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The evaluation of visuospatial performance between screen and paper

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ABSTRACT

This study evaluates the effect of presentation media (PC tablet versus pencil and paper) on the performance, level of visual fatigue, and subjective preference of those taking visuospatial tests. Fifty university students participated and performed three visuospatial short-term memory tests and three visuospatial ability tests by using both types of display media. The display medium substantially affected all of the measured variables ($p < 0.01$). On average, the paper–pencil test scores of the visuospatial short-term memory tests were about 10% higher and the answer time was about 20% shorter than those of the PC tablet tests. The average paper–pencil test score of the visuospatial ability tests was about 35% higher than the average test score of the PC tablet test. The visuospatial performance was substantially decreased under the PC tablet condition compared with that under the pencil–paper condition. In addition, visual fatigue was greater when participants used the PC tablet than when they used a pencil and paper.

1. Introduction

The notebook computer is becoming increasingly prominent and, subsequently, the computer-based test is also being widely applied in various fields. The advantages of using computerized tests include immediate score reporting involving test-taker performance, as well as the reduction in costs related to printing, shipping, and administering paper and pencil tests [1]. Regarding the effect of the presentation mode on test performance, Mazzeo et al. [2] studied the contrast between paper–pencil and computer-based test scores in College-Level Examination Programs (CLEP). They found that the paper–pencil mathematics test scores were 1.74% higher and the English test scores were 3.66% higher than those of the computer-based tests. The disparity in test scores was substantial and was possibly caused by a lack of familiarity and experience in using the computer-based test method. In 2003, Choi et al. [3] reported that when participants took English language tests containing grammar, vocabulary, listening comprehension, and reading comprehension material, the reading comprehension scores of those who took the paper–pencil test were higher than the scores of those who took the computer-based test. Conversely, the listening comprehension test scores were higher for those who took the computer-based test than for those who took the paper–pencil test. The negative effects of the computer-based test include difficulty in taking notes and a lack of concentration caused by eye fatigue. Although display technology has improved in recent years, participants still preferred reading from paper than reading from a screen to comprehensively understand the presented material [4,5].

Most of the previous studies investigating reading comprehension performance in relation to computerized and paper–pencil tests focused on text reading. Information regarding the differences between visual spatial test materials presented on a screen and on paper is also crucial for graphically measuring visuospatial ability. Visuospatial ability is defined as the mental attribute of imagining the shape of an object while it is rotated and remembering the position of the object. This skill involves the cognitive processes of perception, attention, mental imagery, memory, and problem solving. This ability is critical for architects, dentists, chemists, pilots, carpenters, clothing designers, and those who work in similar fields [6]. The visuospatial ability test is used for assessing cognition ability in neurodegenerative disease patients [7], mental development in children [8], and human intelligence [9].

The visuospatial ability test can be divided into three elements: mental rotation, spatial perception, and spatial visualization [10]. A large gender advantage in favor of men was identified in only the mental rotation tests [11]. Minor differences were found in the spatial perception tests [10], whereas in the spatial visualization

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tests, the difference was not substantial [11]. The distinct effect of gender on visuospatial ability was caused by the interaction between life experience and biological propensity [12]. In addition to the gender effect, visuospatial ability performance is also affected by display formats. Van Orden and Broyles [13] compared the visuospatial task performance of participants who used seven types of two-dimensional (2-D) and three-dimensional (3-D) displays. The authors reported that, overall, the task performance of participants who used the 2-D plan, or side-view, display type was more favorable than the task performance of participants who used any other display system, but the 3-D volumetric display type was more suitable for participants performing integration and prediction tasks in a limited 3-D space.

Visuospatial short-term memory assesses the storage demand for visual patterns or sequences of movement without performing further information processing. Traditionally, visuospatial ability and visuospatial short-term memory tests were performed with pen and paper [14] because of the ease of administration and the existence of well-established normative data [15]. However, previous studies did not consider whether the outcome of the computer-based visuospatial ability test would be similar to that of the paper–pencil-based test. Therefore, the objective of this study was to investigate the effect of display media on the subjective preference and the levels of visual fatigue of participants taking the visuospatial ability test and the visuospatial short-term memory test.

2. Method

2.1. Participants

Fifty university students (25 male and 25 female) participated in the experiment. The ages of the participants ranged from 19 to 23 years (mean = 20.22, SD = 0.89). The mean age of male participants was 20.40 (SD = 0.99) years. The mean age of female participants was 20.04 (SD = 0.78) years. All subjects were right handed. Forty of the subjects were near-sighted and all of them wore glasses to have at least 20/25 corrected vision. All participants were required to have no previous experience using a PC tablet to avoid the influence of user experience on the subjective preference of using a PC tablet.

2.2. Experimental design

2.2.1. Independent variables

The independent variables in the experiment were gender (male, female) and display medium (PC tablet, paper–pencil). Participants were requested to take both a PC tablet and paper–pencil test. A PC tablet with a 14-inch touch screen (IBM ThinkPad, screen area 180×245 mm, resolution 1024×768, 16-bit color) was used in this study. Taptagaporn and Saito [16] pointed out that the subjects using a positive display polarity (dark characters on a bright background) produced better visual performance with less visual fatigue than the ones using a negative display polarity (bright characters on a dark background). Thus, a positive display polarity (black text on a white background) was used in this study. The paper–pencil test was prepared using the same format as the computer-based test to minimize the differences in content between the two tests. The paper size is 258 mm * 180 mm. The paper size and the aspect ratio of the paper–pencil test were equal to that of the PC tablet viewing screen, as shown in Fig. 1.

2.2.2. Visuospatial short-term memory test

The visuospatial short-term memory test battery included three sub-tests (i.e., the Corsi block task [17], the arrow span task [18], and the dot memory task [19] (Fig. 2)). The Corsi block task is illustrated in Fig. 2(A). After viewing a series of three images, the participant must number the blocks in the sequence that the dark block appeared. The arrow span task is illustrated in Fig. 2(B). In each image, an arrow pointing in a certain direction was displayed for one second. After viewing a series of three images, the participant was asked to write down the sequence that the arrows appeared in the boxes. The dot memory task is illustrated in Fig. 2(C). A 4×4 matrix was shown to the participant. Each matrix contained a black dot that appeared for one second. After viewing a series of three images, the participant was asked to write down the order and the location that the black dot appeared in the matrix. There was no time limit for taking the three visuospatial short-term memory tests. The participant continued to write until he or she finished the tests. The time taken to complete the tests and the test score for each test were recorded. The answer time was defined as the time interval from when the first test page was shown to the participant until the last question was answered by the participant. During the computer-based test, the answer time was recorded automatically by the computer. The participant was required to click an icon to go to the next page. The answer time ended when the participant clicked the selected answer to the final question. During the paper–pencil test, the answer time was recorded by the experimenter using a stopwatch. A shorter answer time and a higher score indicated an excellent visuospatial short-term memory.

2.2.3. Visuospatial ability test

The visuospatial test battery included the space relation test [20], card rotation test, and hidden pattern test [21], as shown in Fig. 3. In the space relation test (Fig. 3(A)), the participant was presented with a two-dimensional image, and was asked to visualize the image folded into three dimensions. The participant was then asked to identify the image of the three-dimensional shape from a number of provided images. In the card rotation test (Fig. 3(B)), an image appeared on the left side. The participant was asked to decide if the image on the right was the same as the original after rotation, or if it was a reflection of the original image. In the hidden pattern test (Fig. 3(C)), a pattern was presented to the participant. The participant was asked to identify if the pattern was hidden in the subsequent images presented. Participants were given twelve minutes to take the space relation test, six minutes to take the card rotation test, and three minutes to take the hidden pattern test. The test scores of the three subtests were calculated, and a higher test score indicated greater visuospatial ability.

2.3. Visual fatigue and subjective preferences

To measure visual fatigue, critical flicker fusion (CFF) frequency and subjective eye fatigue were evaluated. CFF is an effective measure of visual fatigue [22,23]. CFF measures the minimal number of flashes of light per second at which an intermittent light stimulus no longer stimulates a continuous sensation. The CFF was tested at the beginning and at the end of each experiment session. A decrease in the CFF threshold indicated an increase in visual fatigue [24]. Subjective eye fatigue was evaluated using the Borg CR-10 scale [25]. The Borg CR-10 scale is a 10-point scale, with 0 denoting 'nothing at all' and 10 denoting "almost maximal." Regarding the subjective preference for display media, a five-point scale was used with -2 signifying "dislike it very much" and +2 signifying "like it very much."