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THE IMPORTANCE OF COLOR TRANSPARENCY LEVELS IN AUGMENTED REALITY INTERFACES

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Abstract. *Augmented reality (AR) is intended to be the next interface between humans and computers and between humans and humans with the announcement of the metaverse. The most prevalent AR applications are head-up displays (HUDs) and head-mounted displays (HMDs). When creating applications for such displays, color transparency is one of the essential variables to consider. There is a lack of studies focusing on the usability of color transparency in an augmented reality environment. This study aims to assess the performance of 5 interface conditions (T0, T0.25, T0.5, T0.75, T1) according to the color transparency levels. Participants performed an experiment of button selection tasks with an array of 3 × 3 virtual buttons using Microsoft HoloLens 2. The task completion time and the number of errors were recorded during the experiment. The subjective scores of button visibility and background visibility were also collected. The findings showed a significant difference in task completion time but not in the number of errors among transparency conditions. The color transparency of T0 and T0.25 took significantly longer time than T0.75, T0.5, and T1, according to post-hoc results. The number of errors was largest when alpha was set to 0. There was a significant difference in button visibility and background visibility among transparency conditions. This study recommended the transparency of alpha 0.25, 0.5, and 0.75 for augmented reality interfaces. This study can be referred to during designing augmented reality applications for metaverse and others.*
Keywords: Augmented reality, Interface design

1. Introduction.

Virtual reality (VR) and augmented reality (AR) devices are becoming more popular with the announcement of the metaverse. AR is a combination of the real world and computer-generated information and objects. Virtual environment, real-time interaction and 3D view are the main characteristics of augmented reality [1]. AR is expected to be the next interface between not only humans and computers but also humans and humans. Head-mounted displays (HMDs) for both VR and AR are different due to their differences in characteristics. VR devices use opaque monitors to show images. In contrast, AR devices use optical-see methods that superimpose virtual images or objects optically onto real-world scenes [2], resulting in a virtual transparent object. Several AR HMDs, such as google glass and Microsoft HoloLens, are now available to experience AR environments.

Designing content for AR and MR requires careful consideration of color, lighting, and materials for all your virtual assets or object [3]. Research has been conducted on various

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problems in AR, including interface design, interaction methods, and other usability problems of AR devices [2-11]. Transparency is the quality of being easily see-through. The definition, according to the International Lighting Vocabulary by International Commission on Illumination (CIE), is "the degree of visibility of an object through a medium" [12]. For transparent objects, color appearance is an important and complicated topic because it depends upon many factors, including ambient light, the color appearance of the virtual object, and the color of the real-world background. A solid black object will appear no different from the real world. Color matching criteria were studied for augmented reality without considering the color transparency [13]. Transparency in augmented reality is different from simulated or subtractive filter transparency because of additional light overlaid [14]. It is important to study and control the color transparency of content for many AR applications similar to display technology. A transparent display has been mostly used for AR devices, and various studies have been performed to improve its performance technically. Transparency perception in terms of general color contrast and brightness was also studied [15,16]. There is a lack of studies related to the usability of color transparency in augmented reality environments.

Augmented reality, not virtual reality, is expected to be the primary gateway to the metaverse due to the characteristics of displaying virtual content in real environment. AR can also replace the ecosystem of smart phones and desktops as our interface to digital content. It will be more natural way to interact with content through human perceptual system. To experience such an augmented world, the color transparency of the virtual objects and content is very critical to study. It can help to create balance between the content which can feel deeply real and actual real environment. The Alpha channel of color can control the transparency of a virtual object, so the color transparency was controlled by the alpha channel of the color in the current study. In this study, we analyzed the effect of different levels of color transparency on task completion time, the number of errors, button visibility, and background visibility. For that, an experiment was conducted in an AR environment considering five levels of color transparency. This study can be referred during designing AR applications and making AR devices.

2. Method.

2.1. Participants and apparatus.

Twenty-five university students participated in this experiment with a mean age of 24.5 years. Among them, thirteen were male and twelve were female. Seven participants were with optical aid, whereas eighteen had normal vision. The participants were physically fit and provided an incentive to participate in the experiment. Microsoft HoloLens 2 was used in this experiment as an AR device [17]. The prototype was made in Unity 3D using C# scripting. The lux meter was used to measure the lighting condition of the experimental room. The black screen was used to control the background color effect during the experiment.

2.2. Experimental condition and task.

The experiment was conducted in a seminar room where the light condition was 790-800 lux during the daytime. The field of view of HoloLens 2 was $3°50'$, and the distance between the virtual object and the eye was 120 cm. The prototype consists of nine square buttons (3×3 array) (Figure 1). The color considered in this study was R: 28, G: 207, and B: 30, with five conditions according to the alpha channel (0, 0.25, 0.5, 0.75, and 1) (Figure 2). The alpha channel specifies the transparency of the color. An alpha value of 0 means that the color is fully transparent, and one means the color is opaque. A button selection task was performed in all five conditions. The experiment was within-subject designed. The task was to select a randomly highlighted button and rate the subjective questionnaire for background and button visibility. The 5 point Likert type scale from 1-5 (1 = Extremely Not, 2 = Almost Not, 3 = Average, 4 = Almost Yes, 5 = Extremely Yes) was used to collect the subjective scores.

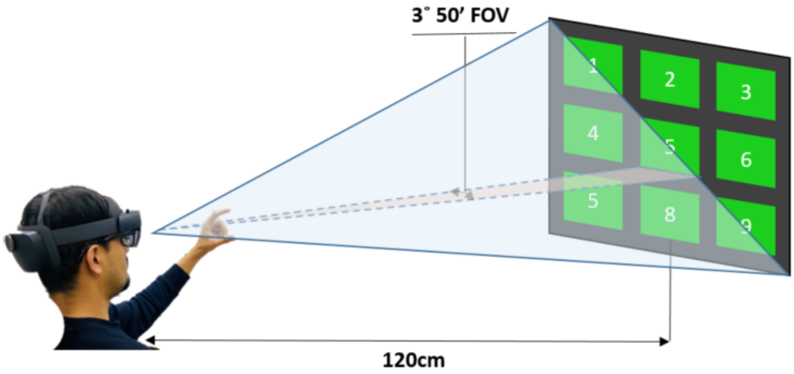

Figure 1. A sample of experimental prototype

Figure 2. Five color transparency conditions in augmented reality

2.3. **Procedure.** All participants attended a practice session with a sample task to familiarize themselves with AR interaction before the actual experiment. HoloLens 2 was calibrated for each participant before the experiment. There were five experimental conditions in the experiment with a rest time of 3 min between each condition. Each condition consisted of 5 sets, and in each set, participants had to select four randomly highlighted buttons. They performed a button selection task for the randomly highlighted buttons. The task completion time and the number of errors were recorded for each experimental condition. The participants provided their subjective feedback about button visibility and background visibility after each set of tasks via a five-point scale. The experiment was Latin square balance designed to prevent the learning effect among participants.

2.4. **Analysis.** ANOVA was performed to analyze the data of task completion time, number of errors, button visibility, and background visibility. Student-Newman-Keuls test was conducted for post-hoc analysis. The statistical analysis was performed in SPSS Statistics.

3. Results.

3.1. **Task completion time.** The statistical results showed a significant difference in task completion time ($F = 17.273$, $p = 0.001$) among the color transparency levels. The post-hoc results revealed a significant difference among T0 and T0.25, T0 and T0.5, T0 and T0.75, and T0 and T1. There is no significant difference between T0.5, T0.75, and T1 (Figure 3).

3.2. **Number of errors.** There was no significant difference between the number of errors ($F = 0.651$, $p = 0.628$) for five conditions of color transparency. According to the results, the mean errors were highest for T0 (Figure 3).

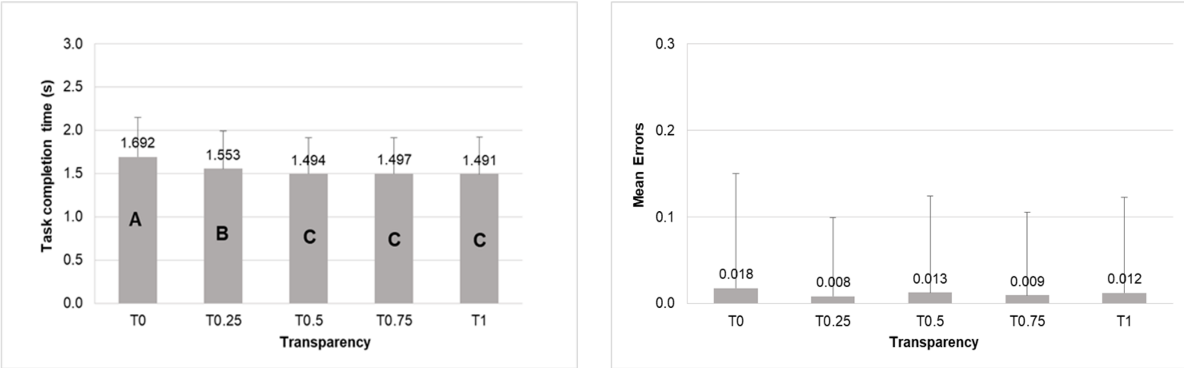

FIGURE 3. Task completion time and mean errors according to color transparency conditions. Different letters are indicating significant difference.

3.3. **Button visibility and background visibility.** There is a significant difference between the scores of button visibility ($F = 32.895$, $p = 0.001$) for the color transparency level. The post-hoc result revealed a significant difference between button visibility scores of T0 and T0.25, T0.25 and T0.5, and T0.5 and T0.75, but not between T0.75 and T1 (Figure 4).

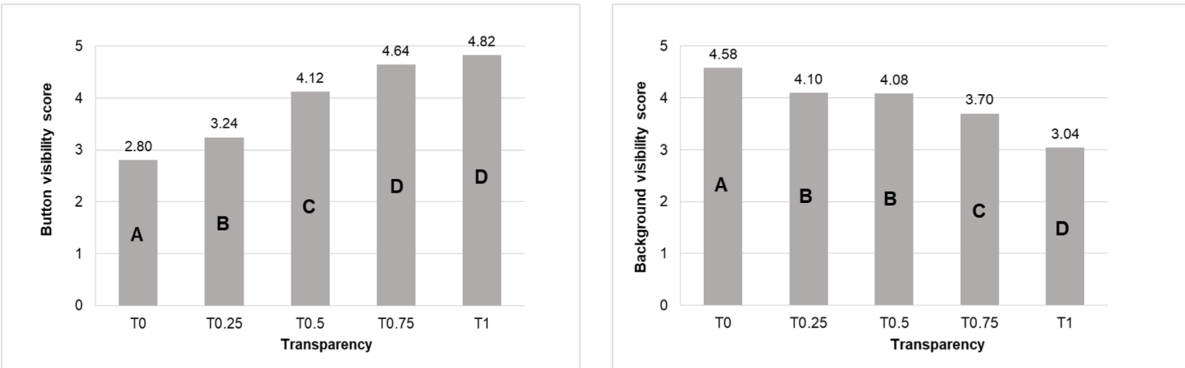

FIGURE 4. Button visibility and background visibility scores according to color transparency conditions. Different letters are indicating significant difference.

There is a significant difference between the scores of background visibility ($F = 10.902$, $p = 0.001$) for color transparency levels. According to the post-hoc results, there was a significant difference between the background visibility scores of T0 and T0.25, T0.5 and T0.75, and T0.75 and T0.1, but not between T0.25 and T0.5 (Figure 4).

4. **Discussion.** In this study, five augmented reality interface conditions based on the level of color transparency were analyzed according to task completion time, number of errors, button visibility and background visibility. According to the results, the interface condition with color transparency T0 and T0.25 took significantly more time than T0.75, T0.5, and T1. The color is almost invisible for T0, so it was expected to take longer than other conditions. T0.5, T0.75, and T1 have no significant difference in task completion time. There was no difference among all five conditions for the number of errors. The highest number of errors was at T0.

Along with task completion time and number of errors, it is also essential to consider the visibility through and of the interface. It is important to balance the virtual object's visibility and background visibility in augmented reality interfaces. Button visibility reflects the virtual object's visibility in the augmented reality condition. The current study results show that the subjective score of button visibility is high (near to extremely visible) for T0.75 and T1. The button visibility at T0, T0.25, and T0.5 are significantly less than at T0.75 and T1. The button is almost visible for T0.5, too. The background refers to the actual real environment, which is a black screen in this case. According to the current study results, the mean scores of the background visibility at T0, T0.25, T0.5, T0.75, and T1 are 4.58, 4.10, 4.08, 3.70, and 3.04, respectively.

According to Figure 5, the color transparency level of 0.25, 0.5, and 0.75 is better for button visibility and background visibility. For task completion time, the color transparency level of 0.25, 0.5, 0.75, and T1 are better than T0; however, T1 is not recommended according to visibility. It will be hard to differentiate between virtual reality and augmented reality at T1. T1 seems almost opaque. Due to this, technically, the transparency level of T0 and T1 is not possible to use in AR environment. This study did not include more diverse technical and scientific feature such as transmittance, pixel structure, various ambient conditions but it was limited to the usability and visibility of transparent AR display including background conditions. According to the results of this study, the recommended color transparency levels for an AR interface are T0.25, T0.5, and T0.75. The optimum level can be in between these conditions, so further study is required in more diverse situations. This study considered the black background, so the authors are further studying with the dynamic background to suggest more detailed guidelines.

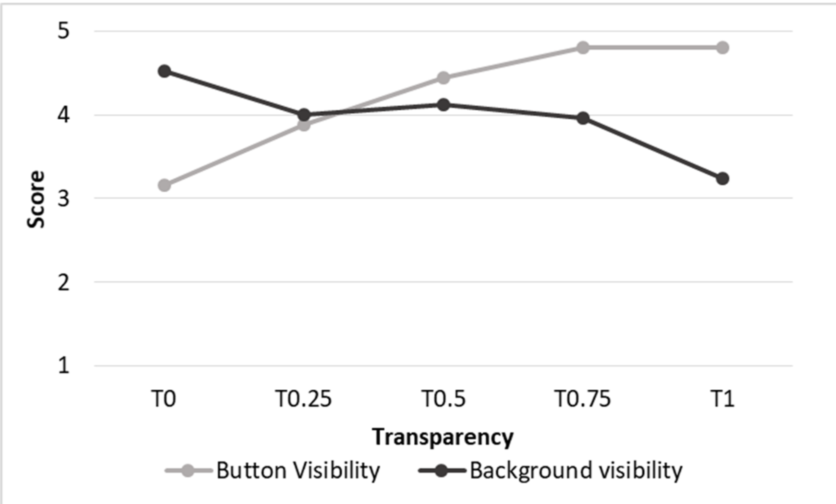

Figure 5. Button visibility and background visibility at different color transparency levels

5. **Conclusion.** This study analyzed the usability of the augmented reality interface according to the color transparency level. Five conditions according to the alpha value of 0, 0.25, 0.5, 0.75, and 1 were studied for task completion time, the number of errors, button visibility and background visibility. According to the results, color transparency at the alpha value of 0.25, 0.5, and 0.75 are recommended for AR application. They need to be studied further in diverse scenarios to get more optimal results. This study can be referred to during designing augmented reality applications for metaverse and others.

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