Interactive Screening for Learning Difficulties: Analyzing Visual Patterns of Reading Arabic Scripts with Eye Tracking

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Abstract. Dyslexia Explorer is a screening program for dyslexia that focuses on mapping visual patterns of reading Arabic scripts to reading difficulties. Dyslexia Explorer is designed to process the eye gaze patterns exhibited by readers with Specific Learning Difficulties (SpLDs) in screening sessions with Arabic stimuli. The screening is based on gaze measures of eye fixation duration for the Area Of Interest (AOI), mean fixation duration, fixation count for the AOI, total fixations count, backward patterns (within words, lines and paragraph). The system is a novel contribution in screening for reading difficulties in the Arabic language. It helps in diagnosing dyslexia by specifying reading deficits, providing objective gaze metrics and linking them to phonological processing difficulties of readers.

Keywords: Dyslexia, Learning Difficulties, Specific Learning Difficulty, Reading Difficulties, Eye tracking, SpLD.

1 Introduction

Specific Learning Difficulties (SpLDs) such as Dyslexia are persistent problems in reading and information processing affecting an estimated 5 to 10% of the Arabic-speaking population [1-3]. Over the past 30 years, abundant evidence has accumulated to indicate that erratic eye movements of people with SpLDs are a reflection of a language processing deficit [5]. In this paper, we describe the design and development of an interactive screening system, called Dyslexia Explorer, for examining visual attention and reading patterns of individuals in their processing of Arabic scripts.

Eye tracking is used to capture visual attention which was otherwise unattainable to specialists dealing with diagnosing this 'invisible disability' [4]. In this system, several near-infrared illuminators, invisible to the reader's eye, create reflection patterns on the cornea. At a high sampling rate of 120Hz, image sensors register the image of the reader's eyes. Image processing is utilized to create a 3D model of the reader's eyes, accurately detect the pupil's position, and identify the correct reflections from the illuminators and their exact positions. A mathematical model of the eye is

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used to calculate the eyes' position in the space allocated for displaying the Arabic script stimuli and the reader's point of gaze. Freedom of head movement was 30x22x30 cm. Head movement compensation algorithms ensured accuracy of gaze detection and precision when subjects, especially children with co-morbid attention deficit and hyperactivity disorders, moved during recordings in relation to the eye tracker. This system is the first Arabic language screening tool, based on visual attention analysis, in the domain of assistive technologies for SpLDs.

2 Dyslexia Explorer

Dyslexia Explorer is a screening program based on visual attention patterns in reading Arabic scripts. It is designed to capture eye gaze of readers in their processing of Arabic script and to decode visual patterns of reading in Arabic and classify them into phonological difficulties in order to help specialists in the SpLDs area to identify problems that individuals with SpLDs experience and design effective remedial programs. The context of use for this interactive screening program and its conceptual design were reported in [11]; and is illustrated in Fig. 1 in which an unobtrusive eye tracking device is placed within range of computer monitor viewing for readers.

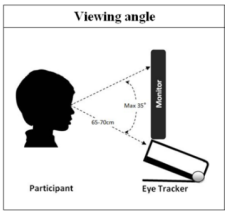

Fig. 1. Setup for the Dyslexia Explorer system

A structured system analysis and design approach was adopted to effectively develop the algorithmic eye gaze analysis screening program. This automated processing depends on some measurements, gathered by eye tracking, to analyze the patterns and produce analytical reports of patterns for special-education practitioners to assist then in identifying the specific reading difficulties of subjects and develop effective remedial programs. The measures are chosen based on the eye gaze metrics and patterns examined in an exploratory study described in [1]. Analysis is based on what is called Area Of Interest (AOI) for each stimuli. The AOIs are for individual words and lines within a segment of Arabic script as depicted in Fig. 2.

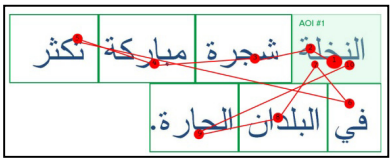

Fig. 2. Areas of Interest for Analyzing Visual Reading Patterns in Arabic Scripts

The system is comprised five key components as illustrated in the architecture in Fig. 3. The first component is "Manage participants" this component manages participants' information either add new participant's info or edit it. This component is comprised of demographic data and cognitive profile of subjects, which can be used in the exploratory component of the system when eye gaze metrics are used to explore the measures that can differentiate between struggling readers and normal readers. The next two components are calculation processes that depend on the eye gaze measurements. The eye gaze raw data are files generated from the eye tracker and contain all information related to each participant's recorded session. The information include: eye fixation coordinates, time stamp for each fixation, and index for each fixation. The component "Filter raw gaze data" filters eye gazes into fixations and saccades based on the Filtering Fixation Algorithm and then the component "Analyze fixations" analyzes and processes fixations to calculate measurements mentioned before. The component "Format and produce report" produces the main output in this system which is an analytical report of aggregate data from all subjects (i.e. 'profile') that is aimed at aiding specialists in their exploration of the dataset. Although normative screening data does not exists for Arabic readers, the specialist can examine the percentile of where the subject exists with regards to different eye gaze measures. This report contains participant information and his/her reading analysis measurements (Mean fixation duration, total fixation count, backward patterns, etc). Finally, "Explore thresholds" component helps specialists to have general overview about results in comparison to the scores recorded previously. Also, shows the degrees of differences between participants. This component plays an important role to design remedial plans for dyslexic children.

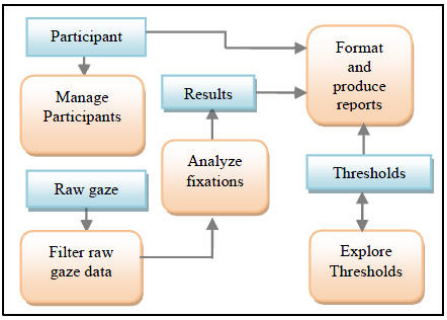

Fig. 3. Architecture of the Dyslexia Explorer system

3 Visual Attention Analysis with Eye Tracking

The Dyslexia Explorer system mainly consists of two processes: Fixation Filtering, and Reading Analysis. The system filters raw gaze data (contains eyes' x/y coordinates, timestamps, and validity code of each gaze), captured by the eye tracker, to fixations and saccades using Fixation Filtering Algorithm. Filtering fixations is the process of grouping raw gaze data collected from the eye tracker to fixation points and saccades lines. This process is important because the tracking process generates fixation points that are close in positions and time stamps. In addition, raw fixations

are related to fine-course analysis which hinder the process of synchronizing or mapping them to human cognitive processes [7,4]. The filtering process starts with mapping the gaze data points to the scene coordinates (i.e. viewing plane) [7]. Following that, it classifies gaze points to fixations or saccades depending on separation thresholds related to the algorithm specification [8]. The Dyslexia Explorer system uses Fixation Filtering Algorithm; a velocity algorithm with two thresholds: velocity and distance [9,10]. This algorithm is chosen because it is suitable for the off-line processing mode as in this system [8].

The system analyzes the fixations under number of measurements (baseline measures were described in [1]): total fixation duration for all Areas of Interest (AOI) in the stimuli, mean fixation duration, fixations' count for all AOI in stimulus and backwards saccades (regressive saccades). The backward saccade may pass on one word, many words or cross lines in the stimulus. An example of this analysis is depicted in Fig. 4. Part-1 of the Reading Analysis component is comprised of visual attention overlaid on the stimulus that has been read. This is illustrated with fixations on the AOI (the green boundaries in Fig. 4). This image shows the raw gaze data of recorded reading after filtered to eye fixations. The circles in the image are the fixations while the lines are saccades. The size of the fixations links directly to the duration of this fixation during the reading process. It helps SpLD practitioners in understanding the flow of the reading and the difficult words that the child spent more time in reading them (this is often depicted in visual scan-paths with several fixations on an AOI or fixations with a relatively large radius). These visual patterns facilitate mapping reading abilities of the individuals to the phonological processing difficulties exhibited in the reading of the stimuli. Part-2 presents quantitative measurements of visual attention distribution in reading; each measure depicted in a separate tab.

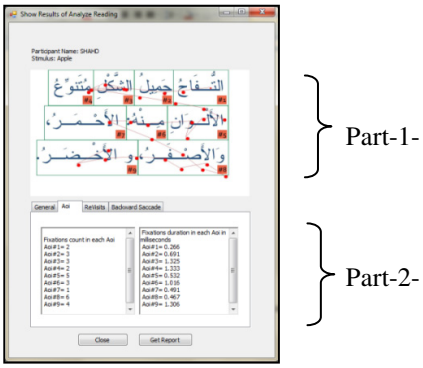

Fig. 4. Reading Analysis in Dyslexia Explorer

4 Conclusion

In this paper, we described the design and development of an interactive screening system for dyslexia in Arabic. The system's key contribution is providing SpLD practitioners with objective screening tools for dyslexia in Arabic by specifying reading

deficits, and linking gaze metrics to phonological processing difficulties. Experimental evaluations comparing visual reading patterns of controls and participants with SpLDs revealed marked differences in the intensity and visual scan-patterns of gaze between the two groups. Evaluations provided evidence of accuracy in capturing visual patterns, and efficiency in screening for irregular visual exploration patterns, particularly regression reading patterns and abnormal intensity on words for struggling readers.

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