Exploring the Time Dilation Gameplay in VR, and its Effect on Presence, VR Sickness, and Performance

Louis Nisiotis
School of Sciences
University of Central Lancashire, Cyprus
LNisiotis@uclan.ac.uk

Panayiotis Hadjidemetriou
School of Sciences
University of Central Lancashire, Cyprus
PHadjidemetriou1@uclan.ac.uk

Nicolas Nouhi
School of Sciences
University of Central Lancashire, Cyprus
NNouhi@uclan.ac.uk

***Abstract*—This study explores the effect of Time Dilation Gameplay mechanic in a VR game and its impact on players' subjective feeling of Presence, symptoms of VR sickness, and to their gaming performance. A comparative study was conducted using a VR First Person Shooter game prototype under two conditions: Normal Gameplay and with Time Dilation, manipulating the in-game time to almost complete standstill when the player stops moving. The results indicated that players in the Time Dilation Gameplay group experienced high degree of Presence comparable to those playing in Normal Gameplay condition, and yielded relatively lower levels of VR sickness, highlighting the need for further investigation on its potential impact on the domain. The players' in-game performance between the two conditions was similar, but the Time Dilation mechanic impacted the way they were navigating and spatially exploring the environment, hence, considerations need to be made in the way tasks, levels, and interactions are designed. The main contributions of this paper are: i) insights on how Time Dilation affects players' feeling of Presence in a VR game; ii) the impact of the mechanic on VR Sickness; and iii) its effect on player performance, providing valuable information for game developers and designers.**

***Index Terms*—Virtual Reality, VR Sickness, Time Dilation, Presence, User Performance**

I. Introduction

Virtual Reality (VR) in entertainment and video games has been gaining significant attention over the past few years, as it offers access to highly immersive and interactive gaming experiences, characterised by enjoyment and engagement. However, a significant problem that hinders its mainstream adoption relate to issues of VR Sickness (VRS), causing user symptoms such as disorientation, nausea and others during and/or after the use of VR. This study aims to evaluate a particular Gameplay mechanic relevant to time manipulation, the Time Dilation, and investigate its effect on players' subjective feeling of Presence, its possible onset on VRS symptoms, and how it affects their gaming performance. Time Dilation is the effect of manipulating time within a game, to either speed up, slow down, or completely stop in-game time during Gameplay. The experiment described in this paper focuses on slowing the Gameplay time to almost a complete stand still when the player is not spatially moving, but angular velocity and body movement to remain unaffected, allowing the player to rotate and visualize the entire scene, and interact with the environment. To investigate this, a VR First-Person Shooter (FPS) game has been developed and a comparative study was conducted evaluating the prototype through Normal and Time Dilation enabled Gameplay.

II. Background and Context

The video game industry is a multi-million dollar sector with established status in the entertainment market for many years. One of the recently raising portions in the gaming domain is VR hardware and VR games. This significant increase is attributed to the exponential improvements in hardware capabilities, decrease in ownership costs, advancements in graphics fidelity and maturity of Gameplay mechanics [1]. Due to the technology's immersive and engaging capabilities, VR gaming is now one of the key developments in the modern video game landscape, and the impact of VR in player experience is a topic that drew significant research interest over the past decade. VR video games are different to traditional video games particularly through the immersive feeling of presence during the gaming experience and the virtual embodiment of the player as the gaming interface [2]. However, while there is growing interest in understanding player experience in VR video games, research in VR FPS games is still at its infancy [3]. Among a range of player experience areas, the challenge provided by the system's mechanics, and the way players interact with a VR game are attracting attention [4]. In particular, the time manipulation Gameplay mechanic altering the flow or perception of time within a game is successfully used in 3D and VR games. However, its impact on players' sense of presence, the potential onset of VR sickness symptoms, and impact to players' gaming performance is still unexplored in video game research.

A. Presence

Presence drew substantial research in video games due to its nature of perceptual illusion that is blurring the differences between the real and virtual worlds [5]. It is defined as

"*the subjective experience of being in an environment when physically situated in another*" [6], and is one of the key determinants for continued intentions to play a video game [1]. Different technologies vary widely in the levels of immersion, with a spectrum ranging from non-immersive desktop experiences to fully immersive VR systems. In particular, VR games yield higher sense of presence compared to non immersive modalities [2]. The connection between technology and presence in video games raises important questions particularly relevant to the context of VR game design and development, where the design choices can potentially impact the users' sense of 'being in' the game, and this is a relatively unexplored area (see systematic review and meta-analysis on effects of game design choices by Caroux [7]).

B. Player Experience

As video games are a method of enjoyment, escape and relaxation, and a platform for social connection, creative expression, and even skills development [8], the aim is to provide enjoyable and dynamically engaging experiences. Therefore, designers and developers focus on creating games that trigger a range of emotions such as enjoyment, fear, sadness, and excitement [9]. Hence, gaming experience evaluation is crucial for development teams to evaluate whether these experiences are successfully implemented. The gaming industry and academic community are increasingly focusing on User Experience and in the Player Experience dimension in particular [10]. Player experience is affected by input and information output (e.g. display, interfaces and interaction methods), in-game content (e.g. Gameplay mechanics, level of challenge) and multiplayer aspects [5]. Especially the game design factors in the way the visual information are displayed, the multiplayer component, and their relevance to presence are extensively researched. However, the impact of game content such as challenge, difficulty, rules, functionality, and game mechanics on presence are still lacking empirical research [7].

C. VR Sickness

One of the main challenges of VR technology is VR Sickness discomfort experienced by some users that can significantly hinder their experience and practicality of the technology. This relates to Motion Sickness (MS), a physiological issue triggered when the sensory information processed by the brain conflicts with the physical motion perceived by the body, leading to symptoms such as dizziness, headaches, and disorientation among others [11]. In virtual environments, this type of discomfort is triggered by visual stimuli in simulators (e.g. driving or flight simulators) and is called Simulator Sickness (SS) or Visually Induced Motion Sickness (VIMS). Unlike MS, VIMS does not involve physical movement in real life [12]. To specifically describe the issue relevant to VR experiences, the term Virtual Reality Sickness (VRS) is used. VRS is a form of MS, arising during or after using VR technology leading to symptoms such as headaches, vertigo, disorientation, nausea, vomiting, stomach discomfort, paleness, eye strain, difficulty in focusing, and tiredness, among others [11]–[13]. The exact causes of VRS are not fully understood, and several theories such as sensory conflict, poison theory, and postural instability are being discussed in the literature [14]. The environment design and the nature of the activity influence VRS [3], and this domain continues to be investigated [15]. The exposure periods, viewer perspectives, Gameplay pace, accelerations, and the environment colors are also potential causes of VRS [16], [17]. The factors causing VRS are categorised in three main areas: hardware and its setup, VR software and content, and the individual's susceptibility to VRS [18], [19]. Best practices and guidelines on the design of VR environments to minimize symptoms exist to aid developers [20]. Various strategies to counter VRS are developed over the years, such as teleportation, field of view adjustments, blurring, rest frames, and dynamic depth of field simulations, which might however decrease the visual clarity of the experience [21]. Leveraging the advancements in VR hardware (enhanced resolution, frame rates, etc.) for improving user experience and reducing VRS is imperative [22]. Considering that individual susceptibility to VRS cannot be controlled, focus is placed on carefully designing VR content, game mechanics, and user interactions. A particular under-explored area is the use of time manipulation game mechanic and its potential impact on VRS symptoms.

III. Time Manipulation as a Core Game Mechanic

Game mechanics concern the rules, simulations, components, player capabilities and interactions with the rules and the game, and are commonly referred to as the tools to perform Gameplay activities [23], [24]. The concept of time in video games is a complex subject that has increasingly drawing the interest of developers and researchers. It relates to the unique ways in which time can be manipulated and experienced within video games, unlocking new potentials for creating immersive and engaging gaming experiences [25]. This mechanic concern ways in which the player or the game itself can manipulate or utilize the concept of time as a key Gameplay element, influencing how the game is played and experienced. Several games have been using time as a main or secondary mechanic to manipulate Gameplay with actions such as preserving time, pausing, slowing time down, replaying and other [25]. For example the 'Prince of Persia: The Sands of Time' incorporates a reverse time mechanic, allowing the player to go back in time during combat and parkour to reverse strategies and navigate through obstacles and challenges respectively. In 'Quantum Break', the main character has the ability to control time through special abilities such as time stop, time vision, focus time, time shield, time blast and time rush. 'Max Payne' features 'bullet time', allowing players to selectively slow down time around them while being able to aim and fire weapons in real time. In VR, the time manipulation mechanic (while underutilised) has also started to be implemented, and it is found in successful titles such as SuperhotVR. SuperhotVR is an adaptation of the Superhot 3D game version, a low-poly VR FPS game where the player can pick up guns and attack enemies while

dodging enemy fire, and time passes only when the player moves. The game is constructed around a Gameplay mechanic of time manipulation linked directly to the player movement [25]. However, the impact of the effect of time manipulation mechanic on the player experience is still under-explored. While research and evaluation of VR game mechanics is recently attracting attention [4], and the effect of the time-slowing mechanism is identified to provide more control over the player decisions [26], more research needs to be conducted to understand its effect onto the players perceived presence and to their gaming performance. Furthermore, in a recent SuperhotVR VRS evaluation, participants suffered most from symptoms in the Nausea and Oculomotor domain [27], indicating a necessity for more research to understand the impact of the time manipulation effect in VRS.

IV. Methodology

To determine the extent to which the Time Dilation Gameplay mechanic influences the players' feeling of presence, in-game performance, and its potential onset of VRS symptoms, a VR FPS game was developed and used in a comparative study with the Time Dilation mechanic as the comparative condition to Normal Gameplay. The aim was to compare player experiences, offering a clear understanding of the effects of this mechanic in a controlled virtual setting. To guide the study, the following research questions have been formulated:

RQ1. How does the Time Dilation Gameplay mechanic affect the players' perceptions of Presence compared to players in Normal Gameplay? This question will explore the experience of the Time Dilation Gameplay mechanic altering the pace and flow of in-game time in comparison with the perceived sense of Presence reported by players in the Normal Gameplay condition.

RQ2. Does the Time Dilation mechanic result in different levels and symptoms of VRS from those reported by players in the Normal Gameplay group? Based on the players' ability to slow down the fast-paced nature of the game to allow for decision-making, reducing the intensity of the visual stimuli and the physical intensity required to keep up with fast paced enemies, this question aims to determine the possible onset of VRS and symptoms in Time Dilation Gameplay compared to Normal Gameplay.

RQ3 How does player performance compare between Normal and Time Dilation VR Gameplay? This question will investigate the extent to which Time Dilation is enhancing, hindering, or maintaining a level of player performance similar to that experienced by players in Normal Gameplay (in terms of accuracy and space exploration).

A. VR Game Design

A fast paced VR FPS game has been developed using publicly available assets, where the manipulation of time is a central feature of the core game mechanics. Time Dilation is linked to the player movement, significantly slowing down the Gameplay time almost to a standstill whenever the player is stationary in the VR scene. However, the player retains full control over their angular velocity and body movements, enabling free rotation of the viewport camera, allowing for comprehensive observation of the surrounding scene, aiming, and interaction with the environment. However, the ability to shoot the gun is restricted by the time pause mechanic. The aim is to create a dynamic Gameplay experience where players can strategically pause action around them while still maintaining control over their viewport, body movement, and aiming. Players are equipped with a shotgun and navigate a level populated with zombie enemies spawning and attacking in waves ("Fig. 1"). The objective is to eliminate all zombies and destroy their spawn areas. Notably, the shotgun is deliberately designed with decreased accuracy, a feature intended to discourage over-reliance on precision aiming, especially during the Time Dilation condition.

Fig. 1. Gameplay Screenshots.

B. Data Collection Instruments

To collect data for this study, a combination of validated quantitative questionnaires and in-game performance measures were used. To measure the players' symptoms of VRS, the Simulator Sickness Questionnaire (SSQ), proposed by Kennedy et al. [28] was used. SSQ is the most commonly used method to provide a description of the overall SS for a particular simulation or simulated environment [28]. SSQ is administered as a pre and post VR exposure questionnaire. The results of SSQ are grouped into four scores: Nausea (N), Oculomotor (O), Disorientation (D), and Total Severity (TS). Each category is defined by the score sum of the symptoms, multiplied by a specific weight (9.54 for Nausea, 7.58 for Oculomotor, and 13.92 for Disorientation). TS is reported as an aggregated result of the previous 3 categories, multiplied by a scaling factor (3.74). SSQ is asking participants to rate 16 symptoms on a 4-point scale ranging from 0-3 (0 no perception – 3 severe perception) after the exposure. The higher scores indicate stronger perceptions of symptoms. The advice for results interpretation refer to negligible (<5), minimal (5–10), significant (10–15), and concerning symptoms (15–20). An overall result of above 20 is considered as very poor. To collect the users' perceptions of Presence in the virtual world, the Presence Questionnaire (PQ) was used [6]. This is a well-known, reliable and validated questionnaire that measures the user degree of presence experienced in a virtual environment by addressing Control (CF), Realism (RF), Sensory (SF) and Distraction factors (DF). CF relate to user actions and the expected behavior of the environment in response. RF refers

to the realism of the scene, content and consistency of information, and the meaningfulness of the experience. SF relate to the visual information received by the user and the richness of the environment. DF concerns distractions that may occur during the experience which could have a negative impact to the user's sense of presence. The total PQ score is calculated by aggregating all items for each user (Min=19, Max=133). Presence items use a 7-point response format, ranging from 1 (Very Strongly Disagree) to 7 (Very Strongly Agree). To collect insights on the players' performance during the game, data was collected though specific in-game statistics: Shooting Accuracy (%), Headshot Accuracy (%), Average Distance for Headshot, and Overall Distance Traveled during the game. A demographics questionnaire was developed, collecting data on players age, gender, VR experience, and gaming habits.

C. Experimental Procedure

Participants were randomly assigned to play the VR game in Normal Gameplay, or with the Time Dilation mechanic enabled. Before their interaction with the VR game, participants completed the SSQ to measure their physical state before entering the VR environment. They also completed the short demographic questionnaire. Participants were administered a Meta Quest 2 VR headset and played the game between 10 and 25 minutes. Immediately after the end of the game, they were administered the post-experience questionnaire including the SSQ to measure their post VR experience symptoms of VRS, and their perception on Presence. The player statistics were extracted directly from the device. 41 participants (34 male, 8 female) have been recruited through an open call for participation. The average age was 21.9 years, (SD=5.8), ranging from 18 to 49 years of age. All participants had normal or corrected-to-normal vision. Participants were mostly PC gamers, with the majority (38.1%) using PC for playing games everyday. 31% of them play games more than 10 hours per day, and 33.3% are playing between 3 to 9 hours daily. However, the majority of the participants (61.9%) had no previous (16.7%), or very limited experience with VR (45.2%). Most of them have never used VR for gaming (33.3%), or they used it very rarely (54.8%). Participants were randomly assigned into two groups experiencing either the Normal Gameplay (n=20), or Time Dilation (n=21) version.

V. Results and Discussion

The data were analyzed using inferential statistics and data visualization techniques. A Shapiro-Wilk test was employed to evaluate the normality of data distribution. PQ data were normally distributed, while data for SS did not follow a normal distribution, which is common for the SSQ [29]. Some of the metrics for Player Performance were also not normally distributed, therefore we have adopted a conservative approach to treat them all as not normally distributed.

A. Presence

The Presence results (Cronbach's α=.879) are presented in Table I. In both experimental conditions, players have experienced high perceptions of Presence, evidenced by the aggregated scores of 97.85 (SD=12.19) for the Normal Gameplay, and 91.31 (SD=16.83) for the Time Dilation Gameplay respectively, out of the maximum 133. The overall scaled Presence results of the Normal Gameplay (M=5.15, SD=.64) show slightly higher values than the Time Dilation group (M=4.8, SD=.88), with slightly higher perceptions of Control and Sensory factors, and similar for Realism factor. Interestingly, the Time Dilation condition yielded better Distraction results (M=5.04, SD=1.03). The results suggest that players in both Gameplay conditions experienced high degree of Presence and perceived good sense of control on the environment (CF), with high Sensory (SF) perceptions towards the received visual information and perceived richness of the environment, with slight differences favoring the Normal Gameplay group. Both groups reported similar high perceptions towards the realism of the scene, content and consistency of information (RF), but the Time Dilation group reported better distractions scores (DF). This could be indicative of the nature of Time Dilation Gameplay, which might engage players to a degree that made them less susceptible to internal and external distractions. An independent sample t-test was conducted to examine differences between the two groups, revealing no statistically significant differences. The results indicate that players achieved high degree and comparable sense of presence in the VR world regardless of the Gameplay conditions, addressing RQ1.

TABLE I
Presence Questionnaire Results

	Total	**Scaled**	**CF**	**SF**	**RF**	**DF**
Normal Gameplay						
Mean	97.85	5.15	5.06	5.23	4.75	4.93
SD	12.19	0.64	0.69	0.79	1.28	1.41
With Time Dilation						
Mean	91.30	4.80	4.80	4.67	4.74	5.04
SD	16.83	0.88	0.92	1.20	1.18	1.03
Legend: CF=Control, SF=Sensory, RF=Realism, DF=Distraction.						

B. VR Sickness Results

The VRS results according to the SSQ (Cronbach's α=.911) are presented in Table II and depicted in "Fig. 2". The analysis focused on the relative differences between the SSQ pre-test and post-test scores to assess the impact of the intervention. When relative scoring generated negative results (occurring when the score after exposure is lower than the pre-exposure score), we have interpreted the intervention as having no negative effect on participants, rather than positive, as suggested by Bimberg et al. [30]. The SSQ results are analysed using Medians and IQR since the data was not normally distributed, but we also reported Means and SD for all sub-scales and the total score to develop a complete understanding of the symptoms as Bimberg et al. [30] recommends. The overall SSQ results indicate that relatively mild VRS symptoms have been elevated for some users in both experimental conditions after the VR experience, but 8 participants (38.1%) did not report any VRS symptoms in the Time Dilation condition,

compared to 4 participants (20%) from the Normal Gameplay group. In addition, 7 participants (35%) reported VRS with a severity score higher than 20 during Normal Gameplay, whereas only 5 (24%), reported symptoms exceeding this severity level in Time Dilation condition. This can serve as a potential initial indication that the Time Dilation mechanic may be generating less VRS in this experiment. Additionally, participants did not report any excessive symptoms during or after the experience. The overall change in the Total Severity (TS) of VRS symptoms reported by the Normal Gameplay group (IQR=48.62) were similar (Mdn=7.48) to the Time Dilation Gameplay (IQR=59.84), and generally between minimal (5-10) symptoms. Visual inspection of data indicated that TS data spread for the Normal Gameplay (IQR=3.74-22.44) was higher than the Time Dilation Gameplay (IQR=0-18.7). The Nausea symptoms were higher in the Normal Gameplay (Mdn=9.54, IQR=19.08) compared to Time Dilation (Mdn=0, IQR=14.31). Higher scores were also reported for Oculomotor symptoms on Normal Gameplay (Mdn=7.58, IQR=15.16) compared to Time Dilation (Mdn=0, IQR=15.16), but visual inspection shows that the spread of reported symptoms results are fairly similar. Notably, Disorientation symptoms were higher in Time Dilation (Mdn=13.92, IQR=34.08) compared to Normal Gameplay (Mdn=0, IQR=24.36). A Mann-Whitney test was then conducted to determine differences in SSQ scores between Normal and Time Dilation Gameplay, revealing no statistically significant differences. The overall results indicate that the severity of VRS symptoms were within acceptable and relatively minimal levels for the majority of players in both conditions, but mostly lower for the group experiencing the Time Dilation Gameplay. The lower Median and IQR of Nausea and Oculomotor symptoms in Time Dilation group could be attributed to the slower pace of the game, which potentially reduces the intensity of visual stimuli that could lead to these symptoms. However, Disorientation symptoms were found higher in the Time Dilation condition, which could indicate that the time perception mechanic may affect the players' spatial orientation and balance in the VR environment and the real world respectively. Overall, the SSQ results revealed that: 1) higher number of players did not experience any VRS symptoms in the Time Dilation compared to Normal Gameplay group, 2) the mechanic develops relatively lower level of VRS symptoms compared to Normal Gameplay, but also causes higher disorientation symptoms, and 3) the results between the two groups were not statistically significantly different. These findings address RQ2, highlighting the need for further research on the impact of Time Dilation on VRS.

C. User Performance

The collected in-game user performance data are shown in Table III and depicted in "Fig. 2". The results indicate that Accuracy% and Average Headshot% were slightly higher in the Normal Gameplay, but fairly similar as can be seen in "Fig. 2", suggesting that Time Dilation is not affecting the key mechanic of accurately shooting enemies. Average Distance to a Successful Headshot was also similar between groups.

TABLE II
VR SICKNESS DESCRIPTIVE RESULTS

	Nausea	**Oculomotor**	**Disorientation**	**Total Severity**
Normal Gameplay				
Median	9.54	7.58	0	7.48
IQR	19.08	15.16	24.36	48.62
Mean	10.97	9.10	18.79	13.84
SD	10.39	10.31	31.38	14.41
Time Dilation Gameplay				
Median	0.00	0.00	13.92	7.48
IQR	14.31	15.16	34.8	59.84
Mean	7.72	9.38	18.56	12.64
SD	10.28	14.56	24.24	16.45

However, the Average Distance Covered in the game revealed significant variations between the Gameplay conditions. The distance covered in Normal Gameplay is 48.55% higher than in Time Dilation condition, which could be attributed to factors such as changes in player movement and shooting strategy due to the altered perception of time, potentially leading them to adopt more cautious or strategic approaches. A Mann-Whitney test was performed to compare the user performance between the two Gameplay conditions, revealing no significant statistical differences. The results suggest that players' performance in both conditions was similar, but with differences in the way they spatially explored the environment, addressing RQ3. The lower distance covered by the Time Dilation group should be considered by level designers, as it may influence players to adopt different strategies and movement patterns.

TABLE III
PLAYER PERFORMANCE STATISTICS

	Accuracy%	**Headshot%**	**Headshot Distance**	**Distance Covered**
Normal Gameplay				
Median	69.31	46.86	3.04	379.07
IQR	9.24	46.69	1.07	508.13
With Time Dilation				
Median	66.25	42.50	3.05	195.71
IQR	23.19	50.27	1.46	232.26

VI. CONCLUSIONS

This paper evaluates the Time Dilation Gameplay mechanic in a VR FPS game, exploring its effect on players sense of Presence, VRS symptoms, and on their gaming performance compared to Normal Gameplay. The results indicated that players enjoyed an immersive VR gaming experience and achieved high degree and comparable sense of presence in both Gameplay conditions. While some VRS symptoms were reported by players in both groups, a higher number of players in the Time Dilation condition experienced no symptoms at all compared to Normal Gameplay group. Furthermore, when symptoms were reported, players in the Time Dilation group reported generally less symptoms on the Nausea and Oculomotor domains, and in Total Severity. Notably, Disorientation symptoms were higher in the Time Dilation group, which could indicate that the mechanic may affect the player's spatial orientation and balance. In turn, this may suggest the need of

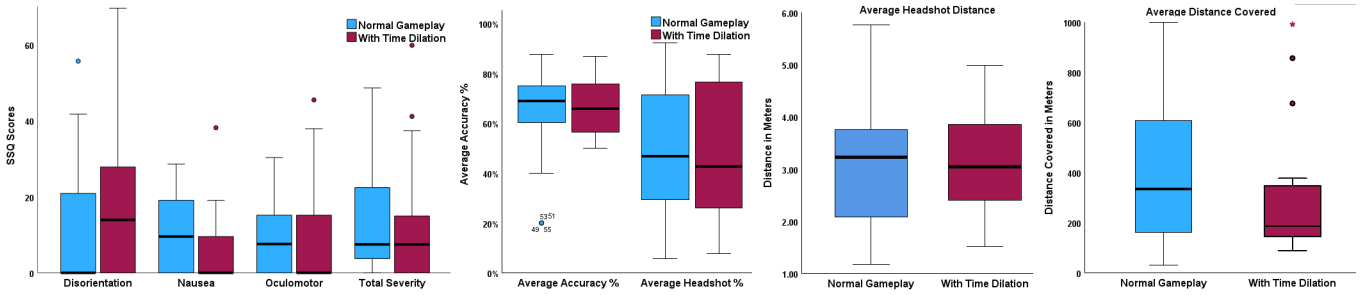

Fig. 2. SSQ and Player Performance Comparative Statistics between the two conditions.

sitting down while playing the particular game. Furthermore, the results indicated that the players' gaming performance in both conditions was similar, but with noticeable difference in spatial exploration between the two groups, as players in the Time Dilation group navigated the environment significantly less compared to the Normal Gameplay group. This finding requires further exploratory research as it could be indicative of a more cautious approach to Gameplay, adopting different strategies, movement patterns, different decision-making, or due to comfort factors. The implications of this study i) can draw interest on VR designers and developers to consider reevaluating level design, objectives, goals, and user interactions to effectively incorporate the Time Dilation Gameplay mechanic into their games, and ii) raise the need for further research to understand the potential of Time Dilation mechanic as a method for mitigating VRS in some VR games.

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