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Beyond Gaming: Neuroscientific Insights Into VR Through Gameflow Analysis

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ABSTRACT

This paper explores the concept of 'gameflow' within the realm of Virtual Reality (VR), extending its application beyond traditional gaming boundaries to encompass various industries. The primary objective is to establish a multifaceted scoring and evaluation system that is adaptable across different sectors, leveraging the universal nature of game-like approaches. Central to our study is the use of VR gaming as a main case study. By adopting neuroscientific methods, specifically functional Near-Infrared Spectroscopy (fNIRS), we aim to validate and refine game evaluation standards. Our research signifies a step in the interdisciplinary application of gameflow analysis, which not only evaluates the gaming experience from a neuroscientific perspective but also underscores the potential of gameflow principles in enhancing user experience and effectiveness in diverse fields.

Keywords: Gameflow, Virtual reality (VR), Neuroscientific methods, Functional near-infrared spectroscopy (fNIRS)

INTRODUCTION

Introduction to VR

Over the past three decades, gaming has been an important driver of advances in real-time computer graphics, sound, and more recently, artificial intelligence. For example, with each new generation of game consoles, game hardware, and software updates, graphics and sound provide a greater sense of realism. Despite the many revolutionary advances in gaming technology, the fundamental interface between humans and gaming systems has received relatively little attention. Therefore, by studying game play and human-computer interaction technology, the gaming experience of professional and casual users can be improved.

The concept of Virtual Reality (VR) refers to a fully simulated reality, which is built with computer systems by utilizing digital formats (Martín-Gutierrez, 2017). Table I shows the three key concepts in the field of virtual reality: immersion, interactivity, and presence. Immersion is created around the user through virtual technologies and devices such as virtual glasses, gloves with motion sensors, head-mounted displays (HMDs), surround sound, and any other element that creates sensory stimulation or sensors that allow the user to interact with a virtual environment as if they were in a real environment. Interactivity refers to the degree and willingness of users to participate in modifying the form and content of the virtual reality environment in real time. Presence is defined as "the subjective experience of being in a place or environment as if one were physically present there, even though one is actually in another place". VR also requires real-time interaction, so the user needs immediate feedback on his or her actions or instructions. This feedback allows the user to react and send instructions to the computer by using a tracker, glove, remote control, or any other input device that simulates real-world user reactions. Output devices (visual, auditory, or tactile) should create the illusion of reality, so hardware and software should be able to render detailed and realistic virtual scenes.

Because the VR environment has its three most significant characteristics: increased participation and immersion, and presence, it allows users to experience more virtual realism, which in turn makes it more enjoyable and paves the way for better video game user experience (Nacke and Lindley, n.d.; Blascovich and Bailenson, 2011; Lim and Reeves, 2010; Nacke et al., 2011).

Table 1. Key concepts of virtual reality.

Concept	Citation
Immersion	(Burdea and Coiffet, 1994; Witmer and Singer, 1998; Ryan, 2001)
Interaction	(Burdea and Coiffet, 1994; Ryan, 2001; Steuer, 1995)
Presence	(Witmer and Singer, 1998; Steuer, 1995; Schubert et al., 2001)

Introduction to Gameflow

The term "flow" was first introduced to describe optimal experience (Blascovich and Bailenson, 2011). Csikszentmihalyi conducted extensive research into what makes experiences enjoyable, based on long interviews, questionnaires, and other data collected over a dozen years from several thousand respondents. He described flow is a deeply immersive state where individuals become thoroughly engrossed in an activity, to the extent that they lose track of time, ignore fatigue, and focus solely on the task at hand. During flow, attention is so completely absorbed in moment-to-moment activities that there is little time left to devote to the mental processes that contribute to the ongoing experience (Lim and Reeves, 2010).

Based on Csikszentmihalyi's model of flow (Blascovich and Bailenson, 2011), Sweetser & Wyeth's gameflow model (Sweetser and Wyeth, 2005) was carried out to distinguish between the high-rated and low-rated games and identify why one succeeded and the other failed. GameFlow is composed of eight elements: concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction. Each of these elements encompasses various criteria that are used to assess the effectiveness and reliability of the gameflow model.

Rather than the traditional two-dimensional (2D) virtual setting, numerous video games are now playable in a stereoscopic three-dimensional (3D) environment, or even using Head-Mounted-Display (HMD VR) based virtual reality systems. A 3D environment is generally considered to offer a more realistic and vibrant experience compared to a 2D setting (Rooney and Hennessy, 2013; Takatalo et al., 2011). The idea of "immersion" boasts a vast historical background across various disciplines. Initially rooted in physics and biology, it described the complete submersion of an object in a liquid. However, over time, the term has acquired broader interpretations in areas like art, literature, psychology, and technology. While not always explicitly named in the past, the essence of immersion in literature and art has always been to deeply engage audiences in captivating stories or visual arts. In psychology, immersion relates to the degree of attention, consciousness, and perception, focusing on how individuals can become deeply involved in an activity, losing awareness of their surroundings. The 20th century saw a shift in focus to the addictive qualities of engaging activities like reading, film-watching, and more.

With the advent of computers and the internet in the latter half of the 20th century, the concept of immersion found new ground in virtual reality (VR) and video gaming. In VR, immersion extends beyond visual and auditory sensations to include interactivity and user participation, aiming to create believable and engaging virtual settings. The rise of multimedia technology led to the birth of interactive art, requiring audience involvement to deepen the immersive experience.

The year 2021 marked the dawn of the Metaverse era, expanding the realms of human existence, sensory perception, and cognitive space (陈钧 and 高凌波, 2023). In this narrower metaverse context, the interaction between humans and the digital world necessitates a more user-friendly and immersive experience. The evolution of the immersion concept thus mirrors humanity's desire to wholly engage with and experience alternate realities. Transitioning from its original physical connotation to psychological, perceptual, and then technological applications, immersion has evolved into an interdisciplinary and multifaceted notion. Today, it encompasses not only complete sensory engagement but also deep emotional, cognitive, and psychological involvement. With the progression of interactive technologies like VR and augmented reality, immersive experiences have become fundamental to digital entertainment, education, and art, offering novel experiential and cognitive dimensions.

BACKGROUND

Background and Context

The concept of gameflow, derived from Csikszentmihalyi's theory of flow, has been a cornerstone in understanding player engagement and satisfaction in video games. Flow, characterized by a state of complete immersion and enjoyment in an activity, has traditionally been applied to assess the quality of gaming experiences. However, with technological advancements, particularly in Virtual Reality (VR), there's a growing need to reevaluate and expand this concept. VR offers immersive, interactive experiences that differ significantly from traditional gaming, bringing new dimensions to player engagement, cognitive processing, and emotional response.

The rapid proliferation of VR technologies has seen their application extend beyond entertainment, into education, psychological therapy, and artistic expression. These developments necessitate a re-examination of gameflow theory to understand how it applies to these diverse contexts. The unique attributes of VR – such as spatial immersion, physical interaction, and heightened sensory feedback – pose new challenges and opportunities for enhancing user experience based on flow principles.

Related Work

Gamers' heightened sensitivity to interaction latency (Claypool and Claypool, 2006) has garnered significant interest in its measurement methods. Shea et al. (2013) assessed the interaction delay and image quality of the OnLive system across various games, computer setups, and network configurations. Their findings indicated that cloud processing adds a latency of 100 to 120 milliseconds to the overall system.

Huang et al. (2013) set up a specialized testbed for cloud gaming to assess its performance across different network scenarios. They emphasized latency as a key performance metric and proposed breaking it down into several segments for a more granular analysis. Building on this, they later focused their research on evaluating the performance of cloud gaming specifically for mobile clients with limited resources. This involved experiments where they varied parameters like resolution, bitrate, and frame rate to understand their impacts on the gaming experience (Huang et al., 2015).

The flow experience is frequently regarded as a crucial benchmark for ideal user experience (UX). According to ISO9241-210 (2010), User Experience (UX) is defined as focusing on the perceptions and responses of a person, the user, that arise from the actual and/or anticipated use of a product, system, or service. Due to the multifaceted nature of User Experience (UX), a variety of components and measurement approaches have emerged to assess this process (Zaharias and Mehlenbacher, 2012).

Research Problem and Objective

The prevalent techniques for gauging flow experience, such as questionnaires and interviews, are inherently retrospective. Flow, however, manifests during an activity when an individual is deeply engrossed in a game, with self-referential thoughts being fully suppressed. Consequently, a paradox arises: when participants are prompted to describe their experience, they have already exited the state of flow and shifted into self-reflection. In essence, the self-report method is subjective and conducted post-activity (Engeser, 2012). A viable alternative is to employ physiological indicators of flow, which are objective and can be measured in real-time during the activity, without disrupting the participant.

METHODOLOGY

To evaluate gameflow elements in VR gaming and establish an interdisciplinary evaluation system, we developed a comprehensive experimental framework by utilizing the principles of gameflow theory and exploring its wide-ranging applications, especially in VR gaming. This framework will leverage advanced neuroscientific instruments, such as fNIRS, to authenticate and refine gaming benchmarks, allowing for a more nuanced and scientifically-grounded understanding of game dynamics and player engagement. This design considered the primary indicators of gameflow such as concentration, challenge, player skills, control, clear goals, feedback, immersion, and social interaction (Sweetser and Wyeth, 2005). Additionally, we incorporate human factors into the experimental design.

Experiment Setup

Functional Near-Infrared Spectroscopy (fNIRS) is a real-time, low-cost, portable and non-invasive brain imaging technology that enables researchers to localize and measure tissue oxygenation (StO2) and cerebral blood flow. In the field of neuroscience, applications of fNIRS have explored the neural underpinnings of various human behaviors, which include studies on the sensorimotor apparatus (Miyai et al., 2001; Shimada et al., 2004), visual stimuli (Taga et al., 2003; Schroeter et al., 2004), and executive functions (Schroeter et al., 2002; Hoshi et al., 2003).

In our research, we expanded upon the methodology used in a previous study aiming to find a reliable method for accurate signal acquisition using tools in real and virtual environments (Gamberini et al., 2008). We focused on exploring the practicality of using fNIRS in the context of immersive VR gaming. To facilitate this, we modified a VR helmet to enable the proper positioning of fNIRS optical fibers on the participants' scalp. The primary objective of our study was to verify whether this innovative setup could effectively and accurately acquire fNIRS signals. This approach holds substantial potential for advancing our understanding of visuo-spatial attention and perception in immersive virtual environments, a topic that has garnered significant interest in various studies (Jewell and McCourt, 2000; Ferber and Karnath, 2001; Longo and Lourenco, 2006; Rorden et al., 2006) . Our study aimed to employ this paradigm to evaluate the effectiveness of our technical solution in capturing fNIRS signals during immersive VR gaming experiences.

Participants

Sixteen participants (5 females and 5 males; M = 28.68 years, range = 19–42 years) participated in the experiment after providing their informed consent. All participants in the study confirmed they had no history of neurological or psychiatric conditions, and none were taking any medications during the testing period. Additionally, all of them had normal or corrected-to-normal vision and standard color vision.

Apparatus

Players participated in virtual games by wearing three different brands and models of VR equipment: HTC Vive Cosmos Elite (the first-generation VR headset launched in early 2015), HTC cosmos elite (the upgraded and advanced version of HTC helmet will be launched in early 2020, the best here is the Vive pro version), Pico Neo 3 Pro enterprise version (domestic VR helmets, which are more common in VR experience stores, launched in mid-2021). Research helmet was modified by VR equipment and fNIRS fibers, which can provide VR games for participants and reach brain areas to record.

Table 2. Virtual reality equipment.

Info	HTC Vive CE	HTC Vive Cosmos Elite	Pico Neo 3 Pro
Immersion			
Manufacturer	HTC	HTC	Pico
Resolution	1080*1200	1440*1700	1832*1920
Refresh Rate	90HZ	90HZ	90HZ
Visible FoV	110°(diagonal)	110°(diagonal)	98°(diagonal)
Tracking Methods	Outside-in tracking	Outside-in tracking	Inside-out tracking
CPU	Intel® Core i5-4590 or AMD FX 8350, Equivalent or Better	Intel® Core i5-4590/AMD FX™ 8350 equivalent or better	Intel® Core i5-4590 and AMD Ryzen 1500 or higher
GPU	NVIDIA GeForce GTX 970/AMD Radeion R9 290, Equivalent or Better	NVIDIA® GeForce® GTX 1060, AMD Radeon™ RX 480 equivalent or better	NVIDIA® GeForce® GTX 1060 and AMD Radeon RX 480 or higher
Operating system	Windows® 7 SP1, Windows® 8.1 or later, Windows® 10	Windows® 11 / 64-bit Windows® 10	Windows® 10 and above

Procedure

Each participant signed an informed consent form before starting the experimental task. Participants were invited to stand in a specific experimental area. The experiment space is approximately is 2 meters by 2 meters by 2.2 meters (2m*2m*2.2m), which is a specific space for VR games. Before starting the experiment, we asked the participant to relax, and then the participant put on the helmet we prepared specifically for this experiment. The VR helmet and the fNIRS optical fiber were placed on his/her head. We have prepared 2 types of games, three games in each type, a total of 6 games, each game lasts 5 minutes. After completing one type of game, take a fifteen-minute break. The total duration of the experiment for each subject is 1 hour.

Before beginning the game session, participants were required to view a tutorial video lasting 2 minutes, which explained the game's mechanics and goals. The gameplay was structured into three progressively challenging levels: the first being Casual Difficulty, the second Advanced Difficulty, and the third Hardcore Difficulty. Each level was played for an approximate duration of 5 minutes. In order to maintain consistency in player experience, the routes taken by players were pre-set. This was necessary as some routes could lead to early game termination.

LIMITATIONS AND FUTURE WORK

Limitations

In the experiment, the control virtual games used were of two genres: horror and relaxation. However, there are many types of games, and different genres can offer varied experiences, sensations, stimulations, and subsequent impacts on players. Therefore, our experiment's use of only these two types of games does present certain limitations. In addition, there are limitations in the following three aspects.

Ecological Validity: The controlled settings of virtual environments and game interfaces used in the study might not fully represent real-world scenarios. This could limit the applicability of the findings in more varied or naturalistic settings.

Participant Diversity: The study's participant pool might have limitations in terms of diversity (age, cultural background, gaming experience, etc.), which can impact the universality of the design principles derived from the research.

Interdisciplinary Challenges: The interdisciplinary nature of combining human factors, brain science, and game design poses inherent challenges. These include potential discrepancies in methodological approaches and theoretical interpretations across different fields.

Future Work

Building on the foundation laid in this paper, our future researches will focus on extending the application of game flow analysis in virtual reality (VR) across industries. While VR gaming is our main case study, we plan to extend the analysis to other VR applications in education, art design, etc. We intend to develop and refine a versatile scoring and evaluation system that can be applied universally, leveraging game-like methods in different contexts. Future research will involve the broader application of neuroscientific methods to validate and improve assessments in different contexts. This comprehensive approach aims to deepen our understanding of the impact of these flow elements, not just in games, but in any VR-based interaction. Ultimately, our ongoing research will contribute to a richer understanding of VR experiences, providing valuable insights and guidance for future applications across disciplines. This work aims to solidify the role of game flow analysis using neuroscience methods, especially fNIRS, as a key tool in understanding and enhancing user engagement and satisfaction in the evolving field of VR technology.

CONCLUSION

In this paper, we explore the concept of 'gameflow,' proposing a novel framework for understanding and evaluating experiences across various industries, not limited to traditional gaming. This research expands the application of 'gameflow' beyond computer and mobile games, encompassing a broader spectrum of activities in fields such as education, psychology, and art. Our primary focus is the development of a universal scoring system and evaluation framework that can be adapted across different sectors. This system is particularly pertinent for the assessment of Virtual Reality (VR) content, which has seen growing applications in numerous domains. Central to our study is the use of a VR game as a case study. We employ functional Near-Infrared Spectroscopy (fNIRS) and other neuroscientific methods to validate the game evaluation standards. In summary, this paper introduces a groundbreaking perspective in assessing interactive experiences, extending the application of gameflow to diverse sectors, and setting a precedent for future interdisciplinary research.

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