Colour – cognitive performance interaction in virtual reality (VR): a study of gender differences

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The immersive qualities of Virtual Reality (VR) technologies offer an enhanced environment for design research. In this study the potential of colour to influence cognitive performance in VR is explored. A series of psychometric experiments were conducted where selected colours were presented to the participants whist in a dark neutral VR room setting. Cognitive performance was evaluated via a series of single choice tests (i.e., tests assessing people's logical and lateral thinking abilities) in a dark environment delivered via a HTC VIVE VR headset. A total of 18 male and 17 female Chinese students between the ages of 20-25 years participated in the experiments. The results indicate that colours delivered via a VR headset can have arousing and impulsive effects on people's cognitive performance. Specifically, female participants made more errors with the yellow backgrounds but fewer errors with the orange backgrounds than male participants. This suggests that gender differences exist in the effects of colour stimuli on people's cognitive performance in VR environments.

Reprinted version published online: 26 January 2022
Original source: Proceedings of the 14th Congress of the International Colour Association (AIC2021)

Introduction

This paper presents new insights from comparative experiments investigating the impacts of hue stimuli on cognitive performance between reality and immersive VR environments but focus on the analysis of gender differences in the VR session. The immersive potential of VR technologies offers a powerful tool to build on a vast range of research and applications involving entertainments, education, architecture, and healthcare [1-4], and is likely to be a significant platform in the future digital landscape. In line with these observations, this study highlights that immersion and presence as key features of the VR experience. The objective aspect of sensory fidelity of the VR technology is known as the immersion. Presence refers to a user's subjective responses of perception of the VR environment, even when he/she is physically located in another place. However, there are questions regarding how well the immersive experience is fully understood and whether there is potential to increase the immersion and engagement? Arousal and impulsiveness are two crucial factors that regulate someone's presence, engagement, and performance and these factors are shown to be evoked by certain colours [5]. Significant contributions have been made by Ilie *et al.* [6], Duan *et al.* [7], and Xia *et al.* [8] in experiments that typically have used neuropsychological cognitive measure approaches as investigative techniques. Their results demonstrate the effects of colour on people's arousal and impulsiveness. Participants were generally shown colours through less immersive technologies such as computer monitors in dark laboratory settings in these studies. Whilst these methods deliver valuable evidence and have produced some significant design potential of colour on arousal and impulsiveness, the question of whether the same effects occur in immersive VR environments is relatively unknown.

 ISSN 2227-1309

Experimental observations concerning colour psychology also indicate that factors including age [9], gender [10], and geographical region [11] may affect colour preference. Males and females have been reported to have substantial differences in their favourite colours [12-15]. However, conflicting opinions exist given that no gender differences were observed in their experimental works [16-19], and this lead to questions as to whether there are gender differences in relation to the colour stimuli on arousal and impulsiveness?.

Experimental

In this study, a series of psychometric experiments were conducted where selected colours were presented to the participants in an otherwise dark neutral VR room setting (Figure 1).

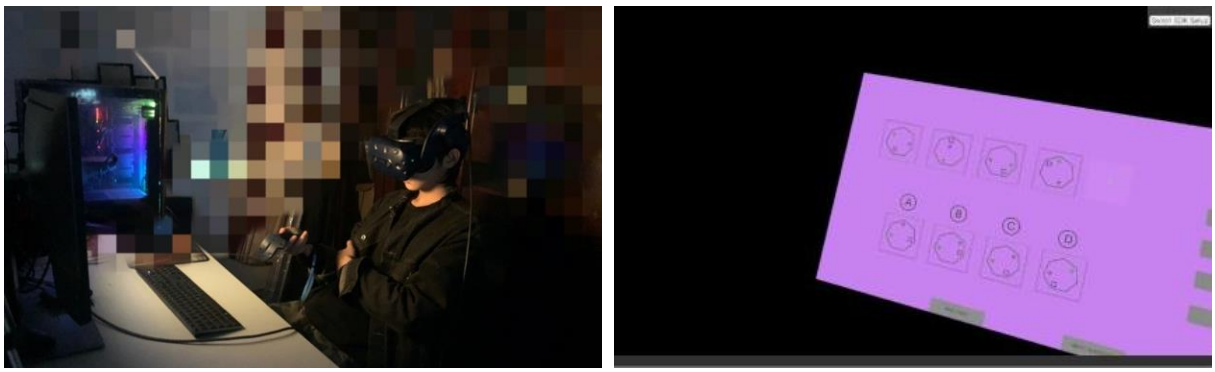

Figure 1: Individual participant using HTC VIVE VR headset to complete each question (left); an example of question displayed in the VR environment (right).

The European Elder (*Sambucus nigra*) was historically regarded as a magical plant with the power to keep evil spirits away and was once thought to have a myriad of uses and health giving properties. Historically various parts of the elder tree have been used in medicine while the berries were used to make wine and pies but also employed as a natural dye. Currently, extracts of the berries are used primarily as anti-viral agents for colds, influenza but recent research shows that they have immune modulating, anti-oxidant, and insulin-stimulating properties due to their high proportions of anthocyanins present [14]. These chemicals are also known to possess anti-inflammatory functions (Figure 2 [13]).

The six colour patches and an equally luminous white reference colour (used as a control) were used as the background colour for a series of questions and adjusted to have a similar lightness and chroma based on the CIELAB values presented through the lens of a VR headset measured by the X-rite i1 Pro in dark laboratory settings (Table 1). The six colour were selected from an Adobe HSB colour system based on former studies by Duan, Rhodes and Cheung [7], Yu *et al.* [20], Eysenck [21] and Singh [22]. Cognitive performance was evaluated via series of single choice tests. A logic rule test and mathematics sequence test assessed logic, a spatial structure test and rotation test assessed lateral thinking abilities, and an odd one out and same detail test assessed detailed abilities. This was conducted in a dark environment via an HTC VIVE VR headset. A total of 18 male and 17 female Chinses students from the department of animation, between the ages of 20-25 years, participated in the experiments. All participants were asked to complete the Ishihara colour vision test before entering the room to confirm that they had normal colour recognition ability. After passing the test, the instructions for the experiment were given to each participant, followed by a series of sample tasks including each type of

psychometric test to familiarise participants with the process before beginning the main experiment. After completing the task, participants were asked to focus on the white reference background through the VR headset for five minutes to adapt to the conditions. The main experiment began five minutes after they had adapted to the experimental conditions.

Colours	L*	C*	h	a*	b*	R	G	B
Visual reference white	72.12	0.49	29.67	0.22	0.19	171.27	170.01	169.86
Red	70.31	70.34	32.83	25.31	34.33	244.31	121.54	103.56
Yellow	70.36	68.05	97.79	-23.83	54.80	187.82	175.99	19.87
Blue	69.32	64.87	288.17	34.01	-35.66	110.09	158.86	255.00
Green	68.89	67.15	178.62	-54.11	-4.18	62.76	193.52	156.59
Orange	69.46	67.66	69.21	-1.63	55.99	242.31	154.31	55.88
Purple	70.57	67.63	321.05	47.39	-22.38	221.76	129.76	243.86

Table 1: The characteristics of the background colours within the VR headset.

Results and discussion

The results are evaluated in terms of participants' error rate and response time when completing a series of single choice tests. Specifically, error rate and response time have shown to be effective indicators and evidenced in a series of psychology literature to study people's arousing and impulsive state [7, 23-25]. A multivariate analysis of variance (MANOVA) was used to analyse a total of 1470 responses (35 participants × 42 questions per participant) obtained from the experiment, and each coloured background was assessed by 35 participants 210 times (each coloured background was assessed six times by each participant). The colours of the backgrounds and the order of presentation of each question were randomised for each participant. The purpose of this was to ensure that if one of the questions were slightly harder, it would be equally likely to have any of the backgrounds and would remove bias.

The results indicate that colours delivered via a VR headset can have arousing and impulsive effects on people's cognitive performance (see Figure 2). It is evident from Figure 2 (A) and (B) that there was a general impact of colour viewed in VR on response time and error rate during the tasks. Specifically, female participants made more errors with the yellow backgrounds ($p = 0.030$) but fewer errors with the orange backgrounds ($p = 0.002$) than male participants. As such, it is reasonable to suggest that gender differences do exist in the effects of colour stimuli on people's cognitive performance in VR environments.

When it came to the response time, both male and female participants viewing the green background gave the fastest responses, while participants viewing the yellow background gave the slowest responses. When considering both the response time and error rate (Figure 2 (C) and (D)), it is clear that both male and female participants viewing the yellow backgrounds experienced the lowest arousal state, and the green and blue backgrounds caused a relatively higher arousal state. Orange, purple and red were located in the high impulsivity quadrant. Male participants experienced the highest impulsivity state with the orange backgrounds.

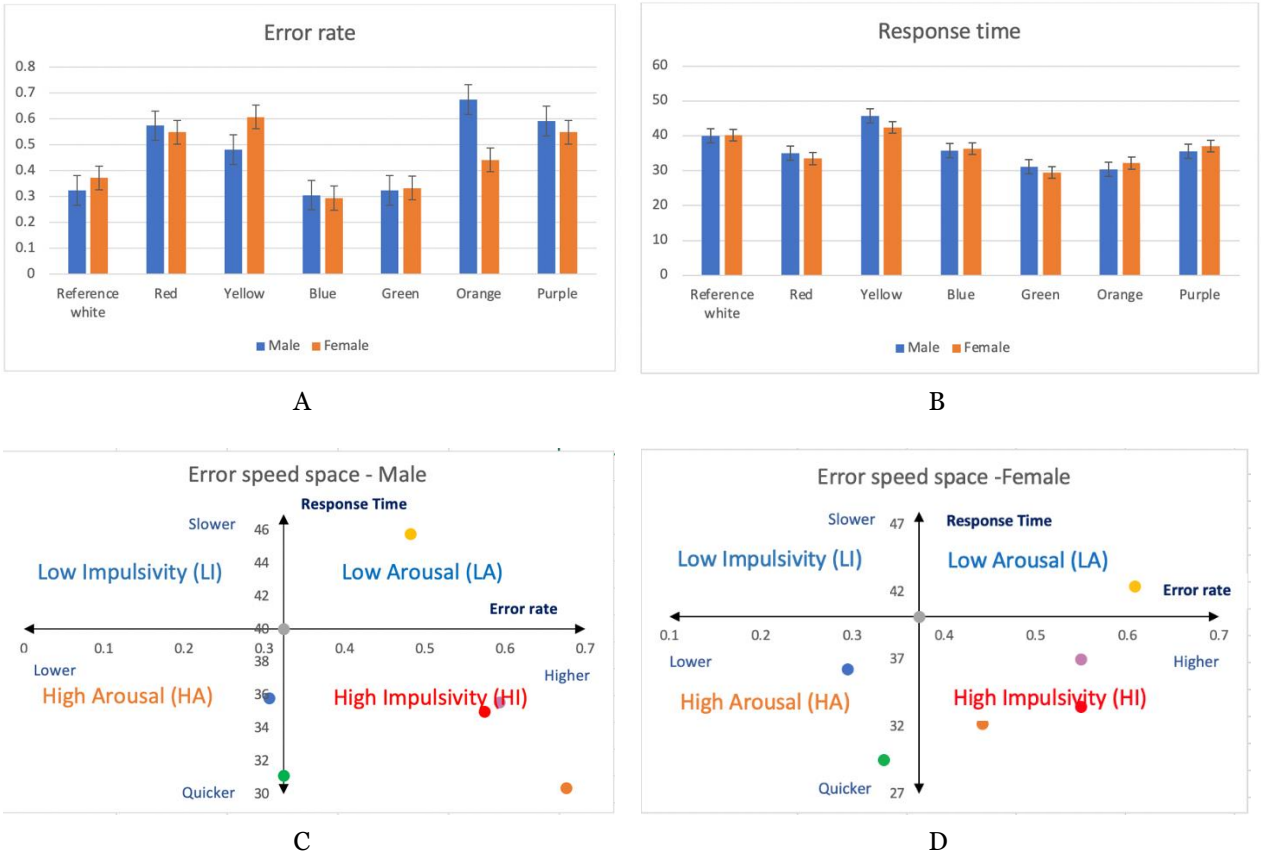

Figure 2: (A) General trend of error rate of male and female participants in completing single choice tests by background colours in virtual reality (VR); (B) General trend of response time of male and female participants in completing single choice tests by background colours in virtual reality (VR); (C) Colour impacts on male participants in VR visualized in the Error-speed space; (D) Colour impacts on female participants in VR visualized in the Error-speed space.

Conclusions

This study explores the design potential of colours to create positive immersion for VR applications but emphasis on the analysis of gender differences. Psychological experiments were carried out to validate the impacts of hue stimuli on people's cognitive performance via immersive VR equipment. The results of this study are an important contribution to the knowledge of immersive VR design. Data obtained from the experiments showed that specific colours could significantly influence people's arousal and impulsiveness, suggesting that colour has an indirect impact on a person's presence and cognitive performance, in line with previous findings [5,6]. Moreover, we found some evidence that differences in colour cognitive performance between the genders do exist. Specifically, the results showed that male participants made fewer errors with the yellow backgrounds but more errors with the orange backgrounds than female participants. The results of this study are somehow similar to a colour preference study by McManus, Jones and Cottrell [13] that found that males showed a greater preference for yellow and a lesser preference for red compared to females. This suggests that the gender differences in cognitive performance may be relevant to colour preference. However, this study has certain limitations. Firstly, all participants were aged from 20 to 25, and thus the findings might not be applicable to children and the elderly. All the participants were Chinese students; therefore, culture may be considered an influencing factor. Also, since all participants involved in this study were students

from the animation department and so are good at lateral thinking, it suggests that colour might have a different impact on lateral and logical thinkers. Although designed to ensure consistency, the participant choice standards could be considered a study limitation. Generally, the findings may encourage VR developers and researchers to consider the effective use of colour to create positive immersion in the experience, and to improve people's presence, engagement and performance when navigating immersive VR environments.

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