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Eye movements predict students' computer-based assessment performance of physics concepts in different presentation modalities

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ABSTRACT

Despite decades of studies on the link between eye movements and human cognitive processes, the exact nature of the link between eye movements and computer-based assessment performance still remains unknown. To bridge this gap, the present study investigates whether human eye movement dynamics can predict computer-based assessment performance (accuracy of response) in different presentation modalities (picture vs. text). Eye-tracking system was employed to collect 63 college students' eye movement behaviors while they are engaging in the computer-based physics concept questions presented as either pictures or text. Students' responses were collected immediately after the picture or text presentations in order to determine the accuracy of responses. The results demonstrated that students' eye movement behavior can successfully predict their computer-based assessment performance. Remarkably, the mean fixation duration has the greatest power to predict the likelihood of responding the correct physics concepts successfully, followed by re-reading time in proportion. Additionally, the mean saccade distance has the least and negative power to predict the likelihood of responding the physics concepts correctly in the picture presentation. Interestingly, pictorial presentations appear to convey physics concepts more quickly and efficiently than do textual presentations. This study adds empirical evidence of a prediction model between eye movement behaviors and successful cognitive performance. Moreover, it provides insight into the modality effects on students' computer-based assessment performance through the use of eye movement behavior evidence.

1. Introduction

Humans use their eyes to explore external environments, identify objects, and guide their behavior. Humans often focus their eye movements on an area of interest, and alternate eyes to acquire better and more acute images. All the information is then processed by the brain, which interprets and synthesizes the images. With more than 80% of our information received from the visual sensory channel, eye movements provide a very important source of cognitive processing. According to the eye–mind assumption, a close relationship exists between eye gaze and attention during the process of visual information presentation (Just & Carpenter, 1976). Some studies reported that the patterns and quantity of eye movement behaviors (number of fixation, mean fixation duration, and regression) reflect the difficulty of information processing in the form of texts and pictures (Rayner, 1998). Liversedge and Findlay (2000) assumed that fixation duration, saccade length, and total reading time are indicators of eye movement behaviors when the readers are reading or conducting visual searches. Moreover, they also held that readers who have difficulty in reading comprehension will re-read the sentences they have read before; thus, regressive eye movement behaviors can provide information regarding one's reading process. These studies showed that there is a link between eye movements and human cognitive processes.

Abbreviations: MFD, Mean Fixation Duration; MSD, Mean Saccade Distance; RRTp, Re-reading Time in Proportion.

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Retrieval is an essential component of the human cognitive process. It involves identifying features and integrating one feature with another, or, more specifically, matching the encoded messages in the human brain and the presented cues in the situation (Herbert & Hayne, 2000; Tulving, 1983). In other words, individuals must allocate their attention to the presented information and retrieve their previously stored information concerning the presented information from their long-term memory in order to answer questions correctly. This process involves identifying critical features in the presented information, searching our long-term memory for matching features, as well as integrating, matching, and verifying the features between the presented and the stored information. A recent study proposed that human eye movement behaviors are related to the identifying and integrating processes (Pollatsek, Reichle, & Rayner, 2006). Researchers have also proposed several reading processing models, such as the E-Z reader (Reichle, Warren, & McConnell, 2009) and SWIFT (Engbert, Nuthmann, Richter, & Kliegl, 2005), that incorporate visual processing, word identification, attention shift, and oculomotor control. In these models, word identification, which involves familiarity check and lexical access, is the core process driving eye movement while reading. Moreover, postlexical integration, which connects one word's meaning with another in context and integrates readers' prior knowledge in long-term memory, influences readers to have regressive eye movement behaviors when they have difficulty in reading comprehension (Mayer, 2003; Reichle, Rayner, & Pollatsek, 2012). Therefore, eye movements and attention allocation have a direct link to word identification and post-lexical integration. Studies of eye movement while reading Chinese have shown that fixation durations and probabilities can reveal processing difficulty when retrieving the lexical properties of foveal and parafoveal words (Tsai, Kliegl, & Yan, 2012; Tsai, Lee, Tzeng, Hung, & Yen, 2004). Some non-reading studies also suggested that eye movements would play an important role in identifying and integrating processes in image searching. For example, Henderson, Brockmole, Castelhano, and Mack (2007) indicated that participants always fixated on the regions where objects were likely to be and that salient regions which lack meaningful features do not compel participants to allocate more attention. With these studies, we are interested in how students' eye movements reflect the process of their retrieving physics concepts presented as pictures and text.

Because of the rapid technological development in recent years, computer-based assessment has been employed for evaluating students' learning performance and generated many methods of assessment (Gikandi, Morrow, & Davis, 2011; Thelwall, 2000). Computer-based assessment has more advantages than traditional pencil-and-paper assessments. Compared to the traditional paper–pencil assessment's narrow focus on grading, computer-based assessment's range of aspects, functions, and methods of evaluation are rather versatile. Computer-based assessment does not simply measure students' learning outcome more efficiently and accurately than traditional pencil-and-paper assessment, but also creates a student-centered learning environment which expands the function of evaluation to facilitate knowledge construction (Angus & Watson, 2009; Gaytan & McEwen, 2007; Tallent-Runnels et al., 2006). Some other studies included an auto-grading function for multiple choice questions (Koong & Wu, 2010) or a personalized adaptive assessment tool (GRE Exam, 2012; Lazarinis, Green, & Pearson, 2010) incorporated into a computer-based assessment system in order to evaluate students' answers or products. Other studies of computer-based assessments have focused both on assessing students' answers and on supplying information about the students' cognitive processing (Csapó, Ainley, Bennett, Latour, & Law, 2012), such as analyzing the students' reaction time in responding to each presented stimulus, recording their paths of reading or assessing the learning materials (Ainley, 2006; Hadwin, Wynne & Nesbitt, 2005; Kyllonen, 2009). Can technology move further to provide students with real-time support for retrieving their knowledge successfully and response correctly? Apparently, the eye-tracking technique has great potential to fulfill this mission for its unique properties to detect when, where, and what human eye gazed in 1/1000 s. In addition, the eye-tracking technique can provide us with the data for the sequence in order to conduct a further analysis, such as recording the sequence of students' fixations in the events in order to track their cognitive processing during the task (Humphrey & Underwood, 2010). According to the students' immediate responses, we employed the eye-tracking technique while the students were working on their computer-based assessment simultaneously to detect their retrieval process in real-time and to track their paths through a task, hoping that this might open a new window on future computer-based assessment.

Many studies assumed that humans process different information via different modalities, as well as processing text and pictures in different cognitive systems (Baddeley, 2000; Baddeley & Hitch, 1974; Clark & Paivio, 1991; Schnotz & Kürschner, 2008). Dual coding theory, which Paivio (1986) proposed that humans process spoken words and text in the verbal system, but process pictures in the nonverbal system. Based on Paivio's theory, Mayer (2003) provided the cognitive theory of multimedia learning and explained the different ways that learners process visual and verbal information. He argued that learners process visual materials via a visual channel while processing auditory materials via a verbal channel. However, while pictorial and printed text materials are processed by learners via a visual channel initially, learners often convert printed text into sound to be processed at verbal working memory; thus, learners use different channels to handle pictorial and printed text materials. Schnotz and Bannert (2003) also indicated that text is regarded as symbols describing an object or the relation to other objects, whereas pictures are considered as icons representing an object or using structural correspondences to convey the relation to other objects. Hence, humans use symbol processing to process text and structure-mapping processing to process pictures. These studies showed that text and pictures are processed using different mechanisms, but they did not illustrate whether the efficiency of human cognitive processing of text is different from that of pictures. We seek to incorporate presentation modality into computer-based assessment in order to explore the efficiency of the human cognitive process.

Previous studies suggest that a relationship exists between eye movement behavior and student learning. Some studies have used eye-tracking techniques to identify various strategies that students use when engaged in problem-solving activities (Grant & Spivey, 2003; Hegarty, Mayer, & Monk, 1995; Hodgson, Bajwa, Owen, & Kennard, 2000) and reading processing (Engbert et al., 2005; Rayner, Chace, Slattery, & Ashby, 2006). Other studies focus on examining students' degree of concept construction during science learning tasks (She & Chen, 2009), finding that middle school students' eye movements are associated with the students' degree of concept construction when learning science concepts. Hence, the greater visual attention they allocated (number of fixations, total inspection time, and mean fixation duration), the more completely they understood the concept of genetics. Similar result reported that 4th graders' learn better when they had more frequency integration of eye movements during gazing science text and picture (Mason, Tornatora, & Pluchino, 2013). Another study using college students resulted in longer average fixation durations and better learning performance by applying color to matching information between the textual and pictorial presentations of the scientific material (Ozcelik, Karakus, Kursun, & Cagiltay, 2009). These studies suggest that eye movement is a valuable method for studying students' learning. With respect to physics concepts, however, there is still a lack of empirical studies that explore the relationship between eye movements and cognitive performance during the computer-based assessment. Thus, this study aims to explore students' cognitive processing during a computer-based assessment and