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Maria Rauschenberger[1], Silke Füchsel[2], Luz Rello[3,4],
Clara Bayarri[4], Jörg Thomaschewski[2]

[1]OFFIS – Institute for Information Technology
maria.rauschenberger@offis.de
[2]University of Applied Sciences Emden/Leer Emden, Germany
sfuchsel@gmx.de, joerg.thomaschewski@hs-emden-leer.de
[3] Change Dyslexia Foundation, Spain
luz@changedyslexia.org
[4] Cookie Cloud Barcelona, Spain
clara@cookie-cloud.com

Abstract. In this work-in-progress we present a computer-based method to design German reinforcement exercises for children with dyslexia. From different schools, we collected more than 1,000 errors written by children with dyslexia. Then, we created a classification of dyslexic errors in German and annotated the errors with different language specific features, such as phonetic and visual features. For the creation of the exercises we took into account the linguistic knowledge extracted from the analyses and designed more than 2,500 word exercises in German that have been integrated in a game available for iOS. The game and the resource of dyslexic errors are available online[1] and they are, to the best of our knowledge, the first contributions of this kind for German.

Keywords: Dyslexia; iOS; Spelling; German; Children; Gamification.

1 Introduction

Dyslexia is a specific learning disability with neurological origin. It is characterized by difficulties with accurate and/or fluent word recognition and by poor spelling and decoding abilities. These difficulties typically result from a deficit in the phonological components of language that is often unexpected in relation to other cognitive abilities. Secondary consequences may include problems in reading comprehension and reduced reading experience that can impede growth of vocabulary and background knowledge [1]. Dyslexia is frequent: Worldwide, 10% of the population and from 5 to 12% of the German students have dyslexia [2].

In Germany, only 25% of the poor spellers achieve average spelling performance during the period of primary school [3]. In a longitudinal study Esser et al. [4] showed

[1] https://itunes.apple.com/us/app/dyseggxia/id534986729?mt=8

[2] Dysgraphia refers to a writing disorder associated with the motor skills involved in writing,

that children with diagnosed dyslexia at the age of eight achieved less school performance and a higher rate of unemployment, than the control group measured afterwards at the age of 25. Schulte-Körne et al. [5] showed that it takes longer for children with dyslexia to achieve school grades that are comparable to the others, even if these children have a socio-economic condition above the average.

Overcoming dyslexia means a great effort for children and requires doing language exercises regularly [6]. Traditionally, these exercises are done using pen and paper. In the case of dyslexia, exercises on paper introduce an added difficulty for some students due to the fact that dysgraphia[2] is comorbid with dyslexia [7].

More recently, it was shown that computer games are a convenient medium to provide exercises in an engaging way to significantly improve the reading performance [10,11] and the spelling performance [12] of children with dyslexia. These methods cannot simply be extended to other languages because manifestations of dyslexia depend on the different orthographies of the languages [13].

In this paper, we present a game for children with dyslexia for German. To make the training exercises, this method uses real errors found in texts written by children with dyslexia. To the best of our knowledge, this is the first time that error-based exercises targeted for people with dyslexia are done for German.

The structure of the paper is stated as follows: Section 2 details related work while Section 3 presents how we created the content design of the application. Finally, we draw conclusions and describe our future work in Section 4.

2 Related Work

There are several approaches of assistive technology for dyslexia [14]. Following, we only present related games to support and train specific issues of dyslexia.

Lernserver is a tool to diagnose dyslexia in German, define the level of support the child needs, and provide support exercises [15]. An evaluation with the Landesinstitut für Schule found out that 78,2 % of the students (N = 3798) improved their writing using this tool [16]. Similarly, *Klex 11*[3] helps to practice vocabulary in German adapted to a certain school degree. These tools only use correct-based exercises in the game. Likewise, *CESAR schreiben 2.0*[4] is a strategy and educational game, which includes listening, spelling and vocabulary.

Kyle et al. [10] compared two computer-assisted reading interventions for English inspired by the Finnish *GraphoGame* [17]: *GG Rime* and *GG Phoneme*. They conducted a user study with 31 children of 6 and 7 years old. While the results show that both games may benefit decoding abilities, no significant effects were found, probably due to an insufficient number of participants or not enough training time. The closest work to us is *Dyseggxia* or *Piruletras* for iOS [18], a game composed of

[2] Dysgraphia refers to a writing disorder associated with the motor skills involved in writing, handwriting and sequencing, but also orthographic coding [7].

[3] http://www.legasthenie-software.de

[4] http://www.ces-verlag.de/deutsch/Schreiben2_0/ schreiben2_produktinfo.php5

error-based exercises to support writing in children with dyslexia in English and Spanish. During eight weeks, the authors carried out a within-subject experiment with 48 children from 6 to 11 years old. Children who played *Dyseggxia* for four weeks in a row had significantly less writing errors in the tests than after playing the control condition for the same time [12]. Our game differs from previous work in being the first tool for German based on written dyslexic errors.

3 Game Content Design

In this section we explain the steps we followed to create the exercises to be integrated in the application. We decided to use errors written by people with dyslexia as the starting point because they can be used as a source of knowledge. Regarding dyslexia, the errors that people with dyslexia make are related to the types of difficulties that they have [19].

3.1 Collecting Texts from Children with Dyslexia

We collaborated with two schools to gather anonymous texts written by students with dyslexia. We collected 47 texts (homework exercises, dictations and school essays) written by students from 8 to 17 years old. A total of 32 texts came from children who have been diagnosed with dyslexia. Teachers collected the remaining texts from children with a high spelling error rate. The children attended primary school, comprehensive school *(Gesamtschule),* high school *(Gymnasium)* or a special school *(Förderschule).*

3.2 Classification of German Dyslexic Errors

We analyzed the errors and defined an error classification for German. Except from the categorie capital letter, the rest of the error types are consistent Pedler's classification of dyslexic errors [21][5]:

- **Substitution:** change one letter by another, **grümeln (krümeln, 'crumble').*
- **Insertion:** insert one letter, **muttig (mutig, 'bravely').*
- **Omission:** omit one letter, **zusamen (zusammen, 'together').*
- **Transposition:** reversing two letters, *Porblem (Problem, 'problem').*
- **Multi-errors:** more than one letter different, **Stag (stark, 'strong').*
- **Word boundary errors**: They are run-ons and split words. A run-on is the result of omitting a space, such as *nichtärgern (nicht ärgern, 'don't tease').* A split word occurs when a space is inserted in the middle of a word, such as *Vogel futter (Vogelfutter, 'bird food').*

[5] Examples with errors are preceded by an asterisk '*'. We use the standard linguistic conventions: '<>' for graphemes, '/ /' for phonemes and '[ ]' for phones.

- **Capital letter**: in German nouns are written with capital letters, while other kinds of words like verbs, adjectives or articles are not. This leads very often to spelling errors frequently based on the lack of attention [22]. For example *geschichten *(Geschichten, 'stories')* or **Glücklich (glücklich, 'happy')*.

3.3 Annotation of Dyslexic Errors

We annotated each of the word-error pairs with linguistic features [23]. Each of the word-error pairs was enriched with specific phonological and visual features derived from the analysis of the errors and some examples:

- **Visual information:** for each of the target and the error graphemes we annotate the letters involved in the error with the following visual information, considering handwritten text. As a guideline we chose the *Lateinische Ausgangsschrift* [24] because it is commonly used in schools where the texts were collected. The tags use for visual information are: (a) the presence of mirror letters (<d> and <b> or <m> and <w>), (b) rotation letters (<d> and <p>.) or fuzzy letters, that is, similar visual letters but not due to rotate or mirror, such as <s> and <z>.
- **Phonetic information:** Each of the error words was tagged using a classification inspired by the error analysis of the *DRT* [20]. This classification is based on traditional articulatory phonetic features [25] and is divided into the following categories: (a) sound distinction, (b) sound sequence, (c) combination of consonants, words with <v>, (d) umlaut, (e) double consonant / false double consonant, (f) lengthening, (g) words with <s/B>, and (h) derivation. For instance, in (h) derivation, related words are often written the same way or similar but pronounced different. To write these words in the right way, one possibility is to have a look at the plural form so that the right writing can be derivate, e.g. *Walt (Wald [valt]; Wälder [vɛldɒ], 'forest')*. We took these features into account to design the exercises (see next Section).

3.4 Exercise Design

First, we analyzed statistically the features of the errors and created a set of linguistic patterns for designing the exercises. Then, we manually created 2,500 exercises for German. The types of exercises were defined according the kind of errors found in our resource. These are:

- **Insertion**: A missing letter is shown and the child need to insert a letter from a set of possibilities displayed on the screen, e.g. **Geburstag, (Geburtstag, 'birthday')*.
- **Omission**: The child is given a word with an extra letter and is asked to identify and remove it, e.g. **Abennd, (Abend, 'evening')* (Figure 1, right).
- **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. **Muntag, (Montag, 'monday')* (Figure 1, left).

- **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. *Hund, '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. *zu, bei ('at, by')*. The user is asked to separate the character chain into different words, e.g. **ausVersehen, (aus Versehen, 'by mistake')*.
- **Transposition**: The child needs to rearrange the letters or the syllables of a word, e.g. **Zugbürcke, (Zugbrücke, 'drawbridge')*.

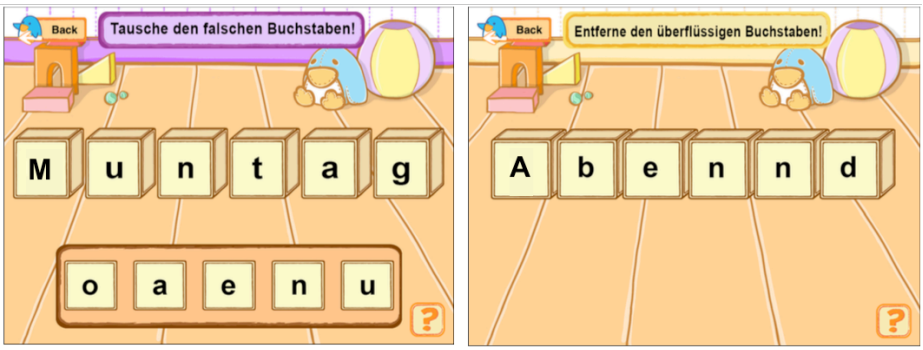

Figure 1: Exercises of Substitution (left) and Omission (right).

The amounts of types of exercises per class are defined according the real errors percentages found in our error list. For instance, omission errors were the more frequent type in dyslexic texts (28.14%), therefore were created more **Insertion** exercises to target this kind of error. The other types of errors were substitution (21.03%), capital letter (10.61%) and no capital letter (7.21%) for **Substitution** exercises, addition (21.03%) for **Omission** exercises, run-on (0.29%) and split in (2.73%) errors for the **Separation** exercises, and transposition (0.88%) for the **Transposition** exercises. We used the multi-errors (18.31%) for higher levels.

3.5 Target Word Selection

To assure that the exercises are useful for the children, we used (1) only valid words in German language, (2) a set of the most frequent words of German[6], (3) words used in books in school in Germany[7], (4) and words from our error list. The final list of words is the intersection of these criteria.

For selecting the words we took into consideration specific difficulties of dyslexia. German words can be very long e.g. *Straßenbahnhaltestelle ('tram stop')*. Since people with dyslexia have difficulties with very long words [26] we included long

[6] http://www.lsa.umich.edu/german/hmr/Vokabeln/frequent_words.html
[7] http://bildungsserver.berlin-brandenburg.de/fileadmin/bbb/unterricht/faecher/sprachen/deutsch/Grundschule/2011_11_25_GWS_1_WEB.pdf

words but not longer than 20 letters. For the **Separation** we chose functional words because of the same reason, people with dyslexia tend to have more errors with small and functional words [27].

3.6 Modification of the Target Words

For the exercises that are not derived directly from the incorrect words in the corpora, we apply the linguistic patterns extracted from the errors to the most frequent words or schoolbook words. For instance, when the sound /a:/ is represented by the letters <ah> *(Wahl, 'election'),* <a> *(Tal, 'valley')* or <aa> *(Haare, 'hair'),* these three groups of letters are frequently mistaken between themselves or by other letters such as <e>. By applying these patterns to the most frequent words we cover relevant words that might not appear in our corpora.

3.7 Selection of the Distractors

Distractors are incorrect options in a multiple-choice answer, which resemble the correct option to 'distract' the player [28]. We selected distractors for each exercise word taking into account linguistic features. For instance, the most frequent errors involve letters which the one-to-one correspondence between graphemes and phones is not maintained, such as in <sch> pronounced as only on phone [ʃ]. Another example is similar letters representing similar sounds, such as the occlusive consonants [t, d, b, p, g]. We used as distractors the letters that tend to induce more errors.

3.8 Difficulty Levels

The game has five difficulty levels: *Initial, Easy, Medium, Hard*, and *Expert*. The levels of the exercises were designed considering the difficulties of people with dyslexia. They have more difficulties with less frequent and longer words [26, 29] and words with complex morphology [27]. Hence, in higher difficulty levels, the target word is less frequent, longer and has a more complex morphology. For instance, only words in *Hard* and *Expert* levels have prefixes and suffixes.

People with dyslexia also struggle with phonetically and orthographically similar words [30]. Phonetically similar words are presented in all levels; orthographically similar words are used in all levels except from *Initial* level.

3.9 Implementation

The application was done in Objective-C by using the Model-View-Controller pattern and a high level abstraction to make it easily portable from iOS to Android and later to any other platform if needed. Since text presentation has a significant effect on reading performance of dyslexic readers, the interface of the game implements the guidelines that – according to the latest findings in accessibility research [8, 9].

4 Conclusions and Future Work

In this paper we have presented a method for creating exercises in German to support the spelling of children with dyslexia. The exercises were created on the basis of the linguistic analyses of errors written by children with dyslexia (from 8 to 17 years old) and can easily be transferred to other languages, because it relies on little language-dependent resources. The tool with the German exercises integrated will be soon available in the App Store.[8] Also, the resource with the German errors and all the annotations is freely available.

The creation of this tool is the first step of a work-in-progress. Our next and final step for future work is to conduct a longitudinal evaluation to measure the efficiency of the tool in a German school with children with diagnosed dyslexia. We also plan to create more types of exercises, adapt the levels, automatically create exercises and improve the application by tailoring the exercises on the basis of the child's performance.

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