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Speed reading on virtual reality and augmented reality

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ABSTRACT

Many virtual reality (VR) and augmented reality (AR) applications in education require speed reading. The current study aimed to explore whether the reading performance on VR and AR is different from that on traditional desktop display, and whether the difference is moderated by the reading speed. Sixty-three college students read Chinese passages at normal (650–750 characters per minute [cpm]) or fast speeds (1000–1400 cpm), and then answered multiple-choice questions. They spent approximately 10% more time in making choice on VR and AR than they did on the desktop display. Teachers should be aware of this difference and allow 10% more time when using VR and AR applications containing text components.

1. Introduction

Virtual reality (VR) and augmented reality (AR) have been introduced into education in the 1990's. Since then, VR and AR technologies have been applied in education of mathematics (Kebritchi, Hirumi, & Bai, 2010; Pasqualotti & Freitas, 2002), geometry (Hwang & Hu, 2013; Kaufmann & Schmalstieg, 2003; Kaufmann, Schmalstieg, & Wagner, 2000), science (Kartiko, Kavakli, & Cheng, 2010), physics (Coller & Shernoff, 2009), chemistry (Merchant et al., 2012), anatomy (Lee & Wong, 2014), astronomy (Johnson, Levine, Smith, & Stone, 2010), foreign language (Ibanez, Kloos, Leony, Rueda, & Maroto, 2011; Yang, Chen, & Jeng, 2010), and art (Di Serio, Ibáñez, & Kloos, 2013). Recent products such as HTC vive and Microsoft HoloLens have made VR and AR technologies more accessible. The effect of VR and AR on improving students' academic performance, however, is inconsistent (Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014) and depends on the design of courses, such as instruction mode (Merchant et al., 2014; Sitzmann, 2011), entertainment value (Sitzmann, 2011), and process control (Vogel et al., 2006).

Reading is one of the most important ways to access knowledge, which is often stored in the form of text in books, articles, and websites. Many VR and AR applications in education require reading, and almost all VR and AR applications contain some text on their interfaces. Reading performance on VR and AR can be different from that on a traditional desktop display, because reading performance usually depends on the device displaying text. For example, people used to read slower on screen than on paper (Dillon, 1992; Gould & Grischkowsky, 1984; Mangen, Walgermo, & Brønnick, 2013; Wilkinson & Robinshaw, 1987), although recently the gap has been diminishing (Chu, Rosenfield, & Portello, 2014; Köpper, Mayr, & Buchner, 2016). Reading on VR and AR may be different from that on liquid crystal display (LCD), the mainstream desktop display, for at least three reasons. First, text in VR and AR is 3D instead of flat, which affects the readability (Jankowski, Samp, Irzynska, Jozwowicz, & Decker, 2010). Second, text in AR is overlaid on the real background, whose texture affects readability (Leykin & Tuceryan, 2004). Third, VR and AR have the potential to enhance learning motivation (Chang, Morreale, & Medicherla, 2010), which in turn would probably improve reading performance. The present study aimed to explore reading performance on VR and AR, compared with that on LCD. The difference, if exists, will

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influence the effect of VR and AR on improving students' academic performance.

Reading tasks on VR and AR are often carried out under time pressure. For example, teachers usually assign reading tasks, on VR/AR or not, with a time limit and then test students' comprehension; instruction and subtitles in videos and games update quickly as the plot unfolds; credits at the end of movies scroll up rapidly; and in some adventure games, letters burn up as players are still reading them. Reading under time pressure, or speed reading, generally results in worse comprehension on the individual level (Carver, 1992): it is a speed-accuracy tradeoff. For example, Poulton (1958) found that reading at about 146 wpm resulted in a better comprehension rate than reading at about 293 wpm did. Dyson and Haselgrove (2001) also found that reading at a normal, comfortable speed resulted in better comprehension than reading at a fast, or twice the normal speed did. Similarly, research on reading languages other than English, such as Chinese (Shui, Fu, Li, & Shen, 2001) and Japanese (Miyata, Minagawa-Kawai, Watanabe, Sasaki, & Ueda, 2012), found that faster reading resulted in worse comprehension. Nevertheless, some other researchers argued that time pressure, if used properly, had the potential to improve reading performance by promoting mindfulness among other mechanisms (Walczyk, Kelly, Meche, & Braud, 1999).

What is more important, time pressure, or the reading speed, could moderate the differences in reading performance across display devices. Ackerman and Goldsmith (2011) found reading comprehension on screen was worse than that on paper only under self-regulation but not under fixed study time. The authors attributed this difference to less accurate prediction of performance and more erratic study-time regulation on screen than on paper under self-regulation. However, Ackerman and Lauterman (2012) later found that reading on screen and paper differed only under time pressure, but not under free regulation. The authors explained that the sample in Ackerman and Lauterman (2012) study had attenuated reluctance to study on screen relative to those in Ackerman and Goldsmith (2011), making the results inconsistent. The present study would explore the interaction between the display device and the reading speed.

The present study aimed to explore (1) people's reading performance across different display devices, i.e., LCD, VR, and AR, and (2) the effect of time pressure on reading performance and especially its interaction with display devices. The results can provide guidance and suggestion for the designers and users of VR and AR applications in education, business and entertainment.

2. Methods

2.1. Design

The present study was a 3 (devices: LCD, VR, and AR) × 2 (speeds: normal or fast) two-factorial mixed design. The device was a within-subject factor, and the speed was a between-subject factor. We used an Oculus Rift CV1 for the VR condition, a Microsoft HoloLens for the AR condition, and an Acer S230HL monitor for the LCD condition. In the normal speed condition, students read paragraphs at speeds of 650, 700, and 750 characters per minute (cpm). In the fast speed condition, the speeds were 1000, 1200, and 1400 cpm. Those speeds were based on pilot studies. The reading speeds were manipulated by controlling the display time for each paragraph. For example, if the paragraph contained 140 characters and was tested at 700 cpm (normal speed), the display time would be 12s (140 character/700 cpm * 60 s/minute).

The dependent variables were the response time of making choices and the accuracy of answering questions. The response time was the time between the appearance of the choices and the selection made by the participants. The accuracy was calculated by dividing the number of correctly answered questions by the total number of questions within each condition.

2.2. Participants

Participants were 63 college students, 34 women and 29 men, aged 20–31 years ($M = 24.3$ years). All reported normal or corrected to normal vision. They were randomly assigned to the normal ($n = 32$) or the fast speed group ($n = 31$). All participants gave written informed consents before participation.

2.3. Apparatus

The experiment was carried out in a sound-insulated chamber with no exposure to daylight. Ambient illumination around the participants' eye position was 680–720 lux (measured using an HCJYET HT-8500 Environment Tester) during the experiment.

Two desks, of 120 cm × 60 cm × 75 cm (length × width × height), were placed against one wall. Two height-adjustable chairs were placed in front of each of the desks. Two keyboards were placed on each of the desks. An Oculus Rift CV1 and a Microsoft HoloLens were placed on Desk 1. An Acer S230HL monitor (23 inches on the diagonal) was placed on Desk 2. The inclination angle of the monitor screen was set at 75° relative to the desk with the top tilted away from the participant, as in Köpper et al. (2016). The app window in the AR condition was projected on the white wall behind Desk 2, and at the same height as the monitor on Desk 1. The distance from participants' eyes to the monitor screen was about 50 cm. The distance from eyes to the optics of VR and AR glasses was about 1.5 cm, but the distance to the virtual wall in VR and the window in AR displaying text was also about 50 cm. The computer used to control the devices and present the stimuli was a Raytine Blade 707, an assembled computer (CPU: Intel i7-6700K; GPU: GIGABYTE GTX1080 8GB).

2.4. Materials

The reading task used 45 items taken from the Chinese Proficiency Test (Hanyu Shuiping Kaoshi in Chinese, HSK, see http://www.chinesetest.cn/gosign.do?id=1&lid=0) Level 5, which has been used in previous research on reading (e.g., Lü & Zhang, 1999). Each item comprised one paragraph and four choices. Only one choice was consistent with the meaning of the paragraph. The paragraphs contained 78-156 characters (M = 107), and the choices contained 5-16 characters (M = 9.6). The following passage is a translated sample:

'Want better sleep quality? Pick the right time to sleep. To sleep sound, the time to fall asleep should be from 9:00 p.m. to 11:00 p.m., 12:00 p.m. to 1:30 p.m., or 2:00 a.m. to 3:30 a.m. It is easier to fall asleep during these periods, because people usually have low energy, slow reactions, and calm emotions.

(Please choose which is consistent with the paragraph you just read)

A. Noontime is not good for sleeping.
B. People should sleep no less than 8 h each day.
C. The time of falling asleep affects the sleep quality.
D. Going to bed early is good for health.'

The answer is C.

Paragraphs were displayed in four to seven lines, and each choice occupied one line. Each line could contain up to 25 characters. All of the characters were black (RGB = 0, 0, 0) and presented in 12-point normal Microsoft YaHei font on a white (RGB = 248, 248, 248) background. We did not use background of RGB (255, 255, 255), because it was dazzling in VR. The text was left aligned without hyphenation.

2.5. Procedure

Participants' genders and ages were gathered during the online recruitment. They arrived at the laboratory room individually. All of the participants read and signed informed consent forms before the experiment, and they were thanked and debriefed after the experiment.

The experiment comprised three blocks, corresponding to the three devices: VR, AR, and LCD. Blocks VR and AR were carried out on Desk 1, Block LCD on Desk 2. Each block comprised three sub-blocks: reading speeds of 650, 700, and 750 cpm for those in normal speed group; reading speeds of 1000, 1200, and 1400 cpm for those in fast speed group. Each sub-block comprised 5 trials, or items. Each item was used only once within each participant. The order of the blocks and items used for each device were counterbalanced between participants.

Participants rested their left middle finger on the key D, left index finger on F, right index finger on J, and right middle finger on K, corresponding to the response of A, B, C, and D, and rested their thumbs on the spacebar. In each trial, they first saw "press spacebar when you are ready" on the display device. The paragraph appeared after the spacebar was pressed, with a countdown in seconds above the paragraph. When the countdown reached zero, the paragraph disappeared, and participants saw four choices of statements, with "Choose by pressing A, B, C, or D" above the choices. Participants were instructed to choose the statement that was consistent with the meaning of the paragraph. They needed to recall the meaning, because they could not re-read the paragraph. The choices disappeared after participants made their selection. No feedback was provided. Participants could rest for a while or proceed to the next trial by pressing the spacebar. In the VR condition, participants saw a virtual wall displaying text right in front of them. If they looked around, they would see the default virtual environment set by Unity: a blue sky over the dark ground. They could not see the laboratory. In the AR condition, participants could still see the real environment through the HoloLens, that is, the laboratory with the wall, the desks and chairs, and the keyboards. A virtual window displaying text was projected on the wall right before the participant. Each participant's response time and selections were recorded.

The program was developed with Unity 5.5 (and deployed on the HoloLens with Microsoft Visual Studio 2015 for the AR condition). Fig. 1 shows how the paragraphs appeared on different devices. To obtain pictures, we used the print screen function offered by Windows for the LCD, the mirroring display function offered by SteamVR for the VR condition, and the mixed reality capture function offered by the HoloLens device portal for the AR condition. Some differences between the demonstrations were due to the different capturing techniques.

We aimed to make the reading tasks across devices as identical as possible to ensure that differences in reading performance could only be attributed to the factor of display devices. The same program was used for all the four conditions, so the fonts, contrast and luminance were all fixed. The refresh rates for all the four conditions were set at 60 Hz.

3. Results

We analyzed the effects of devices and speeds on the response time (RT) and accuracy (ACC). We averaged each participants' RT and ACC across trials within each condition. The main effect of devices on the RT was significant, $F(2, 122) = 6.490$, $p = .002$, $\eta_p^2 = 0.096$ (see Fig. 2). Multiple comparison with Bonferroni adjustment showed that the RT on VR was significantly longer than that on LCD, $t(1, 61) = 3.351$, $p = .004$, 95% CI = [0.194, 1.27]; the RT on AR was also significantly longer than that on LCD, t(1,

Fig. 1. Demonstration of display on LCD, VR, and AR. On the left side are the nine characters in the top-left corners of each display magnified by 200%.

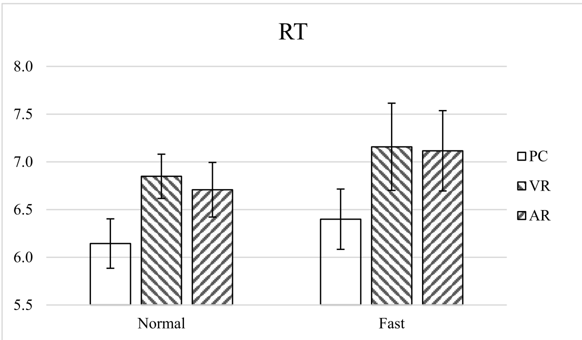

Fig. 2. Response times of making choices on LCD, VR, and AR under normal or fast reading speeds. Error bars stand for *SE*.

61) = 2.818, p = .019, 95% CI = [0.081, 1.20]; the RTs on VR and AR did not differ significantly from each other, $t(1, 61) = 0.419$, p = 1.000, 95% CI = [-0.446, 0.629]. Therefore, reading on VR and AR required about 10% more response time to make choices.

The main effect of speeds on the RT was insignificant, $F(1, 61) = 0.651$, p = .423, 1- β = .125. The interaction of devices and speeds on RT was insignificant, $F(2, 122) = 0.061$, p = .822, 1- β = .059. The main effects of devices and speeds, and the interaction of them on ACC were all insignificant, $ps \geq .517$.

4. Discussion

Text is used in VR and AR applications to convey information effectively, and is often presented in a time-pressed manner. The present study explored reading performance on VR and AR, and the effect of reading speeds. Sixty-three college students were recruited to read Chinese passages at a normal (650–750 cpm) or a fast speed (1000–1400 cpm) and then answered multiple choices questions on VR, AR, and LCD. The results showed that the response times on VR and AR were about 10% longer than that on LCD. The effect of reading speeds and its interaction with display devices on the response time were not significant. The accuracy of answering questions was not affected by display devices or read speeds.

The RTs on VR and AR were about 10% longer than that on LCD when reading at a normal or fast speed, although the accuracy did not differ across devices. In other words, it takes longer to read the choices and then select one on VR/AR than on LCD, to achieve comprehension of similar levels. We speculated that if the response time was also limited, the accuracy of answering the multiple-choice questions on VR/AR would be lower than that on LCD. That would be similar to previous research comparing reading on screen with on paper (Dillon, 1992; Gould & Grischkowsky, 1984; Mangen et al., 2013; Wilkinson & Robinshaw, 1987), which found that reading on computer screens was slower than reading on paper. The difference between reading on screen and paper had been attributed to both technical factors such as display quality and psychological factors such as metacognitive regulation (Ackerman & Lauterman, 2012). These factors probably also caused differences in reading between computer screen and VR/AR. Besides, other factors, such as the 3D display, the pixel density, the field of view, the distance to the eyes, the motion sickness (in VR only), and background texture (in AR only) could also contribute to the differences.

The difference in the RT will affect the user experience and should be considered in the design of VR and AR programs. In exams, 10% is a great deal of time: most students will protest and receive lower scores if teachers announce the end of the exam in the 54th minute of an 1-h exam. The result of the present study indicated that exams on VR and AR become more time-pressed and thus more difficult. Teachers should be aware of this difference, and consider giving students about 10% more time to finish their work if reading tasks are carried out on VR and AR. Similarly, game designers should allow for more response time when transplanting games from PC to VR and AR.

The effect of reading speeds was not significant in the present study. Although the majority of previous research found that when asked to read faster the comprehension rate would drop (Carver, 1992; Dyson & Haselgrove, 2001; Poulton, 1958), other research suggested that comprehension may increase under certain time pressure because of mindfulness (Walczyk et al., 1999) and meta-cognition regulation (Ackerman & Lauterman, 2012). If both mechanisms work simultaneously, they could counteract each other and result in no obvious effect, as in the present study.

No significant interaction between the display devices and reading speeds was found in the present study. In other words, comprehension did not differ under mild or severe time pressure, which is similar to the result of Ackerman and Goldsmith (2011). However, the response time of answering multiple choice questions on VR/AR was longer than that on LCD under both mild and severe time pressure. Studies comparing reading on screen and paper may consider using response time as a performance index. The present study focused on reading Chinese passage. Because Chinese characters usually occupy more pixels than Latin letters do, the effect of devices on reading performance of other language still needs to be explored in future studies.

5. Conclusion

The response time of answering multiple choice questions on VR and AR is approximately 10% longer than that on LCD with both normal and fast reading speeds. Designers of VR and AR programs should give users about 10% more time to respond to text-processing tasks, compared with those programs for PC, to make the difficulty equivalent. Users of VR/AR applications should also be aware of this difference. For example, teachers should give students 10% more time if tests or other text-processing tasks are administrated via VR or AR.

Declarations of interest

None.

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