THE EFFECTS OF CHROMA ON DESIGNERS' INTELLECTUAL ABILITIES IN AN IMMERSIVE VIRTUAL ENVIRONMENT

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ABSTRACT

Immersive virtual reality (VR) technology has gradually found its place within the fashion and creative design industries, aiming to stimulate creativity, imagination, and engagement. However, it's important to note that limited systematic research has delved into the intricate design of immersive VR environments to effectively evoke positive emotions and enhance cognitive performance, particularly with regards to nurturing designers' logical and lateral thinking abilities. Colour, as a pervasive visual design element, has shown that a deliberate approach to hue design can elicit favourable cognitive responses and intellectual capabilities. This research, therefore, endeavours to reignite the exploration of interactions between colour and cognitive performance in VR, focusing on the impact of chroma on intellectual abilities of design students within immersive VR environments. The study employed green-coloured backgrounds across seven chroma levels (90%, 75%, 60%, 45%, 30%, 15%, and 0%), all with equal luminosity settings. Thirty designers and students (15 males and 15 females), ranging from 20 to 28 years old, participated in a series of psychrometric experiments. Their logical and lateral abilities, along with attention to detail, were assessed through a sequence of single-choice tests delivered via an HTC Vive VR system. Data obtained from the experiment were analysed using a multivariate analysis of variance (MANOVA). The findings from this experiment indicate that varying levels of chroma significantly influence the logical and lateral thinking abilities of design students, as well as their attention to detail within immersive VR environments. The outcomes of this research offer potential encouragement for VR researchers to incorporate and maximize the use of advanced immersive computing technologies. The fresh insights gleaned from this study underscore the potential of selective colour application in enhancing intellectual abilities and refining the design of immersive VR experiences. Practical implementation could involve crafting VR applications tailored specifically to stimulate users' creativity, imagination, and logical thinking skills. However, it's important to acknowledge that this experiment's scope was limited to a diverse cultural and age range, necessitating a more comprehensive exploration in the future. Furthermore, extrapolating the effects of chroma on arousal and impulsiveness across the entire colour spectrum based on these selected samples remains a challenging endeavour.

Keywords: Virtual Reality, Chroma, Colour Design, Intellectual Abilities

INTRODUCTION

In the contemporary era, immersive virtual reality (VR) technology has revolutionized various industries, notably fashion and creative design. These sectors have adeptly harnessed VR's capabilities to amplify creativity, imagination, and user engagement. For instance, Tao et al. (2021) emphasized the potential of immersive VR health games to support long-term engagement with therapeutic interventions, suggesting the profound impact of VR on user engagement in health contexts. Similarly, Škola et al. (2020) demonstrated that modern immersive VR applications, when combined with 360° storytelling, can sustain high levels of presence, immersion, and general engagement. Fröhlich et al. (2018) introduced a unique VR-sandbox system, highlighting the potential of VR to foster creativity and exploration by allowing users to design landscapes through haptic interactions. Furthermore, Elor et al. (2021) showcased the effectiveness of a VR game in maintaining engagement and motivation for physical rehabilitation, emphasizing the versatility of VR applications. Yet, as the adoption of immersive VR environments grows, a significant knowledge gap persists regarding their optimal design to foster positive emotional and cognitive outcomes. A particularly uncharted territory is the potential of VR to enhance designers' logical and lateral thinking abilities.

Central to the visual landscape and design process is the ubiquitous element of colour. Emerging research has illuminated the profound impact of colour, specifically hue, chroma, and brightness, on cognitive responses and intellectual capacities (Xia et al., 2021a, Xia et al., 2021b, Xia et al., 2022, Xia et al., 2023). This litany of research outputs, although prolific, beckons for a more scrutinizing assessment of their methodologies and implications. Take, for instance, Xia et al.'s (2021c) endeavours, which purportedly dissect the intricacies of how colour stimuli wield influence over lateral and logical abilities. Their assertions of heightened arousal and impulsiveness induced by certain colours in individuals' cognitive processes are tantalizing, yet warrant a closer examination of the broader ecological validity of such conclusions. Moreover, the ambitious assertions put forth by Xia et al. (2023), delving into the domain of colour attributes' impact on cognitive performance within immersive virtual environments, although intriguing, demand a cautious interpretation. The revelation of colour's influence on thinking and abilities, within the context of virtual experiences, while undoubtedly provocative, necessitates further consideration of the multifaceted factors at play. In essence, while these studies offer preliminary glimpses into the potential interplay of colour and cognition, they beckon for more rigorous exploration and nuanced understanding before we can fully embrace their implications. As such, this study embarks on a novel exploration, aiming to reinvigorate the discourse surrounding the interaction between colour and cognitive performance within the immersive context of VR, with a focus on exploring the potential to positively trigger designers' cognitive responses and intellectual capacities.

In a deliberate focus on the effects of chroma, the study investigates its influence on the intellectual capacities of design students and professionals, thereby providing fresh insights into the untapped potential of selective colour application in immersive VR experience design.
To address these inquiries, the research engaged a cohort of twenty-eight designers and students, encompassing an equal distribution of 15 males and 15 females. Ranging in age from 20 to 32 years old, this diverse group participated in a meticulously designed series of psychrometric experiments, facilitated by an HTC Vive VR system. Through these experiments, the study evaluated participants' logical and lateral thinking abilities, along with their attention to detail, across varying levels of chroma. The ensuing analysis, conducted via a multivariate analysis of variance (MANOVA), uncovers nuanced relationships between chroma, cognitive

performance, and intellectual capacities within the immersive VR environments. The ensuing sections delineate the methodology, results, and implications of this pioneering research endeavor. By shedding light on the intricate interplay between chroma, cognitive faculties, and intellectual capacities within the context of immersive VR, this study lays the foundation for harnessing advanced immersive computing technologies to enhance intellectual capabilities and craft more impactful VR applications tailored to nurture creativity, imagination, and logical thinking abilities. However, it is pertinent to acknowledge the preliminary nature of this study's scope, urging further comprehensive exploration across diverse demographics and broader colour spectrums.

METHODOLOGY

Materials

Chroma trials were conducted utilizing the Unity platform in conjunction with the HTC Vive Pro head-mounted display.

Colour Conditions

The experiments involving chroma employed green backgrounds across seven different chroma levels (90%, 75%, 60%, 45%, 30%, 15%, and 0%), all with uniform luminosity settings. The specific green hue utilized for these experiments is designated as the 90% chroma within this investigation. The attributes of the background colors on both the monitor and the VR headset are detailed in Table 1.

Table 1: The attributes of the background colors within the VR headset.

Colour Conditions	R	G	B	L	a*	b*	C*	h (°)
Green_90%_chroma	23	229	171	81.38	-58.92	15.62	60.946	165.15°
Green_75%_chroma	57	229	181	82.00	-53.80	11.26	54.96	168.18°
Green_60%_chroma	92	229	190	83.00	-46.42	8.00	47.10	170.23°
Green_45%_chroma	126	229	200	84.30	-36.81	4.85	37.13	172.50°
Green_30%_chroma	161	229	210	86.12	-25.26	2.45	25.38	174.46°
Green_15%_chroma	195	229	220	88.36	-12.84	0.66	12.86	177.07°
Green_0%_chroma	229	229	229	90.94	-0.00	0.00	0.00	270.00°

Psychometric Tests

The psychophysical study was carried out to explore how chroma impacts individuals' cognitive capabilities through the use of a Head-Mounted Display (HMD) Virtual Reality (VR) headset. Six distinct types of psychometric tests were employed to evaluate participants' cognitive capacities: logical ability (logic rule test, mathematics sequence test), lateral ability (spatial structure test, rotation test), and detail ability (odd one out, same detail test). Within each test category, seven questions were presented, with each question featuring a distinct coloured background. Consequently, the total number of questions reached 42 (6 test types multiplied by 7 coloured backgrounds), with each participant tasked with responding to the entire set. The assignment of coloured backgrounds to questions and the sequence of question presentation were randomized for each participant. It's important to note that while every participant encountered each question with the seven coloured backgrounds within a given test, the specific colour allocations varied among participants. This approach aimed to mitigate bias,

ensuring that if a question proved slightly more challenging, its association with any particular background for a participant was equally probable. The primary data collected from the experiment encompassed response time and error rates. These metrics will be utilized in the Results section to gauge participants' levels of arousal and impulsiveness, serving as an indirect means to elucidate the influence of colour on individuals' lateral and logical abilities.

Participants

A cohort comprising 30 individuals (15 males and 15 females), aged between 20 and 32 years, was enlisted for the chroma experiment phase. In light of potential cultural influences and to mitigate variations in logical tendencies, the participant pool exclusively consisted of Chinese design students and professionals for this experimental segment.

Experimental Procedure

Prior to commencing the experiments, every participant underwent the Ishihara colour vision test to ensure their normal colour recognition capability. Once participants successfully completed the test, they were provided with a comprehensive explanation of the experimental instructions. Following this, participants engaged in a set of practice tasks for each type of psychometric test to acquaint themselves with the procedure before embarking on the main experiment. Upon concluding these tasks, participants were instructed to focus their gaze on the white reference background presented by the VR headset for a five-minute period, allowing them to acclimate to the conditions. The primary experiment commenced five minutes after participants had acclimatized to the experimental conditions.

RESULT AND DISCUSSION

Utilizing a Multivariate Analysis of Variance (MANOVA) in SPSS, the study sought to discern the impact of distinct chroma levels on participants' cognitive performance. The findings indicated significant variations in response times when participants were engaged in tasks necessitating logical reasoning. Specifically, a statistically significant difference was observed between the chroma levels of 75% and 0%, $p = .006$. For tasks emphasizing lateral thinking capabilities, the data revealed marked disparities in response times, especially between chroma levels of 75% and 30%, $p = .001$, and between 75% and 15%, $p = .031$. Furthermore, error rates in these lateral thinking exercises displayed significant variations across several chroma contrasts: 75% versus 60%, $p = .043$; 75% versus 15%, $p = .013$; 45% versus 15%, $p = .025$; and 30% versus 15%, $p = .043$. In tasks demanding meticulous attention to detail, participants' response times exhibited significant differences at specific chroma contrasts: 75% compared to 60%, $p = .036$; 75% compared to 30%, $p = .022$; 75% compared to 15%, $p = .01$; and 75% compared to 0%, $p = .004$.

These results emphasize the profound impact of chroma variations on cognitive metrics, spanning logical and lateral reasoning, as well as tasks that demand precision. The insights derived from the MANOVA analysis shed light on the intricate interplay between chroma levels and cognitive function, hinting at the potential to design VR experiences that optimize cognitive capabilities and attention to detail.

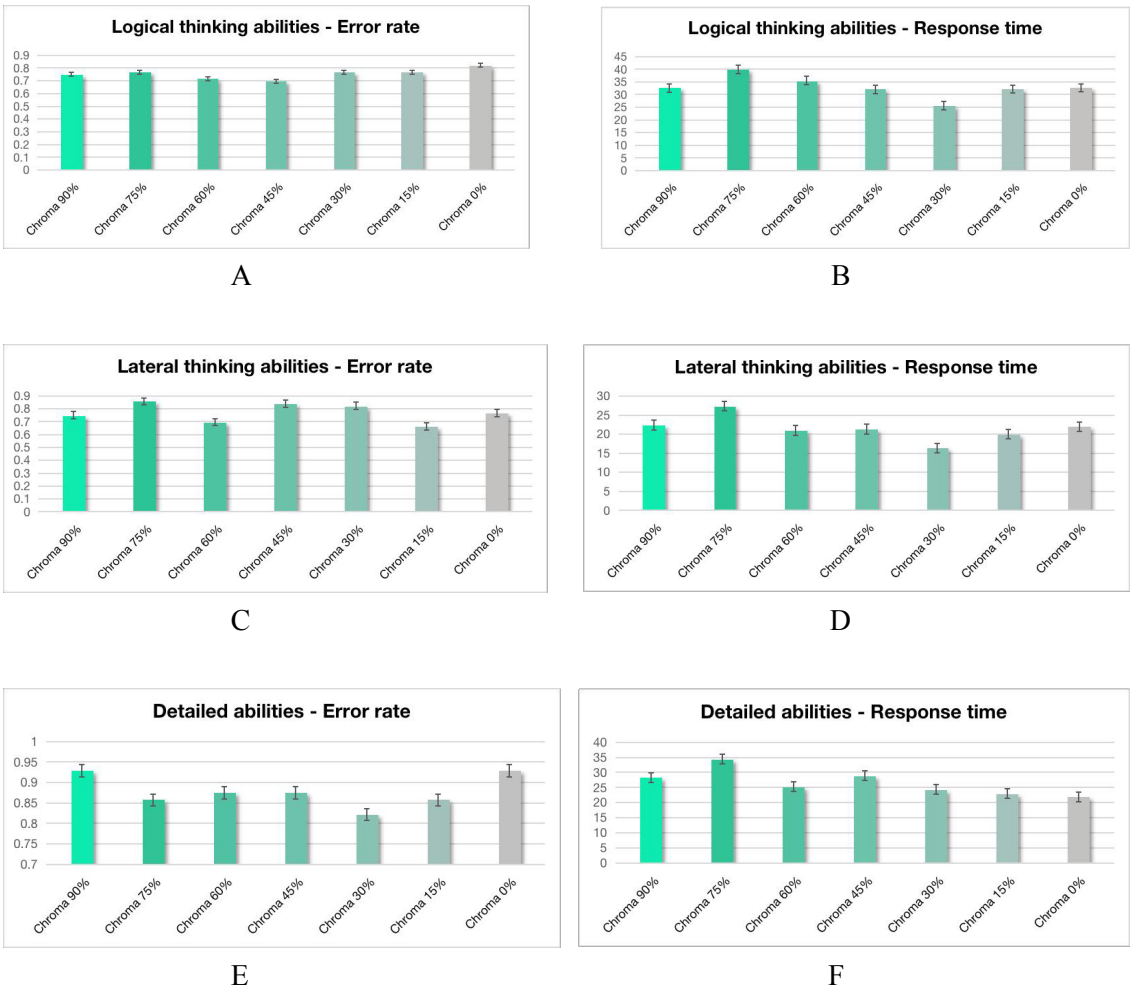

Figure 1. (A) Error rate of participants' performance in logical thinking abilities by background colours in VR; (B) Response time of participants' performance in logical thinking abilities by background colours in VR; (C) Error rate of participants' performance in lateral thinking abilities by background colours in VR; (D) Response time of participants' performance in lateral thinking abilities by background colours in VR; (E) Error rate of participants' attention to details by background colours in VR; (F) Response time of participants' attention to details by background colours in VR.

CONCLUSION

Our research illuminates the intricate relationship between colour chroma and cognitive performance within the realm of immersive virtual reality (VR). As immersive VR technology continues to permeate creative sectors like fashion and design, it offers unprecedented opportunities for nurturing creativity, bolstering engagement, and catalysing imagination. Yet, the quest to design VR environments that optimize emotional and cognitive responses has been hampered by a paucity of in-depth research. Our study sought to bridge this knowledge gap, with a keen focus on how colour chroma can influence the cognitive prowess of designers.

Building upon the foundational research by Xia et al., which highlighted the profound influence of colour on cognitive dynamics, our study ventured into the uncharted territories of VR. We delved into the nuanced effects of chroma variations on cognitive faculties such as logical and lateral thinking, as well as precision. Utilizing the HTC Vive VR system, our rigorous

psychrometric experiments have unveiled ground-breaking insights, suggesting that strategic colour application could revolutionize immersive VR design. This exploration is further contextualized by studies such as those by Elor et al. (2021), which delve into the potential of VR beyond the novelty, especially in physical rehabilitation. Similarly, Fröhlich et al. (2018) and Škola et al. (2020) have emphasized the immersive potential of VR in fostering creativity, playfulness, and cultural heritage engagement. Tao et al. (2021) have also underscored the transformative potential of VR in health games, emphasizing the importance of game design in enhancing cognitive and physical outcomes. The marked disparities in response times across chroma levels, especially in tasks demanding logical reasoning, beckon a deeper exploration into the underlying cognitive mechanics. The linkage between specific chroma intensities and heightened cognitive arousal or impulsivity enriches our comprehension of colour's multifaceted impact. The variations observed in lateral thinking and error rates across chroma gradients further underscore the intricate dance between colour and cognition.

Our research stands as a beacon in the academic landscape, providing empirical validation of chroma's sway over cognitive performance in immersive VR settings. The correlations we've unearthed between chroma shifts and distinct cognitive metrics, such as response times and error rates, champion the idea of colour as a potent catalyst for cognitive immersion. This resonates with the broader understanding that colour's magic extends beyond mere visual appeal, influencing cognitive reactions and intellectual prowess. The ramifications of our findings are manifold, spanning both academia and real-world applications. The knowledge gleaned can pave the way for crafting VR experiences that resonate with specific cognitive goals. By adeptly tweaking colour chroma, designers hold the key to fine-tuning cognitive immersion, arousal, and meticulousness, thereby elevating the user journey. This knowledge transcends the boundaries of creativity, beckoning interdisciplinary synergies and innovations across diverse arenas. Yet, it's paramount to recognize our study's boundaries. Our research lens was primarily trained on a niche demographic of design aficionados, and the emphasis on green hues might not encapsulate the vast chromatic spectrum. Future endeavors should cast a wider net, encompassing diverse demographics and a richer palette of colours. While our insights are invaluable, the intricate interplay between chroma and cognition beckons deeper exploration. To encapsulate, our research stands as a trailblazer, demystifying the role of colour chroma in shaping cognitive trajectories within VR landscapes. Our revelations underscore the promise of judicious colour application in amplifying cognitive immersion and refining VR design. As the VR frontier expands, our insights beckon further scholarly pursuits and inventive applications, fostering cross-disciplinary alliances to harness colour's transformative potential in virtual realms.

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