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Assessing the performance of visual identification tasks using time window-based eye inter-fixation duration

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A B S T R A C T

The objective of this research was to develop a new eye-tracking metric to evaluate human performance of a visual identification task. According to prior research on eye tracking, eye movement metrics could examine relationships between task performance and eye gaze behaviors. However, little is known about the relationship between the eye movements and the performance on the identification task. In this study, by using the time window-based human-in-the-loop simulation representing an anti-air warfare coordinator, we studied the performance on the identification task and eye tracking data during the experiment. The performance was evaluated by the total number of correctly identified aircraft. Saccade duration (SD) and time windows-based inter-fixation duration (TWID) were used to analyze participants' eye tracking data. Transition number (TN) was also used as a metric to compare SD with TWID. The results indicated that both TWID and SD showed a significant difference between excellent performers and others. The participants who perfectly identified all unknown aircraft had much shorter inter-fixation duration compared to others who made mistakes. However, only the well-skilled performers' average TWID was significantly related to TN. The findings of this research supported that TWID could be used as one of the eye movement measures to assess the performance of the identification task in a computer-based environment.

1. Introduction

Eye-tracking data has been used to understand human performance in various domains (Harbluk et al., 2007; Rayner, 1998; Tsai et al., 2012). According to the previous studies, eye movement can be correlated with visual task performance in terms of duration, amplitude, direction, velocity, transition, and knowledge levels (Bednarik and Tukiainen, 2006; Fioravanti et al., 1995; Jarodzka et al., 2010; Vaeyens et al., 2007). In addition, the relationship between pupil dilation and mental workload has been investigated in many studies (Beatty, 1982; Hess and Polt, 1964; Kahneman and Beatty, 1966; Otero et al., 2011). However, despite the numerous successful studies on eye tracking, progress in the analysis of eye movement data for real-life applications is still very much in its infancy. Moreover, there is no applicable eye-tracking metric that can measure the human performance of object identification in dynamic visual stimuli environments. One of the possible reasons is the noise in eye movement data. It is very difficult to identify the moments related to the searching performance of a given task in the entire data record. The longer and the more complex the experiment conducted, the more unrelated movements are recorded in the eye-tracking data. To the best of our knowledge, only a few eye tracking studies have been done using dynamic visual stimuli to identify differences in visual attention (Jarodzka et al., 2010). A dynamic visual searching task makes it very hard for researchers to analyze eye movement data because it is usually involved with the countless combinations of head movements when people perform the tasks.

In this study, the time windows-based inter-fixation duration (TWID) was introduced to eliminate those unimportant data from the entire eye-tracking record. TWID is a saccade analysis based on the time window constraints. The time window is defined as a series of time segments related to task events. Saccade duration is the time between any two adjacent fixations. However, TWID only considers the fixations inside of time windows. By using time window-based human-in-the-loop simulation (J. H. Kim, Rothrock, & Laberge, 2014), we were able to collect more accurate eye

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movement data that is directly related to performing the given task. In addition, simulation time was synchronized with eye tracking time data during the experiment. Hence, it was clearer to find the relationship between eye movement data and human performance using TWID.

2. Literature review

Eye tracking data can be analyzed in many different ways, such as movement, position, numerosity, and latency. In the previous literature, more than one hundred different eye-tracking metrics were used in various fields (Holmqvist et al., 2011). Among them, the rapid movement of inter-fixation, called saccade, is one of the common and popular metrics in the field of eye tracking research (Bojko, 2013). Saccade is the fastest actions produced by human (Pratt and Trottier, 2005). A single saccade typically lasts about 20–35 ms (Poole and Ball, 2005). However, saccade duration, amplitude, direction, velocity, and number could vary because of different perceptual behaviors on a task. During saccades, visual processing is automatically suppressed; in other words, the visual system nearly shuts down, to avoid blurring of the visual image (Stark and Ellis, 1981). The purpose of most saccades is to move eyes to the next viewing position. Since no encoding takes place during saccades, we cannot determine the complexity or salience of an object in an intuitive way. However, saccade has still been proved to be a reliable source to interpret a human performance in many studies. Rayner et al (2012) claimed that regressive saccades (i.e., backtracking eye movements) could act as an indicator of processing difficulty during encoding, and a larger phrase-length regression can represent confusion in a higher level of text processing. Liston et al. (2013) described a simple algorithm to detect saccades and imposed a minimum saccade duration to keep the false-alarm rate at an acceptable level. Also, Vaeyens et al (2007) mentioned that successful soccer players had faster saccade speed rates compared to the less successful group by using more goal-oriented search strategies. Goldberg and Kotval (1999) found that a longer saccade duration represented less efficient scanning during user interface evaluation. Several researchers also chose saccade length and saccade speed as the metrics to measure human performance (Chen et al., 2011; de Greef et al., 2009). Table 1 shows a summary of the saccade-derived metrics, which are commonly used for performance measure. Although there are various models for saccadic programming (Findlay, 1992), the prediction of saccade paths from these models is not inadequate to measure human performance of a visual searching task.

To measure the performance of the identification task, it is important to understand the underlying mechanism of saccadic eye movement, such as how a neuronal system drives saccades and the differences between voluntary saccade and reflexive saccade. Also, it is necessary to investigate a better way to analyze eye tracking data to increase the correlation between saccadic movement and human performance of a visual searching task.

3. Methods

3.1. Participants

A total of 22 students from the University of Missouri (15 males, 7 females) participated in this experiment. The participants had an age range from 20 to 24 (mean = 21.318, standard deviation = 1.323). They did not have any prior knowledge and experience of the task domain. The participants also did not wear glasses or contact lenses, which means that every participant had at least 20/50 of visual acuity. During the calibration procedure, the eye-tracking system was able to capture a stable pupil and corneal reflection of all participants.

3.2. Apparatus

An anti-air warfare coordinator (AAWC) task is a particular domain of time window-based human-in-the-loop (TWHITL) simulation. An operator must defend his or her ship against hostile aircraft (J.-E. Kim, Nembhard and Kim, 2016; Macht et al., 2014). The experimental environment included an eye tracking device, the AAWC radar simulator, and information boards. The eye tracking system (Mobile Eye XG with 30 Hz) was used to record the participant's eye movements. The system allows us to gather precise eye-gaze points by using three corneal reflections with dark pupil methodology. The glasses also allowed participants to have complete freedom of head movement.

AAWC simulation was designed to simulate identifying unknown aircraft in a radar monitoring task. The AAWC interface (see Fig. 1) consists of five sections: 1) radar display screen, 2) data panel, 3) data input panel, 4) system response panel, and 5) manual bar. The radar display screen showed flight paths of all detected aircraft in air space. The data panel displayed more detailed information, such as altitude, speed, and sensor name of the aircraft. The data input panel showed the input data from a keyboard. The

Table 1
Saccade metrics for performance measure.

Metric	Definition	Interpretation	Limitation
Saccade Duration	The time to move between two fixations (in milliseconds)	A decreased processing capacity increased saccade duration (Bestelmeyer et al., 2006)	Blinks interfere with saccadic durations (Rambold et al., 2002)
Saccade Amplitude	The distance traveled from its onset to the offset (pixels)	Represent users' perceptual experience of what they saw.	Less consistency between individuals (Holmqvist et al., 2011)
Saccade Direction	The direction of any saccadic movement (degree)	Commonly used for vision experiments with a central fixation cross surrounded by peripheral targets at fixed saccade angles.	It is hard to interpret the meaning of oblique saccades (Viviani et al., 1977)
Saccade Velocity	The first derivative of saccade distance with respect to saccade duration (pixel/milliseconds)	Change in the velocity might represent tiredness (McGregor and Stern, 1996); Faster saccade can be achieved by using more goal-oriented search strategies and indicate a higher decision-making skill (Vaeyens et al., 2007).	The velocity is typically filtered before being processed. The filters may produce latencies in the results (Inchingolo and Spanio, 1985)
Saccade Number	A total number of saccades from trial start to the end.	More saccades indicate more searching or less efficient search (Goldberg and Kotval, 1999)	People often make more saccades than needed during tasks (Land, 2006)