Dytective: Towards Detecting Dyslexia Across Languages Using an Online Game

Luz Rello
HCI Institute
Carnegie Mellon University
luzrello@cs.cmu.edu

Kristin Williams
HCI Institute
Carnegie Mellon University
krismawil@cs.cmu.edu

Abdullah Ali
University of Maryland
Baltimore County
aali6@umbc.edu

Nancy Cushen White
Department of Pediatrics
University of California San Francisco
nancycushen.white@ucsf.edu

Jeffrey P. Bigham
HCI & LTI Institutes
Carnegie Mellon University
jbigham@cs.cmu.edu

ABSTRACT

At least 10% of the global population has dyslexia. In the United States and Spain, dyslexia is associated with a large percentage of school drop out. Current methods to detect risk of dyslexia are language specific, expensive, or do not scale well because they require a professional or extensive equipment. A central challenge to detecting dyslexia is handling its differing manifestations across languages. To address this, we designed a browser-based game, *Dytective*, to detect risk of dyslexia across the English and Spanish languages. *Dytective* consists of linguistic tasks informed by analysis of common errors made by persons with dyslexia. To evaluate *Dytective*, we conducted a user study with 60 English and Spanish speaking children between 7 and 12 years old. We found children with and without dyslexia differed significantly in their performance on the game. Our results suggest that *Dytective* is able to differentiate school age children with and without dyslexia in both English and Spanish speakers.

Categories and Subject Descriptors

K.3 [**Computers in Education**]: Computer Uses in Education—*Computer-assisted instruction*.

Keywords

Dyslexia, linguistics, games, early detection, diagnosis, assessment, screening.

1. INTRODUCTION

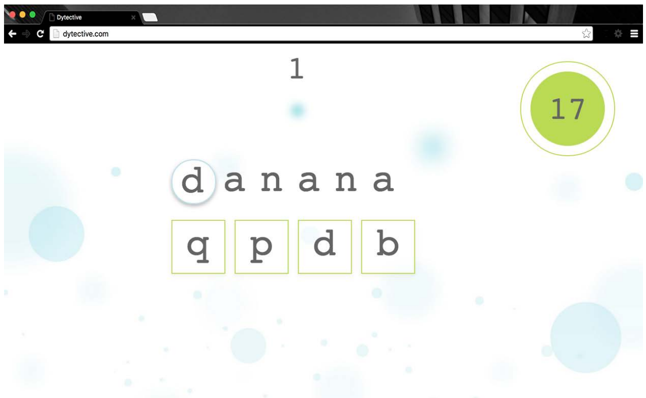

Figure 1: Dytective is a web-based game designed to detect dyslexia in an affordable and scalable way. Players complete linguistically motivated activities.

At least 10% of the population has dyslexia [4]. Dyslexia has a neurobiological basis and results in difficulty with reading and writing [8, 22]. People who know they have dyslexia can learn coping strategies to deal with dyslexia's negative effects [21]. When dyslexia goes undiagnosed, it can be associated with school failure. For example, in Spain over 40% of the school dropout rate is due to dyslexia [10].

Mobile games to detect risk of dyslexia are a promising approach to universal screening of students early enough that they can receive support. However, these games are currently language-specific and implemented in custom computing systems. Thus, it is uncertain whether the games can be extended to other writing systems (orthographies), or even accessed on any device. A browser-based game capable of detecting risk of dyslexia across two of the most widely spoken languages, English and Spanish, could address these limitations in current screeners to advance universal and timely screening for risk of dyslexia.

We designed and created *Dytective* as a browser-based game to distinguish school children with dyslexia who are learning the English and Spanish languages. We then eval-

 ISBN 978-1-4503-4138-7/16/04...$15.00.
http://dx.doi.org/10.1145/2899475.2899491

uated our game with 60 children between 7 and 12 years old (30 English speakers and 30 Spanish speakers). We found that *Dytective* significantly differentiated children with and without dyslexia. Our work contributes a browser-based game integrating 16 indicators of dyslexia to distinguish children with dyslexia from their peers across Spanish and English.

2. BACKGROUND AND RELATED WORK

Definition of Dyslexia. Eighty percent of learning disorders are characterized by difficulty with reading [8, 6]. In the *Diagnostic and Statistical Manual of Mental Disorders (DSM-V)*, dyslexia is described as a *specific learning disorder* having a neurological basis [1]. Dyslexia typically presents as a deficit in the phonological component of language that is not explained by other cognitive deficits, sensory deficits, lack of motivation, or inadequate instruction [8].

Language Dependency. Dyslexia impacts decoding the written symbols of a language using knowledge of spoken language [23]. The expression of dyslexia across different orthographies poses a fundamental challenge for diagnostic criteria of dyslexia [21]. The challenge is in trying to explain varying sensitivity of different native speakers to the statistical properties of their native language known as *orthographic depth*. An orthography's depth is the degree to which a language has a set of rule-based mappings between sounds (phonemes) and spellings (graphemes) (e.g., *gave/save* and *sprint/mint*), and whether those mappings have frequent exceptions (e.g., *have* and *pint*) [13]. Orthographic depth contributes to differences in the ages early learners are expected to master equivalent reading skills across languages [23, 21]. A computer-based approach may be well suited to describing similarities in language dependent features of dyslexia.

Why is Risk of Dyslexia Difficult to Detect?. Detecting dyslexia across languages like English and Spanish is not a trivial task. For instance, the relationships between spellings (graphemes) and sounds (phonemes) in the English language are inconsistent making English an opaque– or deep–orthography. In contrast, Spanish has more consistent mappings between graphemes and spellings making it a more transparent–or shallow–orthography [19]. As a result, reading and writing are much better predictors of dyslexia in English than in Spanish, where reading speed and fluency predominate [21].

Detecting Risk of Dyslexia. Current methods for detecting risk of dyslexia do not address concerns related to how easily the proposed method can be incorporated into existing reading acquisition practices. Paper-based diagnostic tools [3, 2] and neuroimaging [12] can detect dyslexia, but they are not easily deployable at home or in classroom settings where a parent or teacher may first suspect a student is struggling. The complexity of administering these assessments, and the time they require, have led educators to turn towards screening methods to derive a quick assessment of a child's reading progress in order to make decisions regarding a need for intervention or additional reading support [6]. Providing additional support early in reading acquisition has been reported to have profound effects on the incidence of reading failure: reducing 18% incidence to 5% [8].

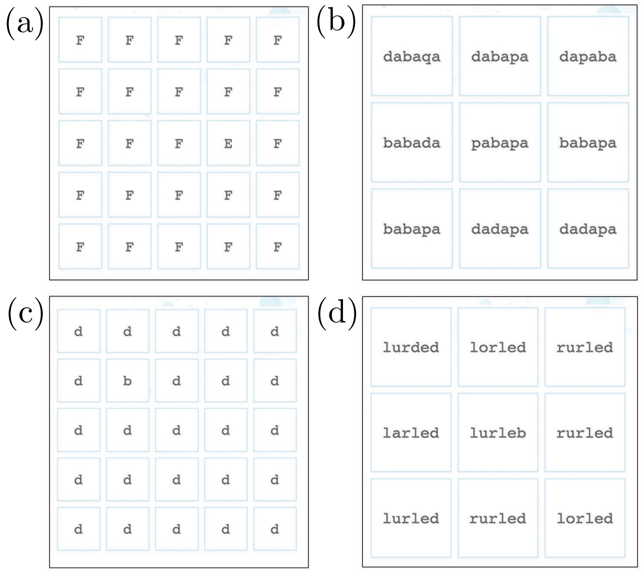

Figure 2: The screen-shot above shows four exercises for Spanish (a and b) and English (c and d): (a) Find and click on the letter that is different (visual). (c) Listen to the name of a letter and click on it as many times as it appears within a time-limit (auditory-visual). (b and d) Listen to the pronunciation of a non-word and click on it as many times as it appears within a time-limit (auditory-visual).

To address issues of scalability and engagement, computerized methods have become a popular line of research for predicting development of dyslexia with machine-learning methods being among the more sophisticated approaches. Prior work has used machine-learning on eye-tracking measures from 97 subjects (48 with dyslexia) to predict readers with dyslexia [16]. Yet this method, like neuroimaging tools [12], does not lend itself to the home or classroom settings where a risk detection tool is needed most. One study used machine-learning methods to detect dyslexia subtypes in the Hebrew language, but data came from existing medical records and did not examine how to scale to new cases [7].

Researchers have begun to design computer games to screen for dyslexia among children prior to or during reading instruction. A few studies have used computer games to detect risk of dyslexia in pre-readers using indicators that may foretell development of dyslexia later in life [9, 5, 20]. Others have used games to identify developmental dyslexia among readers [11]. However, these games focus on specific languages and do not address whether the same game would be successful in a different orthography.

3. A LANGUAGE INDEPENDENT METHOD

We designed *Dytective* with linguistic exercises that would allow us to differentiate children with dyslexia at each stage.

Content Design. First, we conducted a linguistic analysis of the types of written errors that people with dyslexia make. We analyze errors because (i) people with dyslexia

Language	Measure	*Children with Dyslexia*			*Children without Dyslexia*			Significance	%
		M	SD	Mdn	M	SD	Mdn		
English	*Clicks*	7	9.62	10.05	7	9.68	9.12	$W = 143945,\ p = 0.059$	100.62
	Hits	3	3.79	3.81	4	4.42	3.86	$W = 137066.5,\ p = 0.001$	117.41
	Misses	1	3.48	7.4	1	3.21	6.85	$W = 158255,\ p = 0.413$	116.39
	Score	3	3.85	4.02	4	4.45	3.92	$W = 137392,\ p = 0.002$	117.66
	Accuracy	0.5	0.51	0.42	0.67	0.56	0.41	$W = 143331.5,\ p = 0.040$	115.69
	Miss Rate	0.17	0.34	0.38	0.09	0.26	0.34	$W = 173196,\ p < 0.001$	121.43
Spanish	*Clicks*	3	3.95	4.32	5	7.07	7.88	$W = 76537,\ p < 0.001$	178.99
	Hits	2	2.14	2.2	3	3.28	2.47	$W = 80394,\ p < 0.001$	153.27
	Misses	1	1.19	1.93	1	1.06	1.94	$W = 119889,\ p = 0.2423$	112.26
	Score	2	2.20	2.28	3	3.33	2.66	$W = 81106.5,\ p < 0.001$	151.36
	Accuracy	0.67	0.56	0.42	0.80	0.65	0.38	$W = 101728,\ p = 0.001$	116.07
	Miss Rate	0.14	0.32	0.38	0.04	0.20	0.28	$W = 128586.5,\ p = 0.001$	160.00

Table 1: Results for the comparisons between groups: Means, medians, standard deviations, significance and relative percentage differences with respect to the smallest average value.

are not consciously aware of their errors (i.e., suggesting that these errors are processed differently from a cognitive point of view) [14], and (ii) exercises based on written errors by people with dyslexia could be used as input for successful intervention [18] (i.e., meaning that errors are manifestations of the difficulties that people with dyslexia have).

We collected errors written by persons with dyslexia in English and Spanish and analysed the errors from a *visual* point of view (shapes and visual features shared by the letters or other linguistic segments involved in the errors) and from a *linguistic* point of view, taking into account the varying levels of language structure involved in the errors (*e.g.,* phonological, phonetic, morphological, syntactic) [14]. The most frequent linguistic and visual features shared in the errors were incorporated into the exercises. Then we manually created the linguistic exercises taking into consideration *(i)* principles of language acquisition and *(ii)* different cognitive skills that are associated with dyslexia.

The exercises target the following cognitive skills: (i) orthographic processing, (ii) phonological awareness, (iii) reading speed, (iv) phonological memory, (v) phoneme segmentation, (vi) syllable segmentation, (vii) word recognition, (viii) non-word recognition, (ix) syntactic awareness, (x) semantic awareness, (xi) error detection and correction, (xii) written spelling of single words, (xiii) written spelling of non-words, (xiv) working memory, (xv) visual memory, and (xvi) visual attention.

Implementation. *Dytective* is a cross-platform web-based game built in HTML5, CSS, Javascript and a backend PHP server and a database. It was designed with a high level of abstraction to make it easily portable to native iOS or Android for future implementations.

Running Dytective. At each stage, the player's goal is to accumulate points by solving a linguistic problem type as many times as possible in a 25-second time window. In Figure 2, the player hears the target letter/non-word and then a board is shown containing the target as well as distractors that are particularly difficult for people with dyslexia to differentiate. A counter with the score and the remaining seconds appear at the top (Figure 1). After each time window, the player goes on to the next stage to a new linguistic problem type.

4. EXPERIMENTAL STUDY

Using a within-subject design, we conducted two studies with 30 participants for English and 30 for Spanish. For each study, 15 participants had a confirmed diagnosis of dyslexia. Every participant played all stages of *Dytective* over the course of 15 minutes, but they may not have advanced through all of the stages of problems.

Participants. We recruited 60 participants from schools and dyslexia associations. Subjects ranged in age from 7 to 12 years old. Of the English speaking participants, 15 were diagnosed with dyslexia (10 female, 5 male, $M = 9.67, SD = 1.50$); the other 15, without a diagnosis of dyslexia served as a control group (10 female, 5 male, $M = 9.13, SD = 1.13$). Of the Spanish speaking participants, 15 were diagnosed with dyslexia (4 female, 11 male, $M = 9.5, SD = 1.51$); the other 15 without a diagnosis of dyslexia served as a control group (9 female, 6 male, $M = 9.43, SD = 1.50$).

The native language of all participants was either Spanish or English. Four participants were bilingual: 1 from the Spanish group, and 6 from the English group.

Dependent Measures. To measure participants' performance, we used the following *dependent measures* from each stage of exercises: (i) Number of *Clicks* per stage; (ii) *Hits* (*i.e.*, the number of correct answers); (iii) *Misses* (*i.e.*, the number of incorrect answers); (iv) *Score* (*i.e.*, the sum of correct answers for each stage's problem type); (v) *Accuracy* (*i.e.*, the number of *Clicks* divided by the number of *Hits*; and (vi) *Miss Rate* (*i.e.*, the number of *Clicks* divided by the number of *Misses*).

Materials and Procedure. Participation was remote through a computer at home, in a school, or in a specialized center. Participants assented online along with parental or legal guardian consent following protocols approved by our institutional review board (IRB). We guided participants through the procedure via an online video-chat client before allowing them to commence the game. Parents/legal guardians were specifically warned that they could not help their children play *Dytective*, and were asked to confirm in their own words that they would not help. When schools and specialized centers oversaw participation, parental/legal guardian consent was obtained in advance, and the study was supervised by the school counselor or therapist.

4.1 Results

A Shapiro-Wilk test showed that none of the data sets were normally distributed; hence, we used the dependent 2-group Wilcoxon Signed Rank test for non-parametric data to test differences between groups. In Table 1, we show the results for each of the groups. Significant differences between groups–with and without dyslexia–were found for all the dependent measures in the English and Spanish studies except for *Misses* and *Clicks* for the English study.

These results build on earlier findings from the first version of *Dytective* [15, 17], where only Spanish was considered. Using a machine-learning model over the Spanish version, with 243 participants, the model was able to predict dyslexia with 85.85% accuracy [17].

5. CONCLUSIONS AND FUTURE WORK

We have presented *Dytective*, a game to screen for risk of dyslexia for English and Spanish school children. *Dytective*, was created using techniques that can easily be extended to other languages. We evaluated *Dytective* with 60 participants and found significant differences between children with and without dyslexia showing promise that *Dytective* may be able to screen for risk of dyslexia in the future.

To verify these results, our next step will be to conduct a large scale study in collaboration with schools, dyslexia associations, and public institutions. Further, we will apply machine-learning techniques to predict later development of dyslexia. Since estimations of dyslexia are much higher than the actual diagnosed population, we believe *Dytective* has potential the to make a significant impact.

Acknowledgments

We would like to thank Dr. Elsa Cárdenas-Hagan, Gail Kusbit, Dr. María Teresa Moral, Daniela Sánchez Alarcón, Danielle Thompson, and Natalie Winchester for helping us recruit participants and to conduct the user studies.

6. REFERENCES

[1] American Psychiatric Association. *Diagnostic and statistical manual of mental disorders, (DSM-V)*. American Psychiatric Publishing, Arlington, VA, 2013.

[2] E. Carrow-Woolfolk. *OWLS, Oral and Written Language Scales*. NCS Pearson Incorporated, 1995.

[3] F. Cuetos, B. Rodríguez, E. Ruano, and D. Arribas. *PROLEC-R. Batería de evaluación de los procesos lectores, revisada*. TEA, Madrid.

[4] Dyslexia International. Dyslexias Impact. Technical report, 2014.

[5] O. Gaggi, G. Galiazzo, C. Palazzi, A. Facoetti, and S. Franceschini. A serious game for predicting the risk of developmental dyslexia in pre-readers children. In *Proc. ICCCN'12*, pages 1–5. IEEE, 2012.

[6] International Dyslexia Association. Frequently Asked Questions About Dyslexia, 2011. `http://www.interdys.org/`.

[7] Y. Lakretz and M. Rosen-zvi. Probabilistic Graphical Models of Dyslexia. In *Proc. SIGKDD'15*, pages 1919–1928, 2015.

[8] G. R. Lyon, S. E. Shaywitz, and B. A. Shaywitz. A definition of dyslexia. *Annals of Dyslexia*, 53(1):1–14, 2003.

[9] H. Lyytinen, M. Ronimus, A. Alanko, A.-M. Poikkeus, and M. Taanila. Early identification of dyslexia and the use of computer game-based practice to support reading acquisition. *Nordic Psychology*, 59(2):109, 2007.

[10] Ministerio de Educación, Cultura y Deporte. *Informe Redie. La atencion al alumnado con dislexia en el sistema educativo*. Gobierno de Espaa, 2012.

[11] S. Mohtaram, N. C. Pee, and A. S. Sibgatullah. Mobile dyslexia screening test: A new approach through multiple deficit model mobile game to screen developmental dyslexia children. In *Malaysia University Conference Engineering Technology*, 2014.

[12] D. L. Molfese. Predicting dyslexia at 8 years of age using neonatal brain responses. *Brain and language*, 72(3):238–245, 2000.

[13] D. C. Plaut, J. L. McClelland, M. S. Seidenberg, and K. Patterson. Understanding normal and impaired word reading: computational principles in quasi-regular domains. *Psychological review*, 103(1):56–115, 1996.

[14] L. Rello. *DysWebxia. A Text Accessibility Model for People with Dyslexia*. PhD thesis, Universitat Pompeu Fabra, 2014.

[15] L. Rello, A. Ali, and J. Bigham. Dytective: Toward a game to detect dyslexia. In *Proc. ASSETS'15*, Lisbon, Portugal, October 2015.

[16] L. Rello and M. Ballesteros. Detecting readers with dyslexia using machine learning with eye tracking measures. In *Proc. W4A '15*, Florence, Italy, 2015. ACM.

[17] L. Rello, M. Ballesteros, A. Ali, M. Serra, D. Alarcón, and J. P. Bigham. Dytective: Diagnosing risk of dyslexia with a game. In *Proc. Pervasive Health'16*, Cancun, Mexico, 2016.

[18] L. Rello, C. Bayarri, Y. Otal, and P. Pielot. A computer-based method to improve the spelling of children with dyslexia using errors. In *Proc. ASSETS'14*, Rochester, USA, October 2014.

[19] P. H. K. Seymour, M. Aro, and J. M. Erskine. Foundation literacy acquisition in European orthographies. *British Journal of Psychology*, 94(2):143–174, 2003.

[20] L. Van den Audenaeren, V. Celis, V. V. Abeele, L. Geurts, J. Husson, P. Ghesquière, J. Wouters, L. Loyez, and A. Goeleven. DYSL-X: Design of a tablet game for early risk detection of dyslexia in preschoolers. In *Games for Health*, pages 257–266. Springer, 2013.

[21] F. R. Vellutino, J. M. Fletcher, M. J. Snowling, and D. M. Scanlon. Specific reading disability (dyslexia): What have we learned in the past four decades? *Journal of Child Psychology and Psychiatry*, 45(1):2–40, 2004.

[22] World Health Organization. *International statistical classification of diseases, injuries and causes of death (ICD-10)*. World Health Organization, Geneva, 10th edition, 1993.

[23] J. C. Ziegler and U. Goswami. Reading acquisition, developmental dyslexia, and skilled reading across languages: a psycholinguistic grain size theory. *Psychological bulletin*, 131(1):3, 2005.