Towards the Prediction of Dyslexia by a Web-based Game with Musical Elements

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ABSTRACT

Current tools for screening dyslexia use linguistic elements, since most dyslexia manifestations are related to difficulties in reading and writing. These tools can only be used with children that have already acquired some reading skills and; sometimes, this detection comes too late to apply proper remediation. In this paper, we propose a method and present *DysMusic*, a prototype which aims to predict risk of having dyslexia before acquiring reading skills. The prototype was designed with the help of five children and five parents who tested the game using the think aloud protocol and being observed while playing. The advantages of *DysMusic* are that the approach is language independent and could be used with younger children, *i.e.*, pre-readers.

CCS Concepts

•Human-centered computing → Empirical studies in accessibility; Accessibility design and evaluation methods; •Software and its engineering → *Interactive games;*

Keywords

Dyslexia; Detection; Pre-Readers; Serious Games; Gamification; Web-based Assessment

1. INTRODUCTION

The American Psychiatric Organization defines dyslexia as a *specific learning disorder* which is caused by the 'phonological skills deficiencies associated with phonological coding deficits' [1, 16]. This means that people with dyslexia have problems spelling words and decoding what they have heard. Dyslexia does not affect general intelligence, and it is frequent: around 5% to 15% of the population has this learning disorder [1].

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The impact of dyslexia is related to difficulties with reading and writing and for that reason current tools for screening dyslexia use linguistic elements. Examples of digital screening tools for detecting dyslexia in English are **Lexercise Screener** [7] and **Nessy** [8]. Additionally, the computer game **Dytective** [13] is available in English and Spanish with an accuracy of 83% for detecting if a person may have dyslexia or not, according to a game that includes recognition of linguistic elements, phonological awareness and reading comprehension.

Reading and spelling tests need a minimum knowledge of phonological awareness, grammar, and vocabulary of a child to be able to predict dyslexia. This means that children can be detected only after they begin to learn to read (generally, during the first year of school or later). This puts students with dyslexia behind; therefore, new ways of detecting the risk of having dyslexia are needed for pre-readers. Also, all reading and spelling tests are language dependent.

The difficulty in detecting dyslexia before children learn how to read and write is that the standard linguistic manifestations to detect dyslexia (difficulties in reading and writing) are missing. Hence, to detect dyslexia in a child before they gain phonological awareness, new indicators of dyslexia need to be discovered. Huss *et al.* [5] show that sound structure is related to the auditory perception of children with dyslexia. Therefore, we aim to find out if we can distinguish two groups of pre-readers (with and without dyslexia) using musical elements in a first prototype of a game called *DysMusic* (see Figure 1). In this paper, we present the design of the first version of the game *DysMusic* and an usability test with five children and five adults to discover problems that could influence the prediction of the risk of having dyslexia (first prototype was presented in [12]). The rest of the paper is organized as follow: next section presents related work; Section 3 motivates the use of music for predicting dyslexia while Section 4 presents the design of *DysMusic*. In Section 5 we present the usability test and the last sections give our conclusions and future work.

2. RELATED WORK

We focus on examples for digital detection of dyslexia for pre-readers. The tool **DYSL-X** aims to predict if a child has dyslexia at the age of five [4, 15]. It contains three mini-games for different activities to measure indicators (e.g.

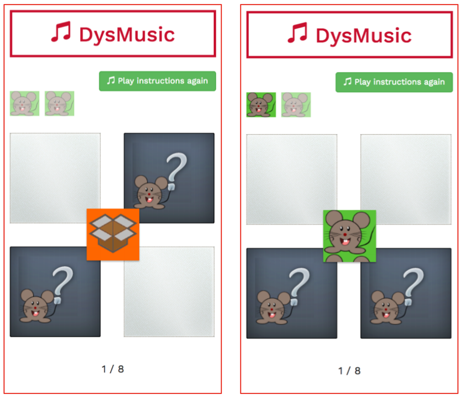

Figure 1: Example of the game *DysMusic* for the first two clicks on two sound cards (left) and then a pair of equal sounds is found (right).

'letter knowledge, FM detection, end-phoneme recognition' [4]) for dyslexia and takes about one hour to complete. The mini-games are designed with a high focus on the game play to motivate the player.

The **AGTB 5–12** is a computer-based memory test for children of five to twelve years-old [14]. The application provides four tasks for the phonological working memory processing, six tasks for the central working memory and two tasks for the visual-spatial working memory. Every task takes seven minutes for testing.

The **Bielefelder Screening (BISC)** is for children at the last year of kindergarten [14]. It contains nine tasks for phonological perception, phonological working memory processing, long-term memory, and visual attention. It clusters the participants in risk groups for dyslexia and takes around 20 to 25 minutes.

In summary, the games described are designed with a high focus on the game design and the suitable interaction for pre-readers. These tools are mainly focused on having letter knowledge and phonological awareness being AGTB 5–12 and BISC the only ones screening pre-readers. All these tools require a minimum linguistic knowledge.

3. WHY MUSICAL ELEMENTS?

People with dyslexia have auditory and visual perception difficulties that seem to be caused by difficulties with the short-term memory [10]. Johnson's work found that 26 out of 60 children with dyslexia had speech and language difficulties and that 75 out of 120 children with dyslexia had problems in the auditory learning [6]. This is applied especially to the phonemic discrimination and therefore the perception of new words are problematic [6], as used in the game *Dytective* [13].

The visual perception has been explored with various games as described in the previous section. To explore the auditory perception without directly referring to letter knowledge or phonological awareness, music can be used as the communication channel.

By musical elements we mean different acoustic parameters of sound (*i.e.*, *frequency*,*duration*, or*intensity*) which relate with perceptual parameters (such as*pitch*,*loudness*, or*timbre*). Some musical elements for readers at the age of 10 have been explored, and some differences have been found for *rise time*, *duration*, *intensity* (related to loudness) and *frequency* (related to pitch) between children with and without dyslexia [5]. The musical elements would be especially helpful for children that have no knowledge of written language.

The case of pre-readers is especially challenging, because dyslexia is known for causing reading and writing problems. As we mentioned, the auditory perception might be correlated to the causes of dyslexia if the cause is phonological [16]. To make our detection game language independent, we will use music (*phonological grammar* [11]), which is similar in prosodic structure in language.

In the literature review we already found indicators in the hearing perception to distinguish between readers with and without dyslexia [5, 10]. However, the auditory perception without using linguistic features for pre-readers has been not studied and used for the prediction of dyslexia in a game.

4. CONTENT DESIGN

The game aims to detect differences in the perception of auditory elements for children with and without dyslexia caused by problems with the short-term memory. As is well-known, a game is more fun than doing a test. We can think that *DysMusic* is an adaptation of the already existing visual game *Memory*.[1]

Instead of finding the same picture under various analog cards, the child will try to find the same musical element behind various digital cards. The game has four tasks and they have to be played without interruptions. Each task includes two subtasks. One subtask has four cards with two sound files (see Figure 1) and the other one has six cards with three sound files. The number of cards is reduced to four and six cards for two reasons: (i) if there is a difference in the perception, only two different musical elements will already show the difference; and (ii) increasing the number of cards is a challenge in itself, especially for younger children.

To avoid external factors that could cause differences in the perception (*e.g.*, due to color blindness), no visual cues (color, shape) where used to distinguish the cards. To avoid random matches, no match is possible within the first click of every subtask. Sound cards for every subtask are in random order and the tasks are counter-balanced with *Latin Squares* [3].

All musical samples are generated by means of a simple sinusoidal waveform (tone) using the *Audacity* free software.[2] Four musical parameters are modified, obtaining a set of waveforms as the one shown in Figure 2 for *Rhythm*. The exact details of each one are given in Table 1.[3]

5. USABILITY TEST

First, internal feedback from HCI researchers improved the application and only minor changes on the game play needed to be done. After that the usability test was conducted by children and parents who are not the authors of this paper and are not familiarized with the research.

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[1]An example of a visual memory game can be found on https://goo.gl/vhWmYs.
[2]*Audacity* is available at http://audacity.es/.
[3]The generated musical elements are available at http://bit.ly/2jeejmC.

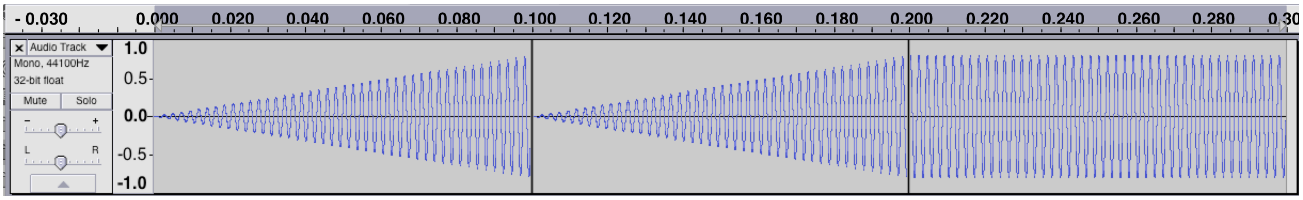

Figure 2: The waveform of the musical element *Rhythm*.

Musical element	Sound Properties
Always the same	*waveform*: sinus, mono files *amplitude*: 0.8 *musical elements*: 2 to 3 sound files *frequency*: 440 Hz unless specified differently
Frequency *(change of tone frequency)*	*2 elements**: 440 Hz, 452.8929 Hz *3 elements***: 2 previous sounds and 446.3998 Hz *fade in/out*: 0.025s *duration*: 0.350s
Length *(change of tone length)*	*2 elements*: 0.350s, 0.437s *3 elements*: 2 previous sounds and 0.525s *fade in/out*: 0.025s
Rise Time *(change of rise time)*	*2 elements*: 0.025s fade in, 0.250s fade in, both with fade out of 0.025s *3 elements*: 2 previous sounds and 0.025s fade in and 0.250s fade out *duration*: 0.500s
Rhythm *(change in rise time for different musical events)*	*2 elements*: (i) musical events with rise time equal to 100ms, 100ms and 0.025s; and (ii) rise time equal to 100ms, 0.025s and 100ms *3 elements*: 2 previous sounds plus one with rise time equal to 0.025s, 100ms, 100ms) *duration*: 0.300s

Table 1: Musical elements generated for the four tasks in *DysMusic*. * 2 elements: (1/2 semitone - 50 cents interval); ** 3 elements: 3 sounds spaced by 25 cents (quarter of a semitone) - 2 previous ones.

5.1 Methodology

Design: Since *DysMusic* is a new application a five user test [9] is conducted to discover (usability) problems which could unintended influence the planned study for predicting risk of having dyslexia. It should be mentioned that a five user test is a preliminary test for finding major usability problems and does not aim to find all usability problems. In a within-subject design, all participants played all four tasks of the game *DysMusic*. Only parents entered additional details for the study (*e.g.*, background information) while using the think aloud protocol [2].

Participants: We recruited ten participants which were five children (users) and five parents. Two female parents (both with age 35) and three male parents (ages 35, 40, and 40) participated. Each parent had two children and five of their children took part in the user testing of *DysMusic*. Two female children (ages 3 and 8) and three male children (ages 5, 9 and 9) participated. All participants were German native speakers. Since there is no indication of significant differences in usability studies for people with or without dyslexia, we did not differentiate the two groups for the usability study.

Procedure: All participants played *DysMusic* over the website[4] with the same tablet (Android Galaxy Tab A). They choose if they wanted to use headphones or not while playing (only one female parents used headphones). First the parent read the study instructions and played with the sound cards (see Figure 1) while using the think aloud protocol. Afterwards, the parent or the first author filled in the background details for the child and the child played with the sound cards. After each subtask the first author asked the participant 'How difficult or easy was it to distinguish between the sounds?'. At the end of game each participant was asked if they had further comments on the interaction design of the game or the musical elements.

5.2 Results

We present now the results of the usability test and the changes we made to *DysMusic*.

Wording and Text: Generally, the parents found the text easy to read and to understand. They reported some spelling mistakes which were mainly caused by the translation process from English to German e.g. *study (English) vs. Studie (German)*.

Also they mentioned the large amount of text for *Online-Consent* and one parent suggested to only present the important information of the *Online-Consent* and give the possibility for further reading.

Interaction: All participants were able to play the memory game with the musical elements instantly and all became faster after the first tasks, independently of the musical element. Only the youngest child (3 years old) had major problems with the amount of six sound cards for all musical elements and did not find any sound pairs. We consider to only use four cards when younger children play *DysMusic*. Some participants suggested to include the button 'let's play' into the *game summary* to make the interaction more visible. The first author observed that the participants started to play faster, especially after the first task, and the delay of releasing the sound cards for the next click helped to control the speed of the game interaction without being annoyingly slow.

User-Interface: In general, all participants liked the structure, layout, and the game elements, *e.g.*, story, and the spoken motivation feedback 'Yeah'. One participant commented that the footer of the game was very visible (large)

[4]The demo of the prototype *DysMusic* is available at http://bit.ly/2mm7MY6

and suggested to make it smaller and more conspicuous. We did this change accordingly.

Musical Elements: All participants commented that they had to listen and concentrate carefully to be able to distinguish the musical elements. Participants had a different perception on how difficult it was to distinguish the sounds and finding the card pairs, depending on the musical elements. But all participants mentioned the first musical element of the first subtask always as difficult, independently from the musical element (because of the counter-balanced design, the musical element order changed). This seems to be because it is the first time they play. For the second subtask, they were already familiarized with the parameter and were able to name it. Two children and three parents mentioned difficulties in recognizing the musical element *Length*. One parent and one child of this group and another parent described more difficulties with the musical element *Frequency*. Only three parents reported difficulties in distinguishing the musical element *Rhythm* and two children mentioned difficulties for the musical element *Rise Time*.

Functionality: The motivation sound between the exercises were not always played on the tablet and needed to be debugged for different devices. Besides, the video sometimes could not be played instantly which might have been caused by bad Wi-Fi connection. A change of the video player, from *HTML 5: video-tag* to *YouTube: Iframe-tag*, prevented the loading problems.

Other Comments: In general, all participants found the task easy to understand. The children expressed more fun while playing than the parents, *e.g.*, smiling or laughing. Three users commented that the game was fun and all users reacted positive on the spoken feedback 'Well done' when it was played. We included more game sound elements, *e.g.*, after each found pair we added a spoken feedback like 'Great' or 'Super'.

6. CONCLUSIONS AND FUTURE WORK

The main advantages of *DysMusic* are that it is language independent and that could be used by pre-readers. Regarding the user test, all participants understood the game easily and played with no interruptions. The next step is to include the visual elements into the game. After that it will be possible to perform a set of experiments with 30 participants to find how musical and visual elements can distinguish between a person with or without dyslexia. To study the dependency on different languages, experiments will be conducted in English, Spanish, and German. The best scenario would be to prove that the approach is truly language independent and only the interface needs to be translated.

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