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Design of Word Exercises for Children with Dyslexia

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Abstract

This paper presents a method to design reinforcement word exercises to support children with dyslexia. The method takes into account linguistic patterns found in the errors written by people with dyslexia and their specific language difficulties. The method has six stages: definition of the exercise type, word selection, word modification, selection of the distractors, creation of the difficulty levels, and selection of the text layout. More than 5,000 word exercises in Spanish and English created with this method have been integrated in a game available on iOS.

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1. Introduction

Worldwide, around 15-20% of the population has a language-based learning disability; where 70-80% of it likely has dyslexia.¹⁷ **Dyslexia** is a neurological learning disability which is characterized by difficulties with accurate word recognition and poor spelling, in particular with new words, rare words, very long words, complex words, and phonetically and orthographically similar words.⁵ Dyslexia is universal and its prevalence varies depending on country or the language from 10-17.5% of the population in the USA¹⁶ to 7.5-11% of the Spanish speaking population.^{32,7}

Overcoming dyslexia means a great effort for children and requires doing regular language exercises.⁵ However, these exercises do not include the following three features that would enrich them:

- (a) Current language exercises do not consider written errors. Since recent studies have shown that people with dyslexia do not consciously detect the errors while reading,³¹ the starting point of our exercises is a target word

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written with an error. In this way we aim to stimulate the strategy of detecting their own written errors and help to create the needed strategies to solve them.

- (b) Traditional pedagogical methods do not take advantage of current computing technology. For instance, nowadays we can personalize the exercises or create a greater number of exercises and levels.
- (c) Current language exercises are typically paper-based. Recent eye-tracking studies have shown that people with dyslexia read significantly faster when the text is presented on the screen using certain parameters.³⁸ However, the paper format prevents customizing the text according to each person needs. Moreover, exercises on paper introduce an added difficulty that some students face from writing on paper due to the fact that dysgraphia¹ is comorbid² with dyslexia.²⁶

Here we present a method for the creation of word exercises to support children with dyslexia for Spanish and English. It has six steps: definition of the exercise type, word selection, word modification, selection of the distractors, creation of the difficulty levels and selection of the text layout. The use of linguistic knowledge and natural language processing techniques has allowed us to create personalized exercises on the basis of the children needs, as we designed the exercises according to writing errors by children with dyslexia. Our exercises were integrated into a game for mobile phones and tablets. To the extent of our knowledge, this application is the only one which contains word exercises scientifically designed on the basis of the empirical analysis of errors written by people with dyslexia.³⁷

Following, we present the sources of knowledge used for the design of the exercises: the dyslexia specific language difficulties (Section 2) and the written errors (Section 3). Then, we explain the steps of our method (see Figure 1) and finally we draw conclusions and point out future work (Section 10).

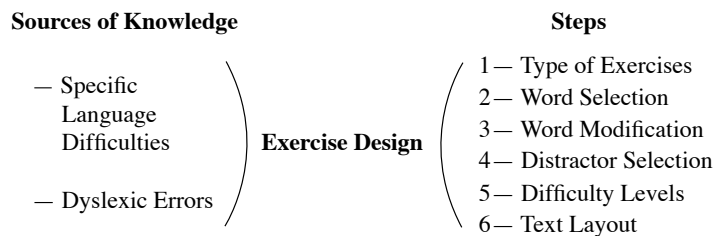


Fig. 1. Illustration of our method.

2. Specific Difficulties

We group the language difficulties that dyslexic people find according to their language level: (a) phonology, (b) orthography, (c) morphology, and (d) lexicon. We only included levels up the lexical level because these are the ones concerning our method. We extracted the language difficulties from the cognitive neuroscience literature.

(a) Orthography:

- (a.1) Orthographic similar words, *addition* and *audition*.¹³
- (a.2) Number and letter recognition and recollection.^{25,36}
- (a.3) Poor spelling.²⁵

¹ Dysgraphia refers to a writing disorder associated with the motor skills involved in writing, handwriting and sequencing, but also orthographic coding.⁴¹

² Comorbidity indicates a medical condition –dysgraphia– existing simultaneously but independently with another condition –dyslexia.

(b) Phonology:

- (b.1)** Phonetically similar words, such as *bite* and *wait*.¹²
- (b.2)** Irregular words, *i.e.* words in which there is no consistent correspondence between grapheme and phoneme *e.g.* *vase* pronounced as /vāz/.¹⁰
- (b.3)** Homophonic words or pseudo homophonic words, *weather* and *whether*.²⁷
- (b.4)** Foreign words.¹²

(c) Morphology:

- (c.1)** Derivational errors, **discomfortable*.²⁷

(d) Lexicon:

- (d.1)** New words, *fantabulous*.¹²
- (d.2)** Pseudo-words and non-words. A non-word is a word that has no meaning, is not known to exist, or is disapproved, such as *happisfaction*.¹⁰
- (d.3)** Less frequent words, *pristine*.³⁴
- (d.4)** Long words, *prestidigitation*.³⁴
- (d.5)** Word additions and omissions and word recognition and recollection.²⁵
- (d.6)** Substitutions of functional words. Function words are words that have little lexical meaning or have ambiguous meaning, but instead serve to express grammatical relationships with other words within a sentence, such as *of* and *for*.²⁷
- (d.7)** Confusions of small words, *in* and *is*.¹²
- (d.8)** Error recognition.³¹
- (d.9)** Numerical expressions written with letters.³⁶

3. Dyslexic Errors

In general terms, errors can be used as a source of knowledge. For instance, the presence of errors in the textual Web have been used for detecting spam,³⁰ or measuring Web quality.⁴ Among the different kinds of errors found in the Web, at least 0.67% errors are made only by users with dyslexia.³ In the case of people with dyslexia, their written errors have been used for various accessibility-related purposes, such as the development of tools like spell checkers^{28,20} or text processors.^{15,18,42} In other areas, they have been used to study different aspects of dyslexia,⁴⁶ such as the phonological processing deficit.^{24,21} People with dyslexia exhibit higher spelling error rates than non-dyslexic people⁹ and, due to this fact, there are diagnosis of dyslexia based on the spelling score.⁴³

As dyslexic errors provide information about dyslexia, we assume that they are a reflection of the difficulties these people have and, therefore, we use them as the source of knowledge for the creation of language exercises.

3.1. Corpus

We have compiled a Spanish corpus (*DysCorpus*) of texts written by children with dyslexia. It is composed of 68 texts with 955 unique errors. The texts are school essays from children with dyslexia between 6 and 15 years old. In³⁵ we described the first version of this corpus, discussing the frequency and types of errors, as well as the criteria for creating and annotating the corpus.

For English, we use the existing list of confusion sets compiled by Pedler to create a spellchecker for people with dyslexia.²⁸ This list is composed of more than 800 confusion sets. A confusion set is a small group of words that are likely to be confused with one another such as *weather* and *whether*.

3.2. Error Analysis

We manually extracted errors from the corpus and annotated the following information:

(a) Characteristics³ of the **error(s)** involved:

- *Simple or multiple errors*: misspellings that do not result in another correct word such as *vajo (*bajo*, ‘under’) (simple) or *arbollos (*árboles*, ‘trees’) (multiple).⁴
- *Real-word errors*: misspellings that result in another valid word. For instance, *witch* being the intended word *which*.
- *Type of the errors*: (i) *substitution*, *ja (*ya*, ‘yet’), (ii) *insertion*, *antún (*atún*, ‘tuna’), (iii) *omission*, *entoces (*entonces*, ‘then’) or (iv) *transposition*, *pateque (*paquete*, ‘packet’).
- *Word boundary errors*: (i) *split words* *per sona (*persona*, ‘person’) and (ii) *run-ons*, *decrystal (*de cristal*, ‘of glass’).
- *First letter errors*, *tro (*otro*, ‘other’) and *last letter errors*, *ma (*más*, ‘more’).

(b) **Characters** involved in the error.(c) **Context** in which the error occurs (the preceding letters and letters appearing after the error).(d) **Levenshtein distance**: the minimum number of single-character edits (insertion, deletion, substitution) required to change the error into the correct word.¹⁹

The type of errors we found are consistent with previous studies in Spanish⁴⁵ and in English.²⁸ One example of a fragment of our texts is given in Figure 2.

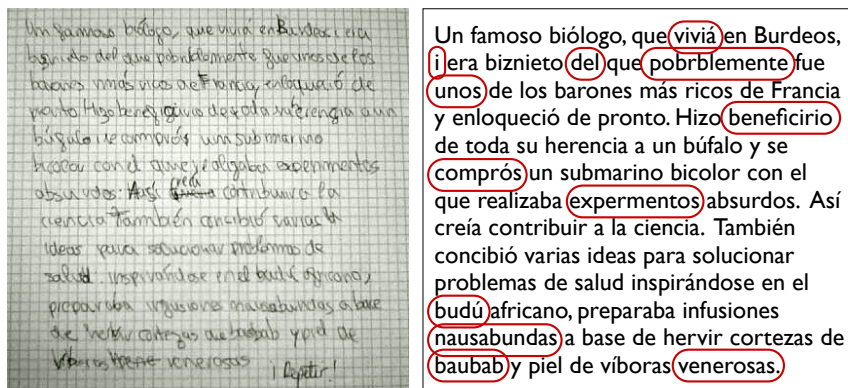


Fig. 2. Example of one story written by a person with dyslexia (14 years old).

An approximated literal translation for the example in Figure 2 is:

A famous biologist, who lived in Bordeaux and was great-grandson of who probably was one of the wealthiest barons in France and suddenly went mad. He chose a buffalo as the beneficiary of his inheritance and bought a bicolored submarine in which he made absurd experiments. He believed that with this he contributed to science. He also conceived various ideas to solve health problems inspired by African voodoo, preparing nauseating infusions based on boiled baobab barks and poisonous snakes.

Here we have the following errors: (i) substitution: *viviá (*vivía*, ‘lived’), *i (*y*, ‘and’), *budú (*vudú*, ‘voodoo’), *venerosas (*venenosas*, ‘poisonous’), *pobrblemente (*probablemente*, ‘probably’) and *baubab (*baobab*, ‘baobab’); (ii) insertion: *comprós (*compró*, ‘bought’); and (iii) omission: *experimentos (*experimentos*, ‘experiments’), *unos (*uno*, ‘some’), *beneficirio (*beneficiario*, ‘beneficiary’), *nausabundas (*nauseabundas*, ‘nauseating’), and *del (*de*, ‘of’).

³ These characteristics are not independent.

⁴ Examples with errors are preceded by an asterisk “*”.



Fig. 3. Exercises of substitution (left), separation (middle) and insertion (right).

4. Type of Exercises

The exercises have been designed considering the (1) dyslexic errors, (2) specific difficulties, and (3) the current pedagogical exercises. We created six types of exercises that present one or several words with errors to be corrected. Some of these exercises are recommended in pedagogy such as the insertion or the omission of letters¹⁴ as well as the separation of joint words.⁵ Following we present the kind of exercises and the specific difficulties they support in parenthesis. All of them support specific difficulties with poor spelling (**a.3**) and error recognition (**d.8**).

- (a) **Insertion:** For this task, the user is given a word with a missing letter and is asked to insert a letter from a set of possibilities displayed on the screen, e.g. **timestre* {*r, m, n, s, p*}, (*trimestre*, 'term') (Figure 3, right) (Specific difficulties **a.1**, **a.2**, **b.1**, **b.2** and **b.3**).
- (b) **Omission:** The user is given a word with an extra letter and is asked to identify and remove it, e.g. **asccessible*, (*accessible*) (Specific difficulties **a.1**, **a.2**, **b.1**, **b.2** and **b.3**).
- (c) **Substitution:** A word with a wrong letter is displayed and the user is asked to identify and substitute the wrong letter by another letter from a set of possibilities displayed on the screen, e.g. **abter* {*r, b, h, f*}, (*after*) (Figure 3, left) (Specific difficulties **a.1**, **a.2**, **b.1**, **b.2** and **b.3**).
- (d) **Derivation:** The root of a word is displayed together with a set of suffixes, where only one is correct. The user has to identify the correct suffix for the root, e.g. *blue* {*able, age, ish, ment*}, (*blueish*) (Specific difficulty **c.1**).
- (e) **Separation:** A set of words, normally composed of a lexical word and a small word or/and functional word are displayed on screen without spaces. Lexical words (e.g. *dog*) form the basic elements of a language's lexicon. They have a lexical meaning which is less ambiguous than the grammatical meanings expressed by functional words (e.g. *at, by*). The user is asked to separate the character chain into different words, e.g. **osopolar*, (*oso polar*), 'polar bear' (Figure 3, middle) (Specific difficulties **d.5**, **d.6**, **d.7** and **d.9**).
- (f) **Transposition:** The user needs to rearrange the letters or the syllables of a word (Specific difficulty **a.2**).

5. Word Selection

For the selection of the words involved in the exercises we took into consideration the specific difficulties of dyslexia and defined the following linguistic criteria:

- (a) **Dictionary Words.** Only Spanish and English words that appear in the *Royal Spanish Academy Dictionary* and in the *New Oxford American Dictionary*, respectively are taken into account. Foreign words, pseudo-words and words with irregular pronunciation are dismissed because they are even more difficult for people with dyslexia (Specific difficulties **a.3**, **b.2**, **b.3** and **b.4**).
- (b) **Frequency Threshold.** We include all the words appearing in *DysCorpus* e.g. **prupo* (*grupo*, 'group') whose frequency is equal or greater to our minimum frequency threshold (Specific difficulty **d.3**).

To pursue the usefulness of the application we guarantee a minimum frequency of each target word. A target word must fulfill one of the following two conditions: it must appear at least 15 times per one million written words according to the *Frequency Dictionary of Spanish Linguistic Units*¹ or it must obtain at least 30 million hits in a major search engine taking into account only Spanish documents.⁵ For instance, *guapo*, ‘handsome’ has a frequency of appearance of 17 times per million words and a hit count of 39.8 millions while *prístino*, ‘pristine’ appears 1 time per million words and has a hit count of 269,000. We combine both sources to allow the appearance of relatively new words. For instance, in the *Frequency Dictionary of Spanish Linguistic Units*, a new word such as *euro* only appears once while it has more than 138 million hit counts.

- (c) **Length Threshold.** People with dyslexia encounter problems with very short and very long words. Therefore, our target words have a minimum of 3 letters and a maximum of 12 letters, except from the *Initial* level which contain some words of 2 letters (Specific difficulties **d.4** and **d.7**).
- (d) **Lemmas.** Words are presented as lemmas, that is, they are presented in their canonical form or citation form of a word. For instance, the verb *cantar*, ‘to sing’ would appear in its infinitive form, *cantar*, or the adjective *guapo*, ‘handsome’ would appear in its least-marked form (singular masculine). The reason motivating this criterion is that the morphological processes involved in inflectional morphology (inflection and conjugation) tend to be regular and therefore are processed differently than the rest of the lexicon acquisition⁶ (Specific difficulty **d.6**).
- (e) **Functional Words.** They only appear in the separation exercises. Function words are words that have little lexical meaning or have ambiguous meaning, but instead serve to express grammatical relationships with other words within a sentence, such as *in*, *at* or *but*. We make this distinction because people with dyslexia encounter different difficulties depending if the word is functional or lexical (Specific difficulty **d.6**).

6. Word Modification

The goal of the each exercise is to correct and create an accurate word. Each exercise presents a target word with an error that determines the type of operation the user needs to perform. For example in **lletter (letter)*, the letter <l> needs to be omitted.

We used all the errors from *DysCorpus* containing a *simple* error as target words for the exercises. We generated the rest of the target words by applying the error patterns found in *DysCorpus* to the most frequent words in Spanish. Now we explain how we selected the errors and where they occur.

- (i) **Error Letter Selection.** We selected the letters that are more frequently involved in errors. For instance, for the insertion exercises we selected the most frequently omitted letters: <h, s, r> or <n>. Also, the most frequently inserted letters such as <t> in **writting (writing)* are chosen for the omission exercises.
- (ii) **Error Position.** Since we observed that insertion and omission of letters happened more frequently in checked syllables (16.66%)⁶, in double letters (12,5 %), and in the first and last letters of the word (26%), we include more cases that take into account such linguistic contexts in the word.

7. Distractor Selection

Distractors are the wrong choices presented together with the correct answer in a multiple choice item to ‘distract’ the player. Good distractors have to resemble somehow the correct answer.²³

We selected as distractors the graphemes which are mistaken more frequently in *DysCorpus*. The distractors were grouped according to the following linguistic criteria.

- (a) **Groups of phonetically similar (or equal) graphemes.** For instance, <y|i>, <c|z>, <c|q>, <b|v> or <g|j>.
- (b) **Groups of orthographically similar graphemes.** For instance, <y|j>, <n|r>, <b|d|g|q>, <ñ|n> or <rr|ll>.
- (c) **Groups of phonetically and orthographically similar graphemes,** such as <m|n> and <b|p>.

⁵ http://www.google.com/advanced_search

⁶ When the syllables end in a consonant.

From the error analysis we could find some phonetic patterns in the errors. For instance, phonetically similar vowels are the ones which are substituted [a|e|o] (open or middle vowels), [i|u] (close vowels) and [i|e] (front vowels). To the contrary, pair vowels which are less similar are never mistaken, e.g. [a|u] (being [a] open and front and [u] close and back).³⁹

8. Difficulty Levels

To define the different difficulty levels of our game we take into account five variables considering the dyslexia related difficulties.

- (a) **Word Frequency.** To support difficulties with new words (**d.1**), pseudo words and non-words (**d.2**), and less frequent words (**d.3**).
We compute the word frequency taking into account (1) frequency per million words (*F/million*) using the *Frequency Dictionary of Spanish Linguistic Units*¹ for Spanish and (2) a major search engine hit counts for English and Spanish.
- (b) **Word Length:** To support difficulty with long words (**d.4**). Word length is defined by number of letters per word.
- (c) **Phonetic similarity:** To support difficulties with homophonic words (**a.2**).
- (d) **Orthographic similarity:** To support difficulties with orthographically similar words (**b.1**).
Since Spanish has a shallow orthography,⁴⁴ orthographic and phonetic similarity are very much related with some exceptions, e.g. <h> is not pronounced. For phonetic and orthographic similarity we took into consideration the number of neighbours which have a *F/million* higher than zero (*NNF*). Neighbors are all the words with the same length as the target word which differ in only one letter,¹¹ for instance, some neighbors of *casa* are: *masa*, *cosa*, *cama* and *caso*. For computing *NNF* and *F/million* we consult the database of indexes of frequency, length, and orthographic neighbours in Spanish.^{29 7} For finding the neighborhood density and frequency in English we used *CLEARPOND Database*.^{22 8}
- (v) **Morphological Complexity:** To support derivational errors (**c.1**).
For measuring the derivational difficulty we took into account the number of morphemes (except from inflection morphemes) of the target word. For instance, *sombra*, ‘shadow’ has one morpheme, *sombrero* (*sombra* + *ero*), ‘hat’, has two morphemes, and *sombrerero* (*sombr* + *er* + *ero*), ‘hatter’) has three morphemes.²

Different levels include different degrees of difficulties taking into account these variables. As the difficulty level increases, the target word is less frequent, longer, has a higher number of neighbors, has more frequent neighbors, and has a more complex morphology. We define five difficulty levels: *Initial*, *Easy*, *Medium*, *Hard* and *Expert*. In Table 1 we show the values of the factors taken into account for each of the levels together with the number of distractors and number of words for the separation exercises.

Parameter	Levels				
	Initial	Easy	Medium	Hard	Expert
Frequency (<i>F/million</i> , hit count)	–	> (200, 600M)	> (100, 300M)	>(15, 30M)	> 1, 1M
Length	3-4	3-5	3-7	3-9	3-12
Orthographic and Phonetic Similarity (<i>NNF</i>)	–	0-2	3-4	–	–
Morphological Complexity	1	1	1-2	2-3	>3
Number of Distractors	1	2	3	4	5
Number of Words (for Separation)	2	2	3	3	3-4

Table 1. Values for the different levels parameters of the exercises.

⁷ <http://www.psico.uniovi.es/REMA/v8n2/a1/anexos.zip>

⁸ <http://clearpond.northwestern.edu/>

9. Text Layout

The presentation of text has an effect on the reading performance of people with dyslexia.¹⁵ Therefore, the exercises shall be presented using the text presentation values that lead people with dyslexia to a more efficient reading according to previous studies with eye-tracking. Therefore, we used sans serif fonts (*Helvetica*, *Arial* or *Verdana*) or the monospaced font *Courier*³³ in its large size (from 18 to 26 points⁴⁰) and we apply the recommended color and brightness contrast using a black font with creme background. The RGB for them are: #FAFAC8 (creme) and #000000 (black) with a color difference of 700 and a brightness difference of 244.³⁸ We did not alternate different typographical cases according to difficulty (b.2).

10. Conclusions and Future Work

In this paper we have presented a method to create exercises to support children with dyslexia on the basis of the analysis of errors written by people with dyslexia in combination with linguistic, pedagogic and cognitive criteria. The method can easily be transferred to other languages, because it relies on very little language-dependent resources.

Around 5,000 exercises developed with this method for English and Spanish have been integrated in a game for iOS called *Dysegxia*.³⁷⁹ From its release in June 2012 until July 2013, it has been installed more than 8,000 times. To ensure the usability and the engagement of the children, we added in-game achievements: points are accumulated by solving the exercises, and a penguin is born, grows, and wins prizes. These achievements can be shared via iOS' Game Center. *Dysegxia* has received a good share of attention by the media. It has been featured in TV3 Televisió de Catalunya, Catalunya Ràdio, and El Periódico.⁸¹⁰ Three centers that support children with dyslexia, *Centro Creix Barcelona*,¹¹ *Centro Coddia*,¹² and *Uditta*¹³ have adopted *Dysegxia* into their curriculum. By being embedded into the pedagogical context of these centres, *Dysegxia* has the potential of playing an essential role in helping children to overcome dyslexia.

We are currently conducting a longitudinal evaluation with the help of two specialized centres' pedagogues and psychologists, which enables us to study its long-term effect on overcoming dyslexia. Future work include the adaptation of the game to different languages and its improvement of the application by tailoring the exercises on the basis of a child's performance and by extending the number of exercises.

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⁹ <https://itunes.apple.com/us/app/dysegxia/id534986729?l=ca&ls=1&mt=8>

¹⁰ <http://www.luzrelo.com/Outreach.html>

¹¹ www.creix.com/Barcelona

¹² www.coddia.com

¹³ <http://www.uditta.com/>

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