Chih-Ming Chen*, Jung-Ying Wang and Yu-Chieh Lin "A visual interactive reading system based on eye tracking technology to improve digital reading performance", *The Electronic Library*, 2019. (Accepted) **[SSCI 收錄] (Post-print version)**

A Visual Interactive Reading System Based on Eye Tracking Technology to Improve Digital Reading Performance

Chih-Ming Chen[1*], Jung-Ying Wang [2] and Yu-Chieh Lin[3]

[1]Graduate Institute of Library, Information and Archival Studies, National Chengchi University, Taipei City, Taiwan, ROC; E-mail: chencm@nccu.edu.tw
[2]Department of Multimedia and Game Science, Lunghwa University of Science and Technology, Taoyuan City, Taiwan, ROC; E-mail: wyy@mail.lhu.edu.tw
[3] Graduate Institute of Library, Information and Archival Studies, National Chengchi University, Taipei City, Taiwan, ROC; E-mail: ilustxrc@yahoo.com.tw
* Corresponding author

Type of paper: Research paper
Keywords: Digital reading, Eye tracking technology, Human-computer interaction, reading behavior analysis
Purpose— Developing attention-aware systems and interfaces based on eye tracking technology could revolutionize mainstream human-computer interaction (HCI) to make that interaction between human beings and computers more intuitive, effective, and immersive than can be achieved traditionally using a computer mouse. This study therefore proposes an eye-controlled interactive reading system (ECIRS) that uses human eyes instead of the traditional mouse to control digital text to support screen-based digital reading for language learning.
Design/methodology/approach— This study uses a quasi-experimental design to examine the effects of an experimental group and a control group of learners who respectively used the ECIRS and a mouse-controlled interactive reading system (MCIRS) to conduct their reading of two types of English-language text online - pure text and Q & A type articles on reading comprehension, cognitive load, technology acceptance, and reading behavioral characteristics. Additionally, the effects of learners with field-independent (FI) and field-dependence (FD) cognitive styles who respectively used the ECIRS and MCIRS to conduct their reading of two types of English-language text online - pure text and Q & A type articles on reading comprehension also are examined.
Findings—Analytical results reveal that the reading comprehension of learners in the experimental group significantly exceeded that of those in the control group for the Q & A article, but the difference was insignificant for the pure text article. Moreover, the ECIRS improved the reading comprehension of FI learners more than it did that of FD learners. Moreover, neither the cognitive loads of the two groups nor their acceptance of the technology differed significantly whereas the reading time of the experimental group significantly exceeded that of the control group. Interestingly, for all articles, the control group of learners read mostly from top to bottom whereas the most of the learners in the experimental group read most paragraphs more than once. Clearly, the proposed ECIRS supports deeper digital reading than does the MCIRS.
Originality and value— This study proposes an emerging ECIRS that can automatically provide supplementary information to a reader and control a reading text based on a reader's eye movement to replace the widely used mouse-controlled reading system on a computer screen to effectively support digital reading for English language learning. The implications of this study are that the highly interactive reading patterns of digital text with ECIRS support increase motivation and willingness to learn while giving learners a more intuitive and natural reading experience as well as reading an article online with ECIRS support guides learners' attention in deeper digital reading than does the MCIRS because of simultaneously integrating perceptual and cognitive processes of

selection, awareness, and control based on human eye movement.

1. Introduction

As more reading is done digitally, the improvement of digital reading competence and the development of an effective digital reading mode for students have attracted increasing attention in the field of e-learning in recent years. Digital reading not only involves static text and images but also audio, video, and animation. Digital reading has some powerful advantages over traditional print reading, such as interactivity, nonlinearity, and immediacy of accessing information (Liu, 2012). However, several studies agree that screen-based reading is likely to be shallow, associated with short attention spans and poor comprehension (Carr, 2010; Liu, 2005; Wolf & Barzillai, 2009). Encouragingly, Chen and Chen (2014) presented a collaborative reading annotation system with a reading annotation and interactive discussion scaffold (CRAS-RAIDS) to improve reading performance in collaborative digital reading environments. They demonstrated that learners who used the CRAS-RAIDS to support collaborative digital reading significantly outperformed those who used the traditional paper-based reading annotation method and face-to-face discussions in direct and explicit comprehension, inferential comprehension performance, and use of a reading strategy. Oliveira, Camacho and Gisbert (2014) presented a case study on digital reading (e-textbook) in a primary education classroom. They found that all students who participated in their experiment liked the e-textbook and they were willing to use it instead of a traditional textbook, but they expressed that the e-textbook did not have enough interactive features to support digital reading. Liu (2012) argued that five areas - digital reading behavior, print vs. digital, preferred reading medium, multi-tasking and learning, and technological advancement and traditional attachment - are worthy of study in the field of digital reading. Obviously, technological advances in digital reading are highly worthy of examination.

The different devices (e.g. mobile phones, smart watches, head mounted displays) that human beings use to access information in daily life have played an important role in shaping their reading habits. Therefore, alternative methods to present textual information for different kinds of devices have become crucial to facilitate information consumption while preserving our capacity to capture the meaning of what we read for learning. Reading for learning means that reading process can be closely connected to the learning process and thus the quality and depth of knowledge construction can be impressive when reading. Castelhano and Muter (2001) summarized that the methods of presenting textual information to readers for learning using different kinds of devices include the moving window, the times square, the linestepping, the sentence-by-sentence presentation, and the rapid serial visual presentation (RSVP). Among those methods, the RSVP that consists of displaying one or more words at a time and in sequential order, thus minimizing the eye movements including saccades and eye blinks generated during reading, and increasing the attentional focus represents one of the main alternatives. However, Benedetto et al. (2015) study indicated that the RSVP negatively affected literal comprehension in the case of Spritz due to suppressing parafoveal processing and regressions (i.e. rereadings of words). Furthermore, the important reduction of eye blinks observed for Spritz might contribute to the increase of visual fatigue. Moreover, Chen and Lin (2016) designed a mobile reading experiment with a two-factor experimental design to assess the effects of the selected static (i.e. paging display type), dynamic (i.e. auto-scrolling display type), and designed mixed text display types (i.e. both static and dynamic text display types), which were respectively presented in sitting, standing, and walking contexts, on reading comprehension, sustained attention, and cognitive load of learners. Their study concluded that the three reading contexts with the three text display types have both advantages and disadvantages for reading comprehension, sustained attention, and cognitive load. As a result, text display type for mobile reading on small screens should be adjusted according to reading context or to improve reading comprehension, attention, or cognitive load.

Eye contact and gaze direction are essential cues that indicate the target of visual interest in human reading process. Gaze behavior reflects cognitive processes and can give hints of a human's thinking and intentions (Majaranta & Bulling, 2014). Thus, eye tracking has been applied to develop novel reading mode in support of more effective digital reading. For example, Biedert et al. (2010) developed a simple-to-use framework to construct a gaze-responsive application, called Text 2.0, that is based on eye tracking technology rather than screen-based digital reading using a mouse. Text 2.0 involves text that "knows" that it is being read and can interact in real time with the motion of a user's eyes (Biedert et al, 2010). However, experimental verification that eye-controlled reading, like that associated with Text 2.0, improves reading performance is lacking and related reading behaviors are not well understood. Biswas and Langdon (2014) studied how users interact with an eye-gaze tracker, which has the potential to be more intuitive than a mouse or touchpad. They found that novice users can point and select in an online shopping task significantly faster using the eye-gaze tracker than using the mouse, but the difference in cognitive load was statistically non-significant. Therefore, this study proposes an emerging eye-controlled interactive reading system (ECIRS) that can automatically provide supplementary information to a reader and control a reading text based on a reader's eye movement. This system can replace the widely used mouse-controlled interactive reading system (MCIRS) on a computer screen to effectively support digital reading using a keyboard and mouse for English language learning. The highly interactive reading patterns of digital text with ECIRS support increase motivation and willingness to learn, while giving learners a more intuitive and natural reading experience. Based on a quasi-experimental design, the research questions of this study are whether or not the differences between the learners of experimental group using the proposed ECIRS and the learners of control group using MCIRS to assist reading English-language texts online in reading comprehension, reading time, cognitive load, and acceptance of technology exist. Moreover, whether or not the differences between the learners with different cognitive styles of experimental group using the proposed ECIRS and the learners with different cognitive styles of control group using MCIRS to assist reading English-language texts online in reading comprehension exist is also examined. Finally, lag sequential analysis is used to characterize behavioral shifts and elucidate behavioral differences among learners of both groups based on time sequences of behavioral events.

2. Literature Review

2.1 Attention-aware systems and their applications in education settings

Developing attention-aware systems (AAS) that can detect users' attention states in real time could revolutionize mainstream human-computer interaction (HCI) to make that interaction between human beings and computers more intuitive, effective, and immersive. Stiefelhagen, Yang and Waibel (2002) indicated that user's focus of attention plays an important role in HCI applications, such as a ubiquitous computing environment and intelligent space, where the user's goal and intent have to be continuously monitored. According to Rapp (2006), AAS may provide benefits of teaching diverse learners, assessing student performance, providing feedback during curriculum development and adding value to computer-assisted teaching methodologies. Generally, developing AAS to identify a learner's attention level could be based on human behaviors, such as head pose (Ba & Odobez, 2009), multiple cues including eye gaze directions and sound sources (Stiefelhagen, Yang &Waibel, 2002) or physiological signal measurements, such as eye gaze (Toet, 2006), brainwave signals (Belle *et al*, 2012; Chen, Wang, & Yu, 2017; Chen & Wang, 2018).

Chen, Wang and Yu (2017) developed a novel AAS capable of recognizing students' attention levels accurately based on brainwave signals, thus having high potential to be applied in providing timely alert for conveying low-attention level feedback to online instructors in an e-learning environment. Results of this study demonstrate that the proposed AAS is effective, capable of assisting online instructors in evaluating students' attention levels to enhance their online learning performance. Moreover, Chen and Wang (2018) developed a novel attention monitoring and alarm mechanism (AMAM) based on brainwave signals to improve learning performance via monitoring the attention state of individual learners and helping online instructors or teaching assistants to improve the sustained attention levels of learners with low-attention states as they perform online synchronous instruction activities. Results of this study verified that the AMAM efficiently promotes the learning performance and sustained attention of learners. Lin and Chen (2019) presented an attention-based video lecture review mechanism (AVLRM) that can generate video segments for review based on students' sustained attention status, as determined using brainwave signal detection technology. The findings of this study showed that AVLRM based on brainwave signal detection technology can precisely identify video segments that are more useful for effective review than those picked by student themselves. Also, Stiefelhagen, Yang and Waibel (2002) proposed to model participants' focus of attention from multiple cues including eye gaze directions and sound sources. Their study indicated that the focus of attention model can be used as an index for a multimedia meeting record as well as can also be used for analyzing a meeting. Therefore, developing a visual interactive reading system based on human's eye movement that can more naturally provide HCI effects on promoting reading performance than does the traditional mouse is a valuable research direction.

2.2 Applications of eye tracking technologies in studies of reading behavior, reading mode, and computer assisted language learning

Since eye contact and gaze direction are essential cues that indicate the target of visual interest in human reading process, eye tracking has been widely used in studies of web browsing behaviors, learning processes in e-learning environments, human cognitive characteristics (Zhan, Zhang, Mei, & Fong, 2016), and digital reading (Biedert et al., 2010). For example, Pan et al. (2004) studied the determinants of ocular behavior on a single web page using eye tracking technology. They found that the gender of the subjects, the viewing order of the contents of a web page, and the interaction between order in which the pages of a site are viewed and site type affect online ocular behavior. Yang et al. (2013) focused on the use of the eye tracking to study the visual attention of university students during a PowerPoint presentation in a real classroom. The results demonstrated that learners pay significantly more attention to text zones on PPT slides and to the narration of the instructor than other zones of PPT slides. Zhan, Zhang, Mei and Fong (2016) used the multi-feature regularization machine learning mechanism, which is based on a Low-rank Constraint that takes into account many aspects of eye movement, including pupils, blinks, fixation, saccade, and regression, to construct a computational model to assess online learners' reading ability. Their computational model has good generalizability with an error of only 4.9% when randomly run 100 times. Additionally, Biedert et al. (2010) developed a reading mode called text 2.0 that can know what a reader is reading and can interact in real time with the motion of a user's eyes based on eye tracking technology.

Moreover, the use of eye tracking technology in studies of computer-assisted language learning has become increasingly common (Liu, 2014; Michel & Smith, 2017; Smith & Renaud, 2013). For example, Smith and Renaud (2013) used eye tracking to measure foreign language learners' noticing of recasts in computer-mediated writing conferences. Their study suggested that eye tracking is a useful tool for understanding visual attention. Stickler, Bryan and Lijing (2016) used eye tracking to study the interactions of online language learners with computers by recording gaze focus. The eye-tracking data were used to provide information on cognitive processes. To discuss challenges in eye tracking with a view to understanding language learning processes, Dussias (2010) used eye tracking data in second language sentence processing research. He reviewed the use of eye tracking in L2 spoken-language comprehension and elucidated why eye tracking is useful in language processing research. Lai et al. (2013) used eye-tracking technology to study human cognitive processes that are associated with learning and reviewed the use of eye tracking methods to investigate learning from 2000 to 2012. Their study noted that eye-tracking technology has promise for enabling educational researchers to connect learning outcomes to cognitive processes. Michel and Smith (2017) provided an overview of eye-tracking research in computer-mediated language learning and proposed many development directions that depend on advances in eye tracking technology. Due to the high potential of applying eye tracking technologies in reading for supporting language learning, this study thus proposes an ECIRS that uses human eyes instead of the traditional mouse to control digital text to support screen-based digital reading for English learning.

2.3 Effects of computer assisted learning for learners with FI and FD cognitive styles on learning performance

Individual learners who are FI are analytic, independent, and socially insensitive and prefer to work alone, while individual learners who are FD tend to be holistic, dependent, and socially aware and are more easily affected by environment (field) than field independent learners (Witkin & Goodenough, 1977). Moreover, a FI learner perceives analytically, analyzes and isolates relevant details, detects patterns, and critically evaluates data whereas FD one perceives holistically, tends to get lost in the stimuli and is unable to distinguish salient points (Fatemi, Vahedi, & Seyyedrezaie, 2014). Furthermore, FI learners trust internal cues, and this is associated with a greater aptitude for restructuring, i.e. for imposing organization on received information, whereas FD learners place their trust in external cues, and tend to accept percents of symbolic representations at face value (Tinajero & Paramo, 1997).

Many field-dependent-independent studies (Kheirzadeh & Kassaian, 2011; Tinajero & Páramo, 1997; Chen, Tan, & Lo, 2016) provide inconsistent results with respect to computer assisted learning performance. Tinajero and Páramo (1997) found that FI learners consistently achieve better academic outcomes than FD students in all of the English learning subjects that they considered. Davis's study (1987) found that children with a FI cognitive style tended to be more efficient readers than those with FD, based on a meta-analysis of 25 correlational studies. Chen (2013) developed an intelligent mobile location-aware book recommendation system (IMLBRS) with map-based guidance to support collaborative problem-based learning in a real-library environment. His study demonstrated that the proposed IMLBRS facilitates better learning performance for learners with FD cognitive style than for learners with FI cognitive style. Chen, Tan and Lo (2016) demonstrated that the digital pen and paper interaction platform (DPPIP), in which digital pen technologies were integrated with printed textbooks and the Moodle course management system to support repeated reading to improve English-language reading fluency, helped learners with FI and FD cognitive styles to improve their oral reading fluency. In contrast, Kheirzadeh and Kassaian (2011) found no difference in the performance of FI and FD cognitive style learners in general language listening comprehension. Due to the inconsistent results with respect to the effects of computer assisted learning tools on learning performance, this study thus examines whether using the proposed ECIRS to assist digital reading provides different benefits to FI and FD cognitive style learners or not.

3. Research Methodology

3.1 Proposed eye-controlled interactive digital reading system (ECIRS)

Cognitive psychologists and, more recently, neuropsychologists have extensively studied human attention as well as human attentional processes have been considered as guided by perceptual and cognitive processes (Roda & Thomas, 2006). Importantly, human perceptual and cognitive abilities are limited resources, whereas attention is the mechanism used to allocate such resources in the most effective way (Roda & Thomas, 2006). Three aspects of attention have been commonly recognized as fundamental: selection, awareness, and control (Baddeley & Weiskrantz, 1993). Based on the theory this study develops an ECIRS that can support human attentional processes guided by perceptual and cognitive processes that simultaneously integrate selection, awareness, and control when reading an article online based on human eye movement.

Figure 1 shows the user interface of the proposed ECIRS that supports the interactive reading of digital texts based on eye movement. The system also supports the interactive reading of digital texts using a mouse. If a learner uses the eye-tracking mechanism to read, then the system automatically detects the current position of the eye movement. If a learner uses the mouse mechanism to read, then the system detects the position of the mouse cursor. If the paragraph in a text is not read, then the background is automatically blurred, as shown in Figs. 2 and 3. This function offers several benefits to readers because it reduces the amount of visible information that is not needed during reading.

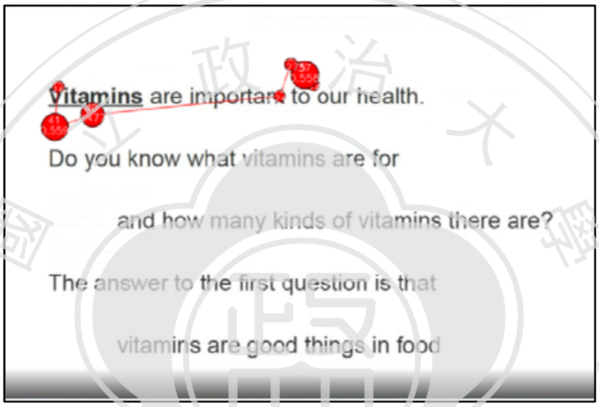

Figure 1.The user interface of the proposed ECIRS

Figure 2. The reading situation by using eye movement

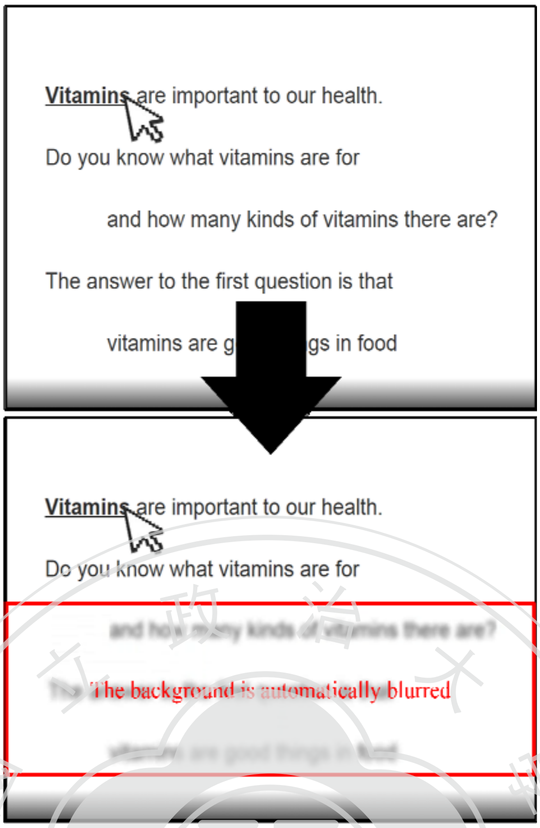

Figure 3. The reading situation by using mouse

The proposed ECIRS and MCIRS can mark texts with annotations in bold. The annotation of content can help readers obtain a deeper and broader understanding in language learning. For example, the text "vitamins" in an article was annotated to provide supplementary information, as shown in Figs. 4 and 5, respectively. A few seconds after a learner gazes at, or uses the mouse to move the cursor to the area of interest (AOI) of the text "vitamins", the annotation of the AOI is automatically provided to the learner. This function provides useful information that helps readers to understand the article. Three types of annotation - words, phrases and translations - provide this additional information, as shown in Fig. 6. Moreover, for convenient, the ECIRS and MCIRS automatically scroll the reading text up or down in response to eye movement or mouse movement by two areas that are located at the top and bottom of the computer screen, respectively. Figure 7 shows the two areas that are gazed at to scroll the text up or down.

Figure 4. The text “vitamins” with annotation in the reading article for the ECIRS

Figure 5. The text “vitamins” with annotation in the reading article for the MCIRS

Figure 6. Three types of annotations- words, phrases and translations

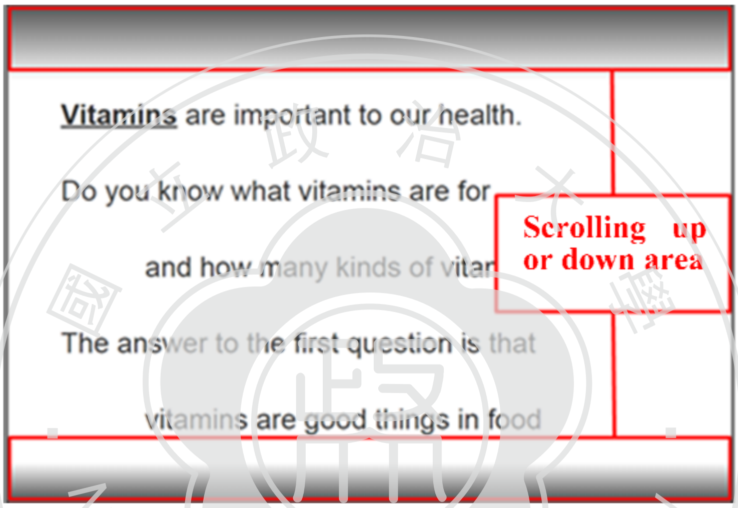

Figure 7. Visual areas for scrolling up or down the reading text by using eye tracking or mouse

The ECIRS used Gazepoint GP3 eye tracker (https://www.gazept.com/product/gazepoint-gp3-eye-tracker/)(Fig. 8), which has a sample rate of 60 HZ and a visual angle accuracy of 0.5-1 degree, and provides open standard APIs, to receive eye movement from a learner. However, sitting still to control a digital text using eye movement may be uncomfortable. To solve this problem, the Gazepoint GP3 eye tracker can track head movements and compensate for them to some degree.

Figure 8. The ECIRS with Gazepoint GP3 eye tracker support

3.2 Reading material

Many studies have demonstrated that learners perform differently when they read texts with different structures (Amiri, Zainal, & Abdul Samad, 2012). In this study, two basic level articles with different text structures that were selected from the General English Proficiency Test (GEPT) in Taiwan are read and the reading comprehension of the participants are examined. The first reading article, a "pure text article", includes text only as article content. The second reading article includes questions and answers, and is called a Q & A article.

3.3 Research participants

A total of 26 Grade 7 students were recruited from a senior high school in New Taipei City, Taiwan, to participate in the instructional experiment. The 26 participants were divided randomly into a control group (eight females and five males) and an experimental group (five females and eight males). The experimental group used the ECIRS as the reading system, while the control group used the MCIRS.

To consider the research ethics of the designed experiment that involves recording eye movement states of the research subjects, written informed consent was obtained from the parents of research subjects following full explanation of the experiment. The informed consent letter contains the specific nature of the research, including that assessing eye movement states by the Gazepoint GP3 eye tracker is safe as well as it would not result in any potential risks to human eyes, the data that collect from them are only for the research, their name will never appear on any data collected and that instead we will provide a unique identification number on their data and that this information will remain secure such that only the principal investigator of this study will have access to it, the collected data that are no longer needed will be destroyed, and how participation will make a contribution to our study's goals.

3.4 Research design

A quasi-experimental design was adopted to study the effects of using the proposed ECIRS and the MCIRS to support the reading of English-language texts online on the reading comprehension, reading time, cognitive load, and technology acceptance of learners in the experimental group and the control group. The experimental procedure involved the following six stages.

(1) First stage

First, the experimental procedure was explained to all of the research participants, who were then invited to complete the Group Embedded Figures Test (GEFT) to identify their cognitive style as FI or FD. Second, to determine the relevant prior knowledge of both groups of learners, all research participants were invited to complete pre-tests concerning the contents of both of the reading texts. Third, learners in the two groups were instructed to use and familiarize themselves with the ECIRS or the MCIRS to support them in reading English text online before the experiment. Finally, nine-point calibration of the used Gazepoint GP3 eye tracker was performed for the learners in the experimental group learners so that the ECIRS would receive correct eye movement data. The first stage takes a total of 30 minutes.

(2) Second stage

In the second stage, the two groups of learners respectively used the ECIRS and the MCIRS to read the pure text article. The PostgreSQL database was used to store information about the reading processes of learners of both groups, one of which used eye movement and one of which used computer mice, to control the reading text. The second stage took 5 minutes. Each research participant finished the reading activity according to herself/himself reading speed within 5 minutes and was not allowed to review the article thereafter.

(3) Third stage

After the reading of the pure text article, both groups of learners were tested for reading comprehension, acceptance of the technology used, and cognitive load, to determine whether the two groups differed in these respects. The third stage took 20 minutes.

(4) Fourth stage

The experimental group of learners who used the ECIRS participated in nine-point calibration of the used Gazepoint GP3 eye tracker before reading the Q & A article. The fourth stage took 1 minutes.

(5) Fifth stage

The fifth stage was the same as the second stage. The two groups of learners used the ECIRS and the MCIRS to read the Q & A article. The PostgreSQL database was used to store the reading processes of the learners in both groups; one used eye movements to control the reading text, based on the Gazepoint GP3 Desktop Eye Tracker, while the other used a mouse. The fifth stage took 5 minutes. Similarly, each research participant finished the reading activity according to herself/himself reading speed within 5 minutes and was not allowed to review the article thereafter.

(6) Sixth stage

The sixth stage was the same as the third stage. After they had read the Q & A article, both groups immediately took tests of their reading comprehension, acceptance of the technology they had used, and cognitive load to determine whether the two groups differed in these respects. The sixth stage took 20 minutes.

3.5 Research tools

3.5.1 English reading comprehension test

Reading comprehension is the ability to process text, understand its meaning, and to integrate with what the reader already knows (Grabe, 2009). To assess how the proposed ECIRS affects the reading comprehension of learners, English articles used in this study were from Taiwan's GEPT (https://www.gept.org.tw/). The aim of the GEPT is to provide a fair and reliable assessment of each ability level in English. Currently, the GEPT is divided into five levels with content appropriate to each level, and each level incorporates listening, reading, writing, and speaking components. Each reading article provided by GEPT also contains a corresponding test that assesses reading comprehension. Two English reading articles with different text structures were selected at the basic level of the GEPT to evaluate the reading comprehension of learners.

3.5.2 Technology acceptance questionnaire

To elicit the participants' opinions about using the ECIRS and the MCIRS to support digital reading, they were invited to fill in a technology acceptance questionnaire after the experiment. The analysis of their responses revealed the participants' subjective perceptions of the extent to which the ECIRS and the MCIRS improved their reading performance and the perceived difficulty of operating the two systems. The technology acceptance questionnaire of Hwang, Yang, and Wang (2013) was used and some sentences modified to conform to the current research, and a Likert 6-point scale was used. The questionnaire included 6 questions that examined two dimensions of perceived usefulness of the system, and 13 questions that examined its perceived ease of use. The

Cronbach's α values of the sub-scales of the perceived usefulness of the system and the perceived ease of use of the system were 0.95 and 0.94, respectively, both indicating good reliability.

3.5.3 Cognitive load scale

To identify how the use of the ECIRS and the MCIRS in digital reading influences cognitive load, the cognitive load scale of Sweller, van Merrienboer and Paas (1998) was used to evaluate each learner's cognitive load. This scale, which comprises one subscale for mental load and one subscale for mental effort, contains four items with responses on a seven-point Likert scale. Two items were associated with mental load (intrinsic load) and two were associated with mental effort (extraneous and germane load); the total score of each subscale was 14. The Cronbach's α value for the cognitive load scale was 0.92; those for the mental effort and mental load sub-scales were 0.86 and 0.85, respectively. These analytical results demonstrate the high reliability of the measurement scale.

3.5.4 Group Embedded Figures Test (GEFT)

Witkin (1971) developed the Group Embedded Figures Test (GEFT) for classifying learners as FI or FD cognitive style learners. The GEFT hides simple geometric figures among more complicated lines, and the examinees must identify the hidden figures. Examinees are classified into FI or FD by the speed and accuracy with which they identify the simple geometric figures. The GEFT (Witkin, 1971) is used herein to identify students' cognitive styles as FI or FD with a view to determining how cognitive style affects English text reading performance using the ECIRS or the MCIRS. The GEFT was translated into Chinese by Wu (1987). The reliability of the scale has been determined using the Sperman–Brown prophecy formula to be 0.82. Any learner whose GEFT score was higher than the average was identified as a FI cognitive style learner, whereas any whose GEFT score was lower than the average was identified as a FD cognitive style learner.

2 Experimental Results

Since the sample size of the study was small and not normally distributed, the nonparametric statistical Wilcoxon Mann-Whitney U test was used assess the reading performance of the participants in each group.

4.1 Analysis of initial reading abilities of learner groups

Before the reading activity was performed, the Wilcoxon Mann-Whitney U test was used to determine differences in the initial English abilities of the learners in the two groups. Table 1 shows the analytical results. For both articles, the differences between the pretest results of the two groups were not significant (pure text article, $Z = -.211$, $p = .833 > .05$; Q & A article, $Z = -.211$, $p = .833 > .05$). These results confirm that the learners in both groups had equivalent prior knowledge with respect to both reading articles.

Table 1. Wilcoxon Mann-Whitney U test of the initial reading ability of both groups for the two types of reading articles

Type of reading article	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Pure text article	Experimental group	13	13.19	171.50	-.211	.833
	Control group	13	13.81	179.50		
Q & A article	Experimental group	13	13.81	179.50	-.211	.833
	Control group	13	13.19	171.50		

4.2 Analysis of reading comprehension of learner in both groups

The Wilcoxon Mann-Whitney U test was conducted to determine whether the reading comprehension differed significantly between the experimental and control groups. Table 2 shows the analytical results, which demonstrate that reading comprehension of the Q & A article differed significantly between the two groups ($Z = -2.089$, $p = .037 < .05$). The experimental group had better reading comprehension than the control group, confirming that the ECIRS significantly improved the reading comprehension of learners. However, no significant difference existed between the groups in their reading comprehension of the pure text article ($Z = -1.837$, $p = .066 > .05$).

Table 2. Wilcoxon Mann-Whitney U test of the reading comprehension of both groups for the two types of reading articles

Type of reading article	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Pure text article	Experimental group	13	10.88	141.50	-1.837	.066
	Control group	13	16.12	209.50		
Q & A article	Experimental group	13	16.58	215.50	-2.089*	.037
	Control group	13	10.42	135.50		

*indicates $p<.05$

4.3 Analysis of reading comprehension of FI and FD cognitive style learners in both groups

The Wilcoxon Mann-Whitney U test was performed to determine whether reading comprehension of each article differed significantly between learners with different cognitive styles in both groups. Table 3 shows the results for the reading of pure text article by the learners with FD cognitive style in both groups. The differences between the pre-test and post-test results were not significant for both groups ($Z = -.961$, $p = .336 > .05$; $Z = -1.431$, $p = .153 > .05$). Table 4 shows the results for the reading of the pure text article by the learners with FI cognitive style in both groups. The differences between the pre-test and post-test results were not significant for both groups ($Z = -.411$, $p = .681 > .05$; $Z = -1.541$, $p = .123 > .05$).

Table 3. Wilcoxon Mann-Whitney U test of reading comprehension in both groups for the FD cognitive style learners by the pre-test and post-test of pure text article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Pre-test	Experimental group	8	5.81	46.50	-.961	.336
	Control group	4	7.88	31.50		
Post-test	Experimental group	8	5.50	44.00	-1.431	.153
	Control group	4	8.50	34.00		

Table 4. Wilcoxon Mann-Whitney U test of reading comprehension in both groups for the FI cognitive style learners by the pre-test and post-test of pure text article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Pre-test	Experimental group	5	8.10	40.50	-.411	.681
	Control group	9	7.17	64.50		
Post-test	Experimental group	5	5.30	26.50	-1.541	.123
	Control group	9	8.72	78.50		

Table 5 shows the results for the reading of the Q & A article by the learners with FD cognitive style learners in both groups. The differences between the pre-test and post-test results were not significant for both groups ($Z = -.961$, $p = .336 > .05$; $Z = -.951$, $p = .342 > .05$). Table 6 shows the results for the reading of the Q & A article by the learners with FI cognitive style. The difference between the pre-test results of the two groups was not significant ($Z = -.411$, $p = .681 > .05$), but that between the post-test results of the two groups was significant ($Z = -3.090$, $p = .002 < .05$). The FI cognitive style learners in the experimental group had significantly better reading comprehension than those in the control group.

Table 5. Wilcoxon Mann-Whitney U test of reading comprehension in both groups for the FD cognitive style learners by the pre-test and post-test of Q & A article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Pre-test	Experimental group	8	7.88	31.50	-.961	.336
	Control group	4	5.81	46.50		
Post-test	Experimental group	8	5.13	20.50	-.951	.342
	Control group	4	7.19	57.50		

Table 6. Wilcoxon Mann-Whitney U test of reading comprehension in both groups for the FI cognitive style learners by the pre-test and post-test of Q & A article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig.
Pre-test	Experimental group	5	7.17	64.50	-.411	.681
	Control group	9	8.10	40.50		
Post-test	Experimental group	5	10.00	90.00	-3.090	.002*
	Control group	9	3.00	15.00		

*indicates p<.05

4.4 Analysis of reading time, cognitive load, technology acceptance and behavioral characteristics of learners in both groups

The Wilcoxon Mann-Whitney U test was performed to evaluate the differences in reading time, cognitive load, and technology acceptance between the two groups. The behavioral characteristics of learners in both groups, including the number of annotation triggers, the annotation trigger time, the length of the reading sequence, and the number of annotation triggers per unit time are also examined. Table 7 presents these results for the pure text article. Cognitive load (Z = -.771, p = .441 >.05), technology acceptance (Z = -1.027, p = .304 >.05), total number of annotation triggers (Z = -1.388, p = .165 >.05), and the annotation trigger time (Z = -.385, p = .700 >.05) did not differ significantly between both the groups. However, the learners in the two groups differed significantly in reading time (Z = -2.232, p = .026 < .05), length of the reading sequence (Z = -3.411, p = .001 < .05), and number of annotation triggers per unit time (Z = -2.513, p = .012 < .05). The learners in the control group had more annotation triggers per unit time than those in the experimental group. However, the reading time and the length of the reading sequence of learners in the experimental group significantly exceeded those of the learners in the control group.

Table 8 presents the results for the Q & A article. The two groups did not differ significantly in cognitive load (Z = -.308, p = .758> .05) and technology acceptance (Z = -.591, p = .555> .05), but they did differ significantly in reading time (Z = -2.282, p = .022 < .05), number of annotation triggers (Z = -2.086, p = .037 < .05), annotation trigger time (Z = -3.414, p = .001 < .05), length of the reading sequence (Z = -3.488, p = .000 < .05), and number of annotation triggers per unit time (Z = -2.538, p = .011 < .05),which were all higher for the experimental group than for the control group.

Table 7. Wilcoxon Mann-Whitney U test of reading time, cognitive load, technology acceptance, and the behavioral characteristics of learners in both groups for the pure text article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Reading time	Experimental group	13	16.85	219.00	-2.232*	.026
	Control group	13	10.15	132.00		
Cognitive load	Experimental group	13	14.65	190.50	-.771	.441
	Control group	13	12.35	160.50		
Technology acceptance	Experimental group	13	11.96	155.50	-1.027	.304
	Control group	13	15.04	195.50		
Number of annotation triggers	Experimental group	13	15.58	202.50	-1.388	.165
	Control group	13	11.42	148.50		
Annotation trigger time	Experimental group	13	14.08	183.00	-.385	.700
	Control group	13	12.92	168.00		
Length of the reading sequence	Experimental group	13	18.62	242.00	-3.411**	.001
	Control group	13	8.38	109.00		
Number of annotation triggers per unit time	Experimental group	13	9.73	126.50	-2.513*	.012
	Control group	13	17.27	224.50		

*indicates p<.05; **indicates p<.01

Table 8. Wilcoxon Mann-Whitney U test of reading time, cognitive load, technology acceptance and the behavioral characteristics of learners in both groups for the Q & A article

	Group	Number of learners	Mean rank	Sum of ranks	Z	Sig. (two-tailed)
Reading time	Experimental group	13	16.92	220.00	-2.282*	.022
	Control group	13	10.08	131.00		
Cognitive load	Experimental group	13	13.96	181.50	-.308	.758
	Control group	13	13.04	169.50		
Technology acceptance	Experimental group	13	12.62	164.00	-.591	.555
	Control group	13	14.38	187.00		
Number of annotation triggers	Experimental group	13	16.62	216.00	-2.086*	.037
	Control group	13	10.38	135.00		
Annotation trigger time	Experimental group	13	18.62	242.00	-3.414**	.001
	Control group	13	8.38	109.00		
Length of the reading sequence	Experimental group	13	18.73	243.50	-3.488***	.000
	Control group	13	8.27	107.50		
Number of annotation triggers per unit time	Experimental group	13	12.38	161.00	-2.538*	.011
	Control group	13	14.62	190.00		

*indicates p<.05; **indicates p<.01; ***indicates p<.001

4.5 Lag sequential analysis of reading process

Lag sequential analysis is used to characterize behavioral shifts and elucidate behavioral differences among learners, based on time sequences of behavioral events (Quera & Bakeman, 2000; Moran, Dumas, & Symons, 1992). To perform the lag sequential analysis, the number of samples in sequential analyses was calculated by frequency of the neighboring pairs of events. The zero-order model proposed by Bakeman (1986) was used to calculate the Z score. A Z score above 1.96 indicates that the sequence presents remarkable coding transfer that the research participants with obvious behavioral transfer in the system's operation could be observed, and a high Z score indicates a larger behavioral transfer compared to a low Z score. The PostgreSQL database was used herein to record the reading processes of the experimental group that used the ECIRS and the control group that used the MCIRS to read two types of interactive text. The reading processes of the learners were recorded. Humans have a typical visual range of 200° and a visual overlap of 120° (Zhou, Gao, &, Meng, 2011). Therefore, three rows of reading text as a visual set were adopted to convert the corresponding text into reading sequential analysis code, as shown in Fig. 9.

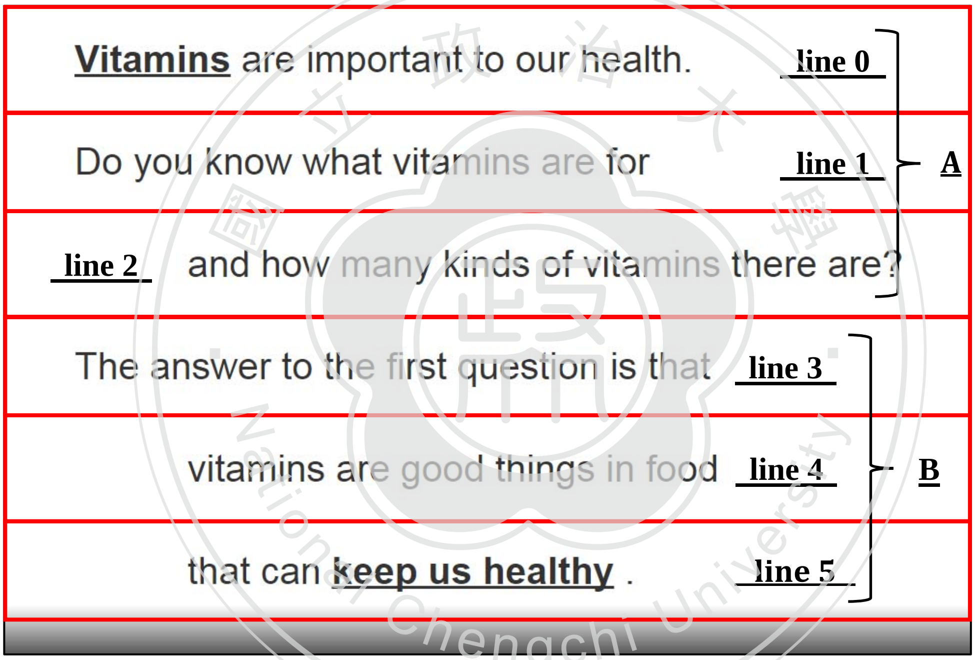

Figure 9. The coding scheme of the reading article for reading sequence analysis based on lag sequential analysis

Figure 10 shows the results of the sequential analysis of the reading of the pure text by the control group using the MCIRS. The control group of learners only looked back to reread the paragraph E from F ($Z = 5.31$). Otherwise, all reading was from top to bottom. This finding may be related to the fact that the paragraph E to F is close to the bottom edge of the screen. Learners must move the mouse to look forward or back to confirm whether the paragraph F is the last paragraph of reading text or not.

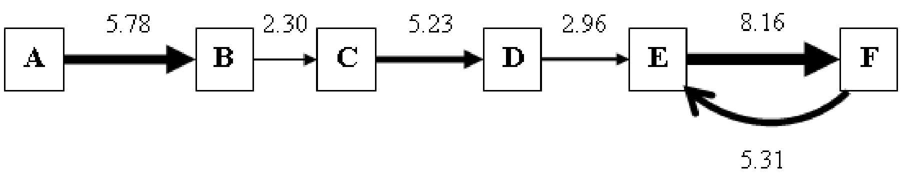

Figure 10. The sequential analysis diagram of control group using the MCIRS to read the pure text article

Figure 11 presents the results of the sequential analysis of the reading of the pure text article by learners in the experimental group who used the ECIRS. Most of the learners in the experimental group looked back and reread most paragraphs. Only the paragraph C to D was not reread in this way ($Z = 1.61 < 1.96$). Meanwhile, the paragraph E to F had the largest Z score ($Z = 12.08$). Similarly, this finding may be related to the fact that the paragraph E to F is close to the bottom edge of the screen. Learners must use their eye movements to confirm whether the paragraph F is the last paragraph of reading text or not.

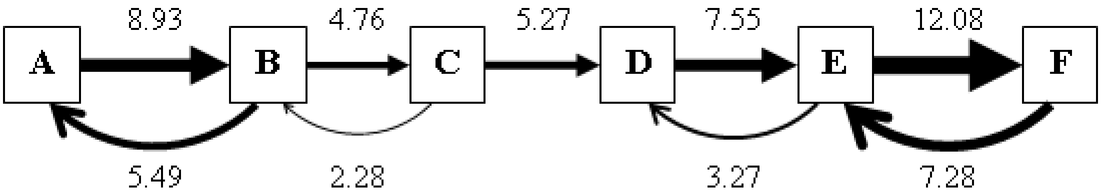

Figure 11. The sequential analysis diagram of experimental group using the ECIRS for the pure text article

Figure 12 presents results of the sequential analysis of the reading of the Q & A article by control group. The learners in the control group read from top to bottom. However, some learners looked back to reread paragraphs in the question and answer part, such as the paragraph A from B ($Z = 4.47$) and G from H ($Z = 4.43$).

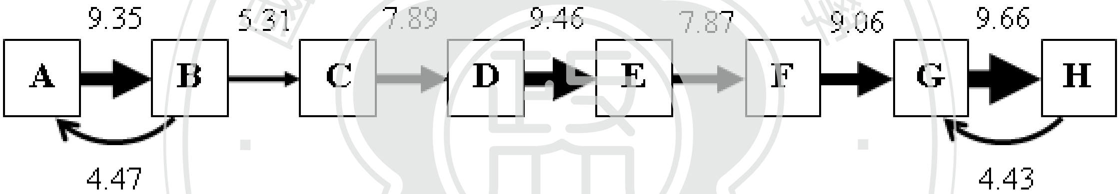

Figure 12. The sequential analysis diagram of control group using the MCIRS to read the Q & A article

Figure 13 presents results of the sequential analysis of the reading of the Q & A article by the experimental group of learners who used the ECIRS. Most of the learners in the experimental group looked back to reread all paragraphs. Clearly, using the ECIRS to read the Q & A article caused learners to read more deeply than they did using the MCIRS, causing them to have greater reading comprehension.

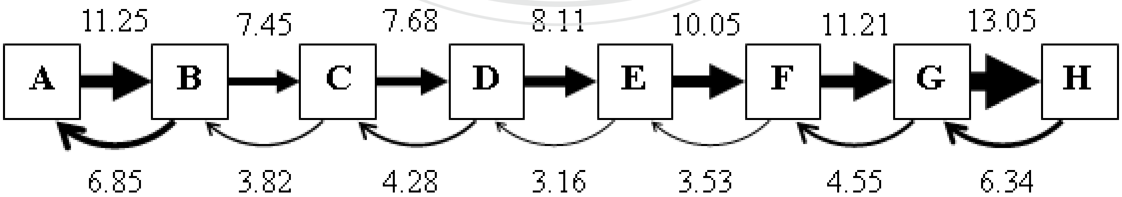

Figure 13. The sequential analysis diagram of experimental group using the ECIRS for the Q & A article

3 Discussion

The results in study demonstrate that learners in the experimental group who used the ECIRS to support their digital reading of a Q & A article had significantly better reading comprehension than those in the control group who used the MCIRS, but the deference in comprehension of a pure text article was not significant. Previous studies (Hsiao & Chen, 2016; Chuang et al., 2014) have found learning interfaces that respond naturally to human sensory organs, such as somatosensorily controlled learning games, can significantly influence learning outcomes because they enable learners to immerse themselves in the learning atmosphere, improving learning performance. The proposed ECIRS is very close to natural human reading by eye, and so yields better reading comprehension than the MCIRS. Previous studies (Kendeou & van den Broek, 2007; Hall, Sabey, & McClellan, 2005) have found that text structure affects learners' reading comprehension and memory, and articles with well structured or highly organized contents favor reading comprehension. The text in a pure text article is all article content, whereas a Q & A article includes questions and answers. Therefore, a Q & A type article has more highly organized contents than a pure text article, and the ECIRS is clearly more favorable for reading an article with highly organized content. Furthermore, the present study demonstrates that the proposed ECIRS provides greater benefit to FI learners than to FD learners in their reading comprehension of a Q & A article. The main reasons inferred by this study are that the proposed ECIRS having the features in automatically providing the internal supplementary cues of reading article using annotations and naturally adopting readers' eye gaze and movements to read an article matches with the information processing and learning style characteristics of FI learners.

Several studies (Carr, 2010; Liu, 2005; Wolf & Barzillai, 2009) have claimed that screen-based reading easily leads to shallow reading, short attention spans, and poor comprehension. However, in this study, for both types of article, the reading time, length of the reading sequence, and number of annotation triggers per unit time of the learners in the experimental group who used the ECIRS to support digital reading significantly exceeded those of the learners in the control group who used the MCIRS. More importantly, this study found that using the ECIRS to support digital reading on a computer screen can naturally guide the learners to look back and reread the text. Clearly, the proposed ECIRS is very helpful in guiding learners to read more deeply in a digital reading environment. Although the use of human eyes as an input method to operate and read digital text is more intuitive, natural, and effective than the use of a mouse, ocular physiology and perception poses some considerable challenges (Majaranta & Bulling, 2014). In particular, the accuracy of the eye tracking may be significantly reduced by the movement of a learner's head and a learner's eyes are prone to fatigue over time during reading. With the recent rapid development of eye tracking technologies, wearable eye tracking glasses (Grushko & Leonov, 2014), which have robust, mobile, and easy-to-use features and are designed to capture natural viewing behavior in any real-world environment, may overcome these challenges.

Finally, some limitations of this study warrant consideration. First, the ECIRS was only assessed for senior high school students of a particular age. Therefore, the results of this research cannot be applied readily to learners of other ages and academic levels. Second, the ECIRS herein used the Gazepoint GP3 eye tracker, which has a sample rate of only 60 Hz and visual angle accuracy of 0.5-1 degree, to receive eye movement signals from the learner. The low-level eye tracker with its lower sample rate and poorer visual angular accuracy than those of a high-level eye tracker with a sample rate of 1kHz and visual angle accuracy of 0.35 degree may result in a poorer ECIRS performance.

4 Conclusions and Future Work

This study demonstrates that the reading comprehension of learners in an experimental group who used the ECIRS to support their digital reading of a Q & A article significantly outperformed those in a control group who used the MCIRS, but no significant difference in reading comprehension was found in their reading of a pure text article. This result demonstrates that the structure of an article affects learners' reading comprehension and eye-movement manipulation is very effective for reading highly organized articles with annotations. Moreover, field-independent learners in the experimental group had a significantly better reading comprehension of a Q & A article than those in the control group, but field-independent learners in the two groups did not differ significantly in their comprehension of a pure text article. The proposed ECIRS improves the comprehension of field-independent learners more than that of field-dependent learners. No significant difference existed between the groups that used the ECIRS and the MCIRS in cognitive load or acceptance of the technology used. Therefore, the proposed ECIRS is as easy to use as the MCIRS. However, the two groups differed significantly in reading time, length of the reading sequence, and number of annotation triggers per unit time, all of which were higher for the experimental group than the control group, regardless of the article read. Additionally, the proposed ECIRS guided learners to look back and reread most paragraphs. Remarkably, the proposed ECIRS caused learners to read digital content more deeply than did the MCIRS.

Additional studies are warranted. First, the proposed ECIRS may be a powerful digital reading tool for people with physical disabilities, and particularly for people with limb disorders who cannot use their hands to use a mouse to read digital text. Therefore, our future work will study the use by disabled people of the proposed ECIRS to support digital reading and its effect on reading comprehension, reading efficiency, cognitive load, and acceptance of the technology. Second, attention detection based on brainwave is useful for diagnosing learning-related conditions such as attentional deficits and hyperactivity (Gevensleben et al, 2009). Therefore, our future work will combine brainwave attention detection (Chen, Wang, & Lin, 2017) and eye tracking to develop an attention diagnostic mechanism that can determine whether a learner's visual attention and brain attention are simultaneously on a text during reading. Such an attention diagnostic mechanism may help low-attention learners review passages that they read with low concentration to improve their reading attention and performance. Finally, owing to the mass digitalization of information, library curation has gradually expanded from the traditional curation of physical objects and collections to digital curation or the integration of substantial and digital curation (Chen & Tsay, 2017). The ECIRS that is developed in this study could be applied to digital curation, to facilitate human interactions with digital objects using eye movement signals, providing an entirely kind of interactive experience.

References

Anderson, L.W. and Krathwohl, D. (2001). *A Taxonomy for Learning, Teaching and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. Longman, New York.

Amiri, F., Zainal, Z., & Abdul Samad, A. (2012), "Effects of text structure on the Iranian students' reading comprehension performance", *Procedia - Social and Behavioral Sciences*, Vol. 66, pp. 402-409.

Bakeman, R. (1986), *Observing Interaction: An Introduction to Sequential Analysis*, Cambridge University Press, New York, NY.

Biedert, R., Buscher, G., Schwarz, S., Möller, M., Dengel, A, & Lottermann, T. (2010), "The text 2.0 framework: Writing web-based gaze-controlled realtime applications quickly and easily", *Proceedings of 2010 Workshop on Eye Gaze in Intelligent Human Machine Interaction*, pp. 114-117.

Biswas, P. & Langdon, P. (2014), "Eye-gaze tracking based interaction in India", *Procedia Computer Science*, Vol. 39, pp. 59-66.

Benedetto, S., Carbone, A., Pedrotti, M., Fevre, K. L., Bey, L. A. Y., & Baccino, T. (2015), "Rapid serial visual presentation in reading: The case of Spritz", *Computers in Human Behavior*, Vol. 45, pp. 352-358.

Ba, S. O. & Odobez, J. M. (2009), "Recognizing visual focus of attention from head pose in natural meetings", *IEEE Transactions on Systems, Man, and Cybernetics, Part B: Cybernetics*, Vol. 39, No. 1, pp. 16-33.

Baddeley, A., & Weiskrantz, L. (1993), "*Attention: Selection, awareness and control. A tribute to donald broadbent*", Oxford: Clarendon Press University.

Carr, N. (2010), "*The shallows: How the Internet is changing the way we think, read & remember",* New York: W. W. Norton and Company, Inc.

Chen, C. M. & Chen, F. Y. (2014), "Enhancing digital reading performance with a collaborative reading annotation system", *Computers & Education*, Vol. 77, pp. 67-81.

Chen, C. M. & Tsay, M. Y. (2017), "Applications of collaborative annotation system in digital curation, crowdsourcing, and digital humanities", *The Electronic Library*, Vol. 35, No. 6, pp. 1122-1140.

Chen, C. M., Tan, C. C., & Lo, B. J. (2016), "Facilitating English language learners' oral reading fluency with digital pen technology", *Interactive Learning Environments,* Vol. 24, No. 1, pp. 96-118.

Chen, C. M (2013), "An intelligent mobile location-aware book recommendation system that enhances problem-based learning in libraries", *Interactive Learning Environments*, Vol. 21, No. 5, pp. 469-495.

Chen, C. M., Wang, J. Y., & Lin, M. (2017), "Enhancement of English learning performance by using an attention-based diagnosing and review mechanism in paper-based learning context with digital pen support", *Universal Access in Information Society*, https://doi.org/10.1007/s10209-017-0576-2

Chen, C. M. & Lin, Y. J. (2016), "Effects of different text display types on reading comprehension, sustained attention and cognitive load in mobile reading contexts", *Interactive Learning Environments*, Vol. 24, No. 3, pp. 553-571.

Chen, C. M, Wang, J. Y., & Yu, C. M. (2017), "Assessing the attention levels of students by using a novel attention aware system based on brainwave signals", *British Journal of Educational Technology*, Vol. 48, No. 2, 348-369.

Chen, C. M. & Wang, J. Y. (2018), "Effects of online synchronous instruction with an attention monitoring and alarm mechanism on sustained attention and learning performance", *Interactive Learning Environments*, Vol. 26, No. 4, pp. 427-443.

Chuang, C. H., Chen, Y. N., Tsai, L. W., Lee, C. C., & Hsin-Chun Tsai, H. C. (2014), "Improving learning performance with happiness by interactive scenarios", *The Scientific World Journal*, 2014, Article ID 807347, 12 pages.

Davis, J. K. (1987), "The field independent-dependent cognitive style and beginning reading", *Early Child Development and Care*, Vol. 29, No. 2, pp. 119-132.

Dussias, P. (2010), "Uses of eye-tracking data in second language sentence processing research", *Annual Review of Applied Linguistics*, Vol. 30, pp. 149-166.

Fatemi, A. H, Vahedi, V. S., & Seyyedrezaie, Z. S. (2014), "The effects of top-down/bottom-up processing and field-dependent/field-independent cognitive style on Iranian EFL learners' reading comprehension",. *Theory and Practice in Language Studies*, Vol. 4, No. 4, pp. 686-693.

Grabe, W. (2009), "*Reading in a second language: Moving from theory to practice*", Cambridge University Press.

Gevensleben, H., Holl, B., Albrecht, B., Schlamp, D., Kratz, O., Studer, P., Wangler, S., Rothenberger, A., Moll, G. H., & Heinrich, H. (2009), "Distinct EEG effects related to neurofeedback training in children with ADHD: a randomized controlled trial", *International journal of psychophysiology*, Vol. 74, No. 2, pp. 149-157.

Grushko, A. I. & Leonov, S. V. (2014), "The usage of eye-tracking technologies in rock-climbing", *Procedia - Social and Behavioral Sciences*, Vol. 146, pp. 169 -174.

Hwang, G. J., Yang, L. H., & Wang, S. Y. (2013), "A concept map-embedded educational computer game for improving students' learning performance in natural science courses", *Computers & Education*, Vol. 69, pp. 121-130.

Hall, K. M., Sabey, B. L., & McClellan, M. (2005), "Expository text comprehension: Helping primary-grade teachers use expository Texts to full advantage", *Reading Psychology*, Vol. 26, No., 3, pp. 211-234.

Hsiao, H. S. & Chen, J. C. (2016), "Using a gesture interactive game-based learning approach to improve preschool children's learning performance and motor skills", *Computers & Education*, Vol. 95, pp. 151-162.

Kheirzadeh, S., & Kassaian, Z. (2011), "Field-dependence/independence as a factor affecting performance on listening comprehension sub-skills: The case of Iranian EFL learners", *Journal of Language Teaching and Research*, Vol. 2, No. 1, pp. 188-195.

Kheirzadeh, S., & Kassaian, Z. (2011), "Field-dependence/independence as a factor affecting performance on listening comprehension sub-skills: The case of Iranian EFL learners", *Journal of Language Teaching and Research*, Vol. 2, No. 1, pp. 188–195.

Kendeou, P., & van den Broek, P. (2007), "The effects of prior knowledge and text structure on comprehension processes during reading of scientific texts", *Memory & Cognition*, Vol. 35, No. 7, pp. 1567-1577.

Lai, M. L., Tsai, M. J., Yang, F. Y., Hsu, C. Y., Liu, T. C., Lee, S. W. Y., et al. (2013), "A review of using eye-tracking technology in exploring learning from 2000 to 2012", *Educational Research Review,* Vol. 10, pp. 90–115.

Liu, P. L. (2014), "Using eye tracking to understand learners' reading process through the concept-mapping learning strategy", *Computers & Education*, Vol. 78, pp. 237-249.

Liu, Z. (2005), "Reading behavior in the digital environment: Changes in reading behavior over the past 10 years", *Journal of Documentation*, Vol. 61, No. 6, pp. 700–712.

Liu, Z. (2012), "Digital reading: An overview", *Chinese Journal of Library and Information Science*, Vol. 5, No. 1, pp. 85-94.

Lin, Y. T. & Chen, C. M. (2019), "Improving effectiveness of learners' review of video lectures by using an attention-based video lecture review mechanism based on brainwave signals", *Interactive Learning Environments*, Vol. 27, No. 1, pp. 86-102.

Moran, G., Dumas, J. E., & Symons, D. K. (1992), "Approaches to sequential analysis and the description of contingency in behavioral interaction", *Behavioral Assessment*, Vol. 14, pp. 65-92.

Majaranta, P. & Bulling, A. (2014), "Eye tracking and eye-based human–computer interaction", S. H. Fairclough and K. Gilleade (eds.), Advances in Physiological Computing, Human–Computer Interaction Series, Springer, pp. 39-65.

Michel, M. C. & Smith, B. (2017), "Eye-tracking research in computer-mediated language learning", In: Language and technology. Encyclopedia of language and education. Springer International Publishing AG, 1-12. ISBN 9783319023281

Oliveira, J. M., Camacho, M., & Gisbert, M. (2014), "Exploring student and teacher's perception of e-textbooks in a primary school", *Comunicar*, Vol. 21, No. 42, 87-95.

Pan, B., Hembrooke, H. A., Gay, G.K. Granka, L.A. Feusner, M. K. & Newman, J. K. (2004), "The determinants of web page viewing behavior: an eye-tracking study", *In ETRA'2004: Proceedings of the Eye tracking research & applications symposium on Eye tracking research & applications*, pp. 147–154, New York, NY, USA.

Quera, V., & Bakeman, R. (2000), "*Quantification strategies in behavioral observation research",* In T. Thompson, D. Felce, & F. J. Symons (Eds), Behavioral observation (1 ed., pp. 297–315).

Rapp, D. N. (2006), "The value of attention aware systems in educational settings", *Computers in Human Behavior*, Vol. 22, pp. 603-614.

Roda, C. & Thomas, J. (2006), "Attention aware systems: Theories, applications, and research agenda", *Computers in Human Behavior*, Vol. 22, 557-587.

Stiefelhagen, R., Yang, J. & Waibel, A. (2002), "Modeling focus of attention for meeting indexing based on multiple cues", *IEEE Transactions on Neural Networks*, Vol. 13, No. 4, pp. 928-938.

Smith, B. & Renaud, C. (2013), "Using eye tracking as a measure of foreign language learners' noticing of recasts during computer-mediated writing conferences". In Second Language Interaction in Diverse Educational Contexts, Edited by Kim McDonough and Alison Mackey.

Stickler, U., Bryan, S. & Lijing, S. (2016), "Using eye-tracking technology to explore online learner interactions", In: Caws, Catherine and Hamel, Marie-Josée eds. *Language-Learner Computer Interactions: Theory, methodology and CALL applications*. Language Studies, Science and Engineering (2). John Benjamins, pp. 163-186.

Sweller, J., van Merrienboer, J. J. G., & Paas, F. G. W. C. (1998), "Cognitive architecture and instructional design", *Educational Psychology Review*, Vol. 10, No. 3, pp. 251-296.

Snyder, L. (2010), "Reading expository material: Are we asking the right questions?", *Topics in Language Disorders*, Vol. 30, No. 1, pp. 39-47.

Tinajero, C., & Páramo, M. F. (1997), "Field dependence-independence and academic achievement: A re-examination of their relationship", *British Journal of Educational Psychology*, Vol. 67, pp. 199-212.

Toet, A. (2006), "Gaze directed displays as an enabling technology for attention aware systems", *Computers in Human Behavior*, Vol. 22, No. 4, pp. 615-647.

Witkin, H. A. (1971), "*A manual for the embedded figures tests*", Palo Alto, CA: Consulting Psychologists Press.

Witkin, H. A., & Goodenough, D. R. (1977). Field-dependent and field-independent cognitive styles and their educational implications. *Review of Educational Research*, *47*(1), 1-64.

Wolf, M., & Barzillai, M. (2009), "The importance of deep reading", *Educational Leadership*, Vol. 66, No. 6, pp. 32-37.

Wu. (1987), "An exploration of the phenomenon of difference between cognitive ability and cognitive style", *Chinese Journal of Education*, Vol. 7, pp. 51–98.

Yang, F. Y., Chang, C. Y., Chien, Y. T., Chiang, C. Y., Lin, M. C., & Lai, H. C. (2013), "Tracking learners' visual attention during a multimedia presentation in a real classroom", *Computers & Education,* Vol. 62*,* pp. 208-220.

Zhan, Z., Zhang, L., Mei, H., & Fong, P. S. W. (2016), "Online learners' reading ability detection based on eye-tracking sensors", *Sensors,* Vol. 16, 1457.

Zhou, Q., Gao, C., & Meng, Z. (2011), "The bounded rationality model-based game intelligent decision-making method", In: Deng H., Miao D., Lei J., Wang F.L. (eds) Artificial Intelligence and Computational Intelligence. AICI 2011. Lecture Notes in Computer Science, vol 7002. Springer, Berlin, Heidelberg