerson et al., 2003). Overall, deaf participants are slower than controls but their inter-individual variability in RTs grows by the same factor as it occurs in hearing participants. Thus, deaf participants were not only slower than hearing control subjects, but also more variable, coherently with the law of RTs that states that the spread of the distribution grows as a function of the mean (Wagenmakers & Brown, 2007).

As the condition means of the two groups did not overlap, in order to get a more continuous distribution we replicated the means versus standard deviations plot also using performance on single words in the database, averaging across deaf and hearing subjects, respectively. The relevant data are presented in Figure 2. The fit of the linear regression is moderate ($r^2 = 0.42$) with an intercept on the x-axis of 441.4 and a slope of 0.65, confirming a general tendency for variability to increase as a function of condition's difficulty.

Next, we tested whether the slowness of deaf individuals could be ascribed to the presence of a global factor. To this aim, the prediction of RAM (Faust et al., 1999) of a linear relationship between the condition means of the two groups was examined. The resulting Brinley plot is presented in Figure 3. The dotted diagonal line in the graph indicates the reference for identical performance in the two groups. Inspection of the figure indicates a linear relationship accounting for all conditions ($r^2 = 0.51$). The intercept of the linear fit is 135.51, indicating that deaf subjects were about 136 ms slower than controls. However, their slowness did not vary in a multiplicative way with the difficulty of experimental conditions. In fact, as shown in Figure 3, the slope was close to unity (b = 0.93) and the regression line was nearly parallel to the diagonal dotted line, indicating that both groups were modulated in a similar way by condition difficulty (as due to the influence of psycholinguistic variables).
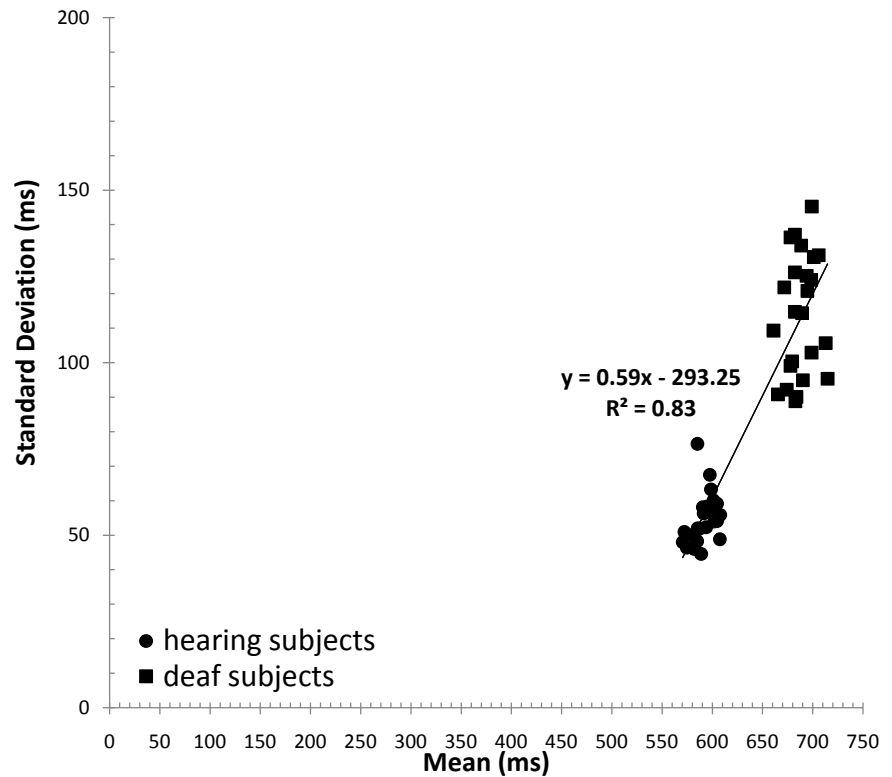
Figure 1. Condition means (in ms) are plotted against the standard deviations of the corresponding conditions. Data of deaf and control subjects are separately presented.
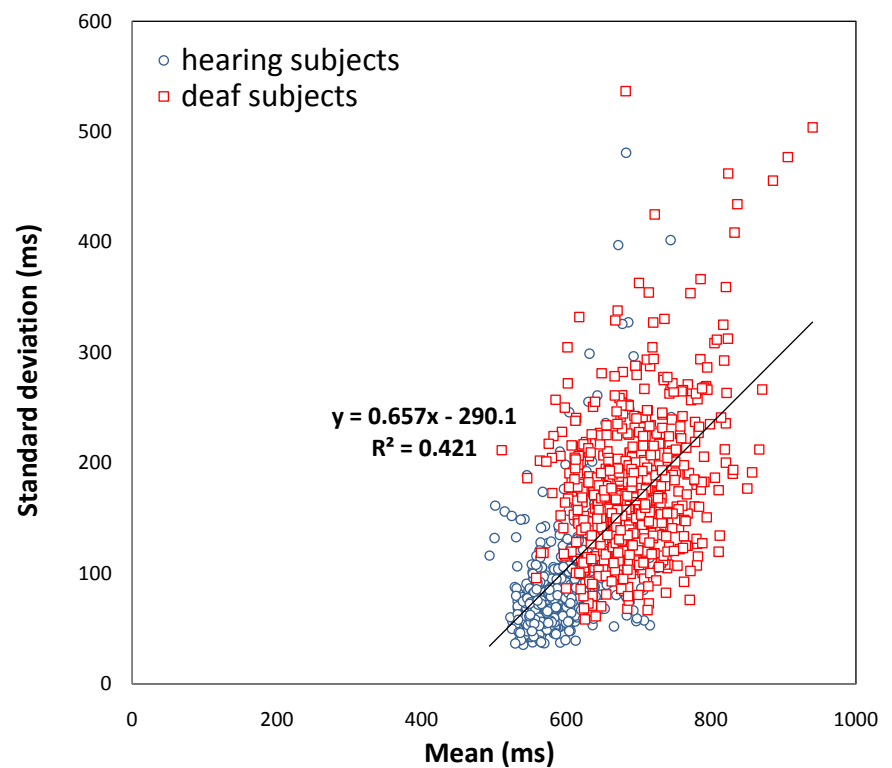
Figure 2. Mean for individual words (in ms) are plotted against standard deviations. Data of deaf and control subjects are separately presented.
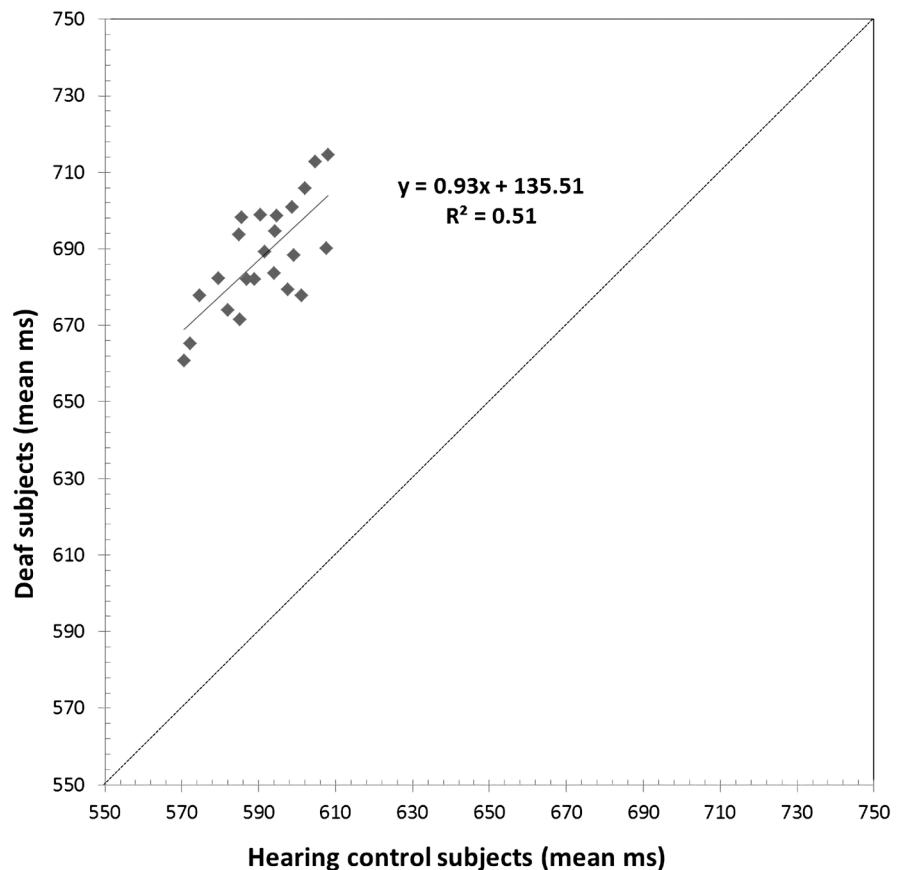
Figure 3. Condition means (in ms) of deaf and control subjects are plotted against each other. The dotted diagonal line indicates the reference for identical performance in the two groups.

Summary of results

Overall, data confirmed that deaf children read slower than hearing controls across conditions. However, this slowness was not affected by a multiplicative factor and both groups were modulated in a similar way by condition difficulty (i.e. as an effect of psycholinguistic variables). Rather the difference could be explained in terms of constant value (intercept). Based on the RAM, the slowness in reading of deaf individuals does not depend upon the influence of a global (multiplicative) factor. For this reason, we did not proceed with the transformation of raw data in z score as suggested by RAM model in case of the existence of a global factor affecting performances (Faust et al., 1999).

3.2. Exam of Psycholinguistic Variables Affecting Reading Accuracy and Speed

To examine the influence of psycholinguistic variables on word recognition, we run two separate linear mixed effects models on vocal RTs.

Results of the first model highlighted the significance of the main effects of the group factor ($F_{(1,15677)} = 71.17$, $p < 0.0001$; $\beta = 37.38$): deaf subjects were slower than controls (mean RTs = 721.54 ms and 685 ms, respectively; diff. = 36.5). The

main effect of length ($F_{(1,15677)}$ = 10.73, p < 0.001; β = 2.78) indicated that RTs slowed by an average of 3.5 ms per each additional letter (mean RT latencies were 627 ms, 639 ms, 645 ms, 654 ms, and 645 ms for 4, 5, 6, 7, 8 and 9-letter words, respectively). The effect of the contextual rules factor was significant ($F_{(1,15677)}$ = 8.26, p < 0.01; β = 5.83). As expected, a greater number of contextual rules in the word yielded slower vocal RTs: words without contextual rules were read on average in 639 ms, words including one grapheme with a contextual rule in 643 ms and words with two or more complex graphemes in 656 ms. The word frequency main effect was significant ($F_{(1,15677)}$ = 14.49, p < 0.0001; β = −0.06). Word frequency affected vocal RTs especially for lower frequency stimuli: stimuli belonging to the 1st tertile of the word frequency distribution (i.e. more infrequent words) were read on average in 658 ms, while words in the 2nd and 3rd tertile (i.e. medium and high frequency stimuli) were read with faster (and similar) RTs (mean of 637 and 634 ms, respectively). The main effect of the imageability factor ($F_{(1,15677)}$ = 4.84, p < 0.05; β = −2.53) indicated that more imageable words (3rd tertile = 639 ms) were read faster than words with medium and lower imageability (2nd and 1st tertile = both 645 ms). The analysis highlighted that the group factor did not interact with any psycholinguistic variable examined: thus, the aforementioned pattern of psycholinguistic variables affecting reading speed was comparable in the two groups of subjects. Random effects of items and participants were both not significant (Zs < 1).

Results of the second model highlighted the significance of the main effects of the group ($F_{(1,15677)}$ = 49.51, p < 0.0001; β = 26.08): Deaf subjects were slower than controls (mean RTs = 735 ms and 699 ms, respectively). Vocal RTs decreased as a function of visual confusability ($F_{(1,15677)}$ = 14.28, p < 0.0001; β = −29.94), passing from 647 ms of the 1st tertile (high-confusability words), to 643 ms to the 2nd tertile (medium-confusability words), to 639 ms of the 3rd tertile (low-confusability words). Age of acquisition affected vocal RTs ($F_{(1,15677)}$ = 19.07, p < 0.0001; β = 5.39) especially for early acquired words: stimuli belonging to the 1st tertile of the age of acquisition distribution (i.e. early acquired words) were read on average in 634 ms, while words in 2nd tertile in 646 ms and words acquired later (i.e. 3rd tertile) in 650 ms. The effect of stress ($F_{(1,15677)}$ = 4.82, p < 0.05; β = 5.22) highlighted that readers of both groups were faster in reading typically stressed words (i.e. words with the stress on penultimate syllable; M = 641 ms) than atypically stressed words (i.e. words with stress on antepenultimate syllable; M = 653 ms). The analysis indicated that the group factor did not interact with any psycholinguistic variable examined: thus, the aforementioned pattern of psycholinguistic variables affecting reading speed was comparable in the two groups. Random effects of items and participants were both not significant (Zs < 1).

Note that the N-size effect was not significant in this analysis ($F_{(1,15677)}$ = 1.16, ns; β = 0.49). In order to further explore this effect, the analysis was replicated adding in the model the Frequency by N-size interaction, as well as the Group by Frequency by N-size interaction. Apart from the previously described results, the

analysis confirmed the absence of a main effect of N-size ($F_{(1,15673)}= 0.02$, ns; $\beta = -0.02$), but indicated the presence of the N-size by frequency interaction ($F_{(1,15673)} = 5.25$, $p < 0.05$; $\beta = -0.01$) pointing to a facilitatory effect of a large N-size for low- and very low-frequency words while no effect was present for high- and medium-frequency words. However, also in this case, the Group by Frequency by N-size interaction was not significant indicating that the influence of N-size factor was similar in the two groups also in the case of low frequency words. Also the other interactions with the group factor were again all not significant. Finally, the random effects of items and participants were both not significant (Zs < 1).

Summary of results

Deaf participants were slower in reading with respect to hearing subjects. However, their reading performance was modulated by the same variables affecting unimpaired readers. In fact, reading speed of both groups was affected by all the visual, lexical, sublexical and semantic variables examined, and no effect interacted with the group factor.

Deaf subjects reached a moderately good accuracy in reading (95.29%), even though their performance was lower with respect to that of hearing control participants, for whom the errors were nearly absent. Note that the presence of ceiling effect in accuracy data did not allow investigating whether, in reading accuracy, deaf participants were modulated by psycholinguistic variables in a different way with respect to hearing subjects.

3.3. Reading Comprehension

Deaf subjects had a lower accuracy in text comprehension (52.3%; SD = 2.62) compared to control participants (83.13%; SD = 1.18; $t_{(25)} = 3.54$, $p < 0.001$).

4. Discussion

The study investigated the reading skills of deaf subjects with a particular interest in the role of psycholinguistic variables and also taking into account the possible influence of a global factor. To this aim, we examined visual, phonological, lexical and semantic effects in order to understand whether one or more of them would affect the reading of deaf individuals in a peculiar way with respect to hearing subjects. To obtain a sufficiently reliable check of the effects of these variables we presented the participants with the whole set of words in the Varless 2 database. Results generally confirmed the effectiveness of this approach. Indeed, significant effects were obtained for letter confusability, word length, frequency, and imageability, age of acquisition and stress as expected (Barca et al., 2002). Also, the effect of N-size was detected when nested with word frequency as previously reported (Barca et al., 2007; Marinelli et al., 2013). Thus, the design of the study appears sufficiently powerful to detect any change in reading processes by deaf readers if they were present. Overall, the results indicated that as a group deaf young adults were slower and also less accurate than

controls closely matched on gender, age and educational level. Yet, the group difference was quantitatively small (ca. 35 ms) and the reading speed of the two groups was modulated in a similar way by the variables examined. Indeed, no interaction with the group factor approached significance, indicating that the impact of the psycholinguistic variables considered was similar in the two groups.

The application of the RAM model (Faust et al., 1999) on vocal RTs highlighted the absence of a global factor affecting reading of deaf individuals. According to the RAM model, general "cognitive speed" and level of processing required to perform a given task (or "difficulty") interact multiplicatively to produce actual reading performance. In the present data, the differences between the two groups grew linearly as a function of condition difficulty, but the slope of the linear regression was near unity, indicating the absence of a multiplicative difference between the two groups as a function of condition difficulty. This highlights that group differences were "genuine", i.e. not due to an over-additivity effect (or global factor). This finding highlights the qualitative difference between the reading slowness of deaf individuals and that of other clinical samples, such as dyslexic children (for a review see Zoccolotti et al., 2019), for which over-additivity accounts for a large proportion of the reading slowness. Across conditions, deaf subjects were slower in reading compared to hearing participants. However, this group difference did not grow numerically as a function of condition difficulty, but it was constant.

It is not entirely clear how this constant value should be interpreted. On logical grounds, it may be thought to indicate the longer time spent for planning the articulatory movement by deaf participants compared to controls. Indeed, the quality of phonological output was generally poor and a lenient scoring system was adopted so as not to penalize the pronunciation defects of deaf subjects. However, it should be noted that, if this interpretation were correct, one would expect that, in the plot matching condition means and standard deviations, the x-intercept would be slightly longer in the case of the RT means of deaf individuals as compared to that of control subjects (Myerson et al., 2003). This pattern could not be detected in the present data and one single regression line accounted reasonably well for the data of both groups in the plot based on the condition means as well as in that based on single word items. However, the group difference was indeed small, amounting to ca. 35 ms in terms of group means. Therefore, it is possible that the plot analysis was simply not sensitive enough to detect such a small difference. Ideally, one should have a larger spread of condition means to obtain a reliable estimate of the intercept on the x axis separately for the two groups of individuals. At any rate, what seems clear, based on models of RTs, such as RAM (Faust et al., 1999) and DEM (Myerson et al., 2003), is that the present data are not in keeping with the idea that the central, or decisional, components of the reading process are impaired in deaf individuals.

A small but detectable group difference was present also in terms of reading

accuracy. As controls were near ceiling, it was not possible to examine this group difference further. It appears that a different experimental design is necessary if one wants to examine differences in terms of reading accuracy.

Results showed a marked difference between deaf and control subjects in comprehension skills: deaf participants had a lower performance in the task of comprehending a written text than hearing control subjects, coherently with previous results (e.g. Wauters et al., 2006). It does not seem likely that the comprehension difficulty of deaf subjects can be entirely explained by problems in word decoding as these were comparatively small as compared to the comprehension deficit. On the contrary, it has been proposed that general linguistic difficulties may contribute to this outcome (Musselman, 2000). Further, it is possible that difficulties in comprehending syntactic contrasts may also contribute in dampening performance in text comprehension (Bishop, 1983).

To place the present results in a context is important to consider the characteristics of our samples: The deaf young adults examined here had completed high school and were proficient both in using oral communication and ISL. Therefore, it seems important to restrict the interpretation of the present findings in light of these characteristics of the examined sample. The literature on reading skills of deaf individuals emphasizes the presence of large individual differences which are still not fully comprehended (e.g. Bélanger & Rayner, 2015). In this perspective, the present data are in keeping with the idea that at least a proportion of deaf individuals may reach a level of performance similar, or only slightly inferior, to that of matched hearing subjects. The present study adds to this conclusion that, if reading performance is relatively good, it is modulated by the same psycholinguistic parameters known to affect reading in typically developing individuals. Further research is needed to examine a wider spectrum of reading skills in deaf individuals and how these might be related to the role of visual, phonological, lexical and semantic factors in reading.

5. Conclusion

Overall, the present finding highlight that the reading skills of deaf young adults were lower than those of a closely matched control group. In particular, as a group they were slower and less accurate in reading single words aloud. However, the group difference in reading speed was quantitatively small (ca. 35 ms) and the RTs of deaf individuals were influenced by psycholinguistic variables in a similar way as those of the control subjects. Furthermore, the group difference in reading speed was constant; i.e. it did not vary as a function of condition difficulty. Based on DEM (Myerson et al., 2003), this indicates that the source of the effect does not involve the central, or decisional, components of the reading process.

Therefore, at least in a sample of young adults with good academic achievement and both oral and sign language communication skills, it appears that the deficit in reading decoding is comparatively small. By contrast, deaf individuals

were markedly affected in the comprehension of a text, indicating that additional factors presumably play a role in this case. It appears important to extend these findings to a larger group of deaf individuals with a wider spectrum of communication skills.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

Angelelli, P., Putzolu, A., Iaia, M., Marinelli, C. V., Gasperini, F., Chilosi, A. M., & Brizzolara, D. (2016). Spelling Impairments in Italian Dyslexic Children with and without a History of Early Language Delay. Are There Any Differences? *Frontiers in Psychology—Educational Psychology, 7,* 527. https://doi.org/10.3389/fpsyg.2016.00527

Barca, L., Burani, C., & Arduino, L. S. (2002). Word Naming Times and Psycholinguistic Norms for Italian Nouns. *Behavior Research Methods, Instruments, & Computers, 34,* 424-434. https://doi.org/10.3758/BF03195471

Barca, L., Ellis, A. W., & Burani, C. (2007). Context-Sensitive Rules and Word Naming in Italian Children. *Reading and Writing, 20,* 495-509. https://doi.org/10.1007/s11145-006-9040-z

Barca, L., Pezzulo, G., Castrataro, M., Rinaldi, P., & Caselli, M. C. (2013). Visual Word Recognition in Deaf Readers: Lexicality Is Modulated by Communication Mode. *PLoS ONE, 8,* e59080. https://doi.org/10.1371/journal.pone.0059080

Bélanger, N. N., & Rayner, K. (2013). Frequency and Predictability Effects in Eye Fixations for Skilled and Less-Skilled Deaf Readers. *Visual Cognition, 21,* 477-497. https://doi.org/10.1080/13506285.2013.804016

Bélanger, N. N., & Rayner, K. (2015). What Eye Movements Reveal about Deaf Readers. *Current Directions in Psychological Science, 24,* 220-226. https://doi.org/10.1177/0963721414567527

Bélanger, N. N., Baum, S. R., & Mayberry, R. I. (2012a). Reading Difficulties in Adult Deaf Readers of French: Phonological Codes, Not Guilty! *Scientific Studies of Reading, 16,* 263-285. https://doi.org/10.1080/10888438.2011.568555

Bélanger, N. N., Mayberry, R. I., & Rayner, K. (2013). Orthographic and Phonological Preview Benefits: Parafoveal Processing in Skilled and Less-Skilled Deaf Readers. *The Quarterly Journal of Experimental Psychology, 66,* 2237-2252. https://doi.org/10.1080/17470218.2013.780085

Bélanger, N. N., Slattery, T. J., Mayberry, R. I., & Rayner, K. (2012b). Skilled Deaf Readers Have an Enhanced Perceptual Span in Reading. *Psychological Science, 23,* 816-823. https://doi.org/10.1177/0956797611435130

Bertinetto, P. M., Burani, C., Laudanna, A., Marconi, C., Ratti, D., Rolando, C. et al. (2005). *CoLFIS (Corpus e Lessico di Frequenza dell'Italiano Scritto) [Corpus and Frequency Lexicon of Written Italian].* https://www.istc.cnr.it/it/grouppage/colfis

Bertone, C., & Volpato, F. (2009) Oral Language and Sign Language: Possible Approaches for Deaf People's Language Development. *Cadernos de Saúde, 2,* 51-62.

Bishop, D. V. M. (1983). Comprehension of English Syntax by Profoundly Deaf Children. *Journal of Child Psychology and Psychiatry, 24,* 415-434. https://doi.org/10.1111/j.1469-7610.1983.tb00118.x

Blythe, H. I., Dickins, J. H., Kennedy, C. R., & Liversedge, S. P. (2018). Phonological Processing during Silent Reading in Teenagers Who Are Deaf/Hard of Hearing: An Eye Movement Investigation. *Developmental Science, 21,* e12643. https://doi.org/10.1111/desc.12643

Brown, C. A., & Bacon, S. P. (2010). Fundamental Frequency and Speech Intelligibility in Background Noise. *Hearing Research, 266,* 52-59. https://doi.org/10.1016/j.heares.2009.08.011

Burani, C., Arduino, L. S., Marinelli, C. V., & Barca, L. (2015). *Variabili lessicali e sub-lessicali-2: Valori per 626 nomi dell'italiano.* https://www.istc.cnr.it/it/grouppage/varless

Caselli, M. C., Maragna, S., & Volterra, V. (2006). *Linguaggio e Sordità. Gesti. segni e parole nello sviluppo e nell'educazione.* Bologna: Il Mulino.

Chesi, C. (2006). *Il linguaggio verbale non standard dei bambini sordi.* Roma: Edizioni Universitarie Romane.

Chilosi, A. M., Brizzolara, D., Lami, L., Pizzoli, C., Gasperini, F., Pecini, C., & Zoccolotti, P. (2009). Reading and Spelling Disabilities in Children with and without a History of Early Language Delay: A Neuropsychological and Linguistic Study. *Child Neuropsychology, 15,* 582-604. https://doi.org/10.1080/09297040902927614

Conrad, R. (1979). *The Deaf Schoolchild.* London: Harper and Row.

Cornoldi, C., Pra Baldi, A., & Giofrè, D. (2017). *Prove MT Avanzate-3-Clinica. La valutazione delle abilità di Lettura, Comprensione, Scrittura e Matematica per il biennio della Scuola Secondaria di II Grado. Erikson.*

De Luca, M., Barca, L., Burani, C., & Zoccolotti, P. (2008). The Effect of Word Length and Other Sublexical, Lexical and Semantic Variables on Developmental Reading Deficit. *Cognitive and Behavioral Neurology, 21,* 227-235. https://doi.org/10.1097/WNN.0b013e318190d162

Domìnguez, A. B., & Alegrìa, J. (2010). Reading Mechanisms in Orally Educated Deaf Adults. *Journal of Deaf Studies and Deaf Education, 15,* 136-148. https://doi.org/10.1093/deafed/enp033

Domínguez, A. B., Carrillo, M. S., del Mar Perez, M., & Alegría, J. (2014). Analysis of Reading Strategies in Deaf Adults as a Function of Their Language and Meta-Phonological Skills. *Research in Developmental Disabilities, 35,* 1439-1456. https://doi.org/10.1016/j.ridd.2014.03.039

Emmorey, K., Midgley, K. J., Kohen, C. B., Sehyr, Z. S., & Holcomb, P. J. (2017). The N170 ERP Component Differs in Laterality, Distribution, and Association with Continuous Reading Measures for Deaf and Hearing Readers. *Neuropsychologia, 106,* 298-309. https://doi.org/10.1016/j.neuropsychologia.2017.10.001

Faust, M. E., Balota, D. A., Spieler, D. H., & Ferraro, F. R. (1999). Individual Differences in Information-Processing Rate and Amount: Implications for Group Differences in Response Latency. *Psychological Bulletin, 125,* 777-799. https://doi.org/10.1037/0033-2909.125.6.777

Fischler, I. (1985). Word Recognition, Use of Context, and Reading Skill among Deaf College Students. *Reading Research Quarterly, 20,* 203-218. https://doi.org/10.2307/747756

Franchi, E., & Musola, D. (2010). *Acquisizione dell'italiano e sordità. Omaggio a Bruna Radelli. Libreria Editrice Cafoscarina.*

Geers, A. (2003). Predictors of Reading Skill Development in Children with Early Cochlear Implantation. *Ear and Hearing, 24,* 59S-68S.

https://doi.org/10.1097/01.AUD.0000051690.43989.5D

Geers, A. E., & Hayes, H. (2011). Reading, Writing, and Phonological Processing Skills of Adolescents with 10 or More Years of Cochlear Implant Experience. *Ear and Hearing, 32,* 49S-59S. https://doi.org/10.1097/AUD.0b013e3181fa41fa

Glezer, L. S., Weisberg, J., Farnady, C. O. G., McCullough, S., Midgley, K. J., Holcomb, P. J., & Emmorey, K. (2018). Orthographic and Phonological Selectivity across the Reading System in Deaf Skilled Readers. *Neuropsychologia, 117,* 500-512. https://doi.org/10.1016/j.neuropsychologia.2018.07.010

Gutierrez-Sigut, E., Vergara-Martínez, M., & Perea, M. (2017). Early Use of Phonological Codes in Deaf Readers: An ERP Study. *Neuropsychologia, 106,* 261-279. https://doi.org/10.1016/j.neuropsychologia.2017.10.006

Gutierrez-Sigut, E., Vergara-Martínez, M., Marcet, A., & Perea, M. (2018). Automatic Use of Phonological Codes during Word Recognition in Deaf Signers of Spanish Sign Language. *Formal and Experimental Advances in Sign Language Theory, 1,* 1-15.

Harris, M. Y., & Terlektsi, E. (2010). Reading and Spelling Abilities of Deaf Adolescents with Cochlear Implants and Hearing Aids. *Journal of Deaf Studies and Deaf Education, 16,* 24-34. https://doi.org/10.1093/deafed/enq031

Johnson, C., & Goswami, U. (2010). Phonological Awareness, Vocabulary, and Reading in Deaf Children with Cochlear Implants. *Journal of Speech, Language, and Hearing Research, 53,* 237-261. https://doi.org/10.1044/1092-4388(2009/08-0139)

Kyle, F. E., & Harris, M. (2006). Concurrent Correlates and Predictors of Reading and Spelling Achievement in Deaf and Hearing School Children. *Journal of Deaf Studies and Deaf Education, 11,* 273-289. https://doi.org/10.1093/deafed/enj037

Leybaert, J. (1993). Reading in the Deaf: The Roles of Phonological Codes. In M. En, D. Marschark, & Clark (Eds.), *Psychological Perspectives in Deafness* (pp. 203-227). Hillsdale, NJ: Erlbaum.

Lyxell, B., Sahlén, B., Wass, M., Ibertsson, T., Larsby, B., Hällgren, M., & Mäki-Torkko, E. (2008). Cognitive Development in Children with Cochlear Implants: Relations to Reading and Communication. *International Journal of Audiology, 47,* 47-52. https://doi.org/10.1080/14992020802307370

Marcet, A., & Perea, M. (2017). Is Nevtral Neutral? Visual Similarity Effects in the Early Phases of Written-Word Recognition. *Psychonomic Bulletin & Review, 24,* 1180-1185. https://doi.org/10.3758/s13423-016-1180-9

Marcet, A., & Perea, M. (2018). Can I Order a Burger at Rnacdonalds.com? Visual Similarity Effects of Multi-Letter Combinations at the Early Stages of Word Recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 44,* 699. https://doi.org/10.1037/xlm0000477

Marinelli, C. V. (2010). *Reading and Spelling in Skilled and Dyslexic Children: A Cross-Linguistic Perspective.* Doctoral Dissertation in Cognitive Neuroscience. Rome: Sapienza University.

Marinelli, C. V., Angelelli P., Di Filippo, G., & Zoccolotti, P. (2011). Is Developmental Dyslexia Modality Specific? A Visual-Acoustic Comparison on Italian Dyslexics. *Neuropsychologia, 49,* 1718-1729. https://doi.org/10.1016/j.neuropsychologia.2011.02.050

Marinelli, C. V., Traficante, D., & Zoccolotti, P. (2014). Does Pronounceability Modulate the Letter String Deficit of Children with Dyslexia? A Study with the Rate and Amount Model. *Frontiers in Psychology, 5,* 1353. https://doi.org/10.3389/fpsyg.2014.01353

Marinelli, C. V., Traficante, D., Zoccolotti, P., & Burani, C. (2013). Orthographic Neigh-

bourhood-Size Effects on the Reading Aloud of Italian Children with and without Dyslexia. *Scientific Studies of Reading, 17,* 333-349.
https://doi.org/10.1080/10888438.2012.723080

Marinelli, C. V., Trenta, M., Benassi, M., Burani, C., & Zoccolotti, P. (in preparation). *Psycholinguistic Factors Affecting the Error Profile in a Regular Orthography.*

Marschark, M., & Harris, M. (1996). Success and Failure in Learning to Read: The Special Case (?) of Deaf Children. *Reading Comprehension Difficulties: Processes and Intervention, 12,* 279-300.

Mayberry, R. I., del Giudice, A. A., & Lieberman, A. M. (2011). Reading Achievement in Relation to Phonological Coding and Awareness in Deaf Readers: A Meta-Analysis. *Journal of Deaf Studies and Deaf Education, 16,* 164-188.
https://doi.org/10.1093/deafed/enq049

Mayer, C., Watson, L., Archbold, S., Ng, Z. Y., & Mulla, I. (2016). Reading and Writing Skills of Deaf Pupils with Cochlear Implants. *Deafness & Education International, 18,* 71-86. https://doi.org/10.1080/14643154.2016.1155346

Mazzotta, S., Barca, L., Marcolini, S., Stella, G., & Burani, C. (2005). Frequenza, immaginabilità ed età di acquisizione delle parole: In che misura influenzano la lettura dei bambini italiani? *Psicologica clinica dello sviluppo, 2,* 247-266.

McEvoy, C., Marschark, M., & Nelson, D. L. (1999). Comparing the Mental Lexicons of Deaf and Hearing Individuals. *Journal of Educational Psychology, 91,* 312.
https://doi.org/10.1037/0022-0663.91.2.312

Moeller, M. P., Tomblin, J. B., Yoshinaga-Itano, C., McDonald Connor, C., & Jerger, S. (2007). Current State of Knowledge: Language and Literacy of Children with Hearing Impairment. *Ear and Hearing, 28,* 740-753.
https://doi.org/10.1097/AUD.0b013e318157f07f

Moreno-Pérez, F. J., Saldaña, D., & Rodríguez-Ortiz, I. R. (2015). Reading Efficiency of Deaf and Hearing People in Spanish. *Journal of Deaf Studies and Deaf Education, 20,* 374-384. https://doi.org/10.1093/deafed/env030

Musselman, C. (2000). How Do Children Who Can't Hear Learn to Read an Alphabetic Script? A Review of the Literature on Reading and Deafness. *Journal of Deaf Studies and Deaf Education, 5,* 11-31. https://doi.org/10.1093/deafed/5.1.9

Myerson, J., Hale, S., Zheng, Y., Jenkins, L., & Widaman, K. F. (2003). The Difference Engine: A Model of Diversity in Speeded Cognition. *Psychonomic Bulletin & Review, 10,* 262-288. https://doi.org/10.3758/BF03196491

Paizi, D., De Luca, M., Zoccolotti, P., & Burani, C. (2013). A Comprehensive Evaluation of Lexical Reading in Italian Developmental Dyslexics. *Journal of Research in Reading, 36,* 303-329. https://doi.org/10.1111/j.1467-9817.2011.01504.x

Perfetti, C. A., & Sandak, R. (2000). Reading Optimally Builds on Spoken Language Implications for Deaf Readers. *Journal of Deaf Studies and Deaf Education, 5,* 32-50.
https://doi.org/10.1093/deafed/5.1.32

Perry, C., Ziegler, J. C., & Zorzi, M. (2007). Nested Incremental Modeling in the Development of Computational Theories: The CDP+ Model of Reading Aloud. *Psychological Review, 114,* 273-315. https://doi.org/10.1037/0033-295X.114.2.273

Pisoni, D. B., Kronenberger, W., Conway, C. M., Horn, D. L., Karpicke, J., & Henning, S. (2008). Efficacy and Effectiveness of Cochlear Implants in Deaf Children. In M. Marschark, & P. Hauser (Eds.), *Deaf Cognition: Foundations and Outcomes* (pp. 52-101). New York: Oxford University Press.
https://doi.org/10.1093/acprof:oso/9780195368673.003.0003

Raven, C. J. (2008). *Standard Progressive Matrices.* O.S. Giunti.

Sánchez, E., & García-Rodicio, H. (2006). Re-lectura del estudio PISA: Qué y cómo se evalúa e interpreta el rendimiento de los alumnos en la lectura. *Revista de Educación, 1,* 195-226.

Strong, M., & Prinz, P. M. (2000). Is American Sign Language Related to English Literacy? In C. Chamberlain, J. Morford, & R. Mayberry (Eds.), *Language Acquisition by Eye* (pp. 131-141). Hillsdale, NJ: Erlbaum.

Tomblin, B. J., Harrison, M., Ambrose, S. E., Walker, E. A., Oleson, J. J., & Moeller, M. P. (2015). Language Outcomes in Young Children with Mild to Severe Hearing Loss. *Ear and Hearing, 36,* 76S-91S. https://doi.org/10.1097/AUD.0000000000000219

Transler, C., & Reitsma, P. (2005). Phonological Coding in Reading of Deaf Children: Pseudohomophone Effects in Lexical Decision. *British Journal of Developmental Psychology, 23,* 525-542. https://doi.org/10.1348/026151005X26796

Wagenmakers, E. J., & Brown, S. (2007). On the Linear Relation between the Mean and the Standard Deviation of a Response Time Distribution. *Psychological Review, 114,* 830-841. https://doi.org/10.1037/0033-295X.114.3.830

Wang, X., Caramazza, A., Peelen, M. V., Han, Z., & Bi, Y. (2014). Reading without Speech Sounds: VWFA and Its Connectivity in the Congenitally Deaf. *Cerebral Cortex, 25,* 2416-2426. https://doi.org/10.1093/cercor/bhu044

Wauters, L. N., Van Bon, W. H. J., & Tellings, A. E. J. M. (2006). Reading Comprehension of Dutch Deaf Children. *Reading and Writing, 19,* 49-76. https://doi.org/10.1007/s11145-004-5894-0

Williams, C., & Mayer, C. (2015). Writing in Young Deaf Children. *Review of Educational Research, 85,* 630-666. https://doi.org/10.3102/0034654314564882

Zoccolotti, P., De Luca, M., Di Filippo, G., Marinelli, C. V., & Spinelli, D. (2018). Reading and Lexical Decision Tasks Generate Different Patterns of Individual Variability as a Function of Condition Difficulty. *Psychonomic Bulletin and Review, 25,* 1161-1169. https://doi.org/10.3758/s13423-017-1335-3

Zoccolotti, P., De Luca, M., Judica, A., & Spinelli, D. (2008). Isolating Global and Specific Factors in Developmental Dyslexia: A Study Based on the Rate and Amount Model (RAM). *Experimental Brain Research, 186,* 551-560. https://doi.org/10.1007/s00221-007-1257-9

Zoccolotti, P., Marinelli, C. V., Martelli, M., Spinelli, D., & De Luca, M. (2019) Psycholinguistic Factors and Global Components in Developmental Dyslexia. In S. Sulpizio, L. Barca, S. Primativo, & L. S. Arduino (Eds.), *Word Recognition, Morphology and Lexical Reading: Essays in Honour of Cristina Burani* (pp. 67-94). London: College Publications.