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Navigating Time Through Space: The Role of Spatial Frames of Reference in Spatial and Temporal Perception in Virtual Reality*

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Abstract

This study investigated the intricate relationship between spatial frames of reference (egocentric, or self-centered, versus allocentric, or environment-centered) and content eventfulness on subjective time perception within virtual reality (VR) environments. Additionally, it examined how prior VR experience might influence the sense of spatial presence. Seventy-nine participants were recruited to view four 360° VR videos, each systematically manipulated for spatial frame of reference (first-person egocentric vs. third-person allocentric) and content eventfulness (dynamic/narrative vs. neutral/ambient scenes) in a 2x2 within-subjects design. Participants then ranked these videos by perceived duration and completed a modified spatial presence questionnaire. The findings indicated that participants reported a strong sense of spatial presence, particularly for object/people presence and sound localization, confirming the immersive setup's effectiveness. However, tactile engagement received lower ratings. Crucially, prior VR experience did not significantly affect participants' perceived spatial presence. Regarding time perception, allocentric videos, especially those with eventful content, were more frequently perceived as longer in duration. Conversely, egocentric videos, particularly the uneventful ones, were consistently perceived as shorter, with the egocentric-uneventful condition demonstrating a statistically significant compression of perceived duration. This suggests that egocentric framing might compress subjective time, possibly by enhancing embodiment. The study also clarified that the presentation order of the videos did not significantly influence temporal judgments. This research highlights the complex interaction between spatial framing and content in shaping time perception in immersive environments, reinforcing the idea that space and time are deeply interdependent in human cognition.

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INTRODUCTION

Our subjective experience of the world is embedded within the fundamental dimensions of space and time, which have long been the subject of research. While historically treated as distinct domains in psychological research, recent interdisciplinary findings suggest a deep interdependence between spatial and temporal processing. It is known that space and time are interrelated and when making inferences on time durations, one cannot ignore spatial cues in the environment (Robinson et al., 2019). In cognitive neuroscience, both spatial reference frames and temporal judgments have been shown to rely on overlapping neural substrates, notably within the frontoparietal attentional network (Coull et. al., 2000). Psychological research has established that emotional and motivational states impact spatial and temporal perception. Yet, the cognitive and perceptual mechanisms by which spatial context—particularly the frame of reference—modulates temporal perception remain underexplored. The role of egocentric (self-centered) versus allocentric (environment-centered) spatial coding has been well-characterized in domains such as navigation, action planning, and memory. However, how these reference frames influence subjectivetime duration is far less established. At the same time, the event structure or content density of an experience, whether it is filled with dynamic (eventful) or uneventful stimulus has been shown to affect perceived duration. For example, Stojić, Topić, & Nádasdy (2023) found that children and adults diverge in their time estimates depending on the eventfulness of visual scenes, underscoring the developmental plasticity and cognitive complexity of time perception. Building on these observations, emerging studies suggest that spatial and temporal representations are not only correlated but may share representational resources. Clinical evidence from patients with spatial neglect shows impaired representation of past events on the mental timeline (Saj et al., 2013), suggesting that the ability to perceive and mentally represent time may depend on intact spatial processing systems. Additionally, theoretical frameworks such as psychological spacetime (Conway et al., 2016) posit that human cognition may operate within a subjective analog to physical spacetime—modulated by attention, embodiment, and contextual anchors.

Given the growing availability of immersive virtual reality (VR), researchers now can precisely manipulate spatial frames and environmental features while maintaining ecological validity. VR offers an interesting opportunity to investigate how changes in spatial viewing perspective (egocentric vs. allocentric) and content eventfulness modulate temporal judgments, spatial presence, and cognitive integration. This study synthesizes current knowledge on the interaction between spatial reference frames and time perception, emphasizing the relevance of virtual reality as a methodological tool. We critically examine evidence from cognitive psychology, neuroscience, and VR-based studies to:

- Clarify how egocentric and allocentric frames modulate perceived durations,
- Explore the influence of eventfulness and environmental richness on time estimation,
- Highlight gaps in the literature regarding neural mechanisms and multi-modal integration, and
- Propose future research directions leveraging immersive technologies to advance our understanding of subjective time.

Hypotheses

Building on prior work showing that eventfulness and spatial context influence duration judgments (e.g., Stojić et al., 2023), we predicted that spatial reference frame and content eventfulness would interact to shape perceived duration in immersive VR. Specifically:

- Allocentric–uneventful will be perceived as longest: Allocentric viewing encourages broad environmental scanning and self-location relative to surroundings (Gorisse et al., 2017) which in the absence of dense events, may heighten awareness of elapsed time.

- Egocentric–eventful will be perceived as shortest: Egocentric viewing combined with high eventfulness may increase embodiment and attentional engagement, narrow temporal awareness and compressing perceived duration.
- Spatial frame and eventfulness effects will be independent of presentation order, as prior studies have found minimal sequence-related biases in adult samples.
- Prior VR experience will not significantly affect presence ratings, given that immersive environments can produce strong spatial presence even in novice users (Slater & Wilbur, 1997).

SPATIAL FRAMES AND TEMPORAL PERCEPTION: A LITERATURE OVERVIEW

VISUAL AND SPATIAL PERCEPTION

Human visual perception involves an efficient yet selective interpretation of overwhelming sensory input. Our ability to detect, locate, and categorize objects in space supports essential functions such as recognition, interaction, and navigation (Carrasco, 2018; Wade & Swanston, 2013). The visual system must resolve these tasks while operating under significant metabolic constraints, which has led to an evolutionarily tuned system that prioritizes goal-relevant information and filters out non-essential details (Bruce, et al., 2003).

Beyond basic object perception, humans rely on visual-spatial perception—the capacity to process the location and configuration of objects in relation to oneself and other landmarks. This ability is supported by spatial memory, which allows individuals to store and retrieve information about their environment to guide future actions (Iachini et al., 2023). Together, these mechanisms enable complex behaviors such as tool use, locomotion, and interaction with dynamic surroundings.

One of the earliest conceptualizations of internal spatial representation comes from Tolman's notion of the cognitive map (Colombo et al., 2017), which has since been supported with the discovery of place cells in the hippocampus (O'Keefe & Dostrovsky, 1971). These findings underscore the view that spatial knowledge is encoded in internalized, coordinate-based systems—critical for both navigation and episodic memory.

EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE

Spatial cognition relies on reference frames—coordinate systems that determine how location and movement are encoded. The two dominant systems are egocentric (self-centered) and allocentric (world-centered) frames of reference (Iachini et al., 2023). Egocentric representations encode spatial locations relative to the observer's body (e.g., "the tea cup is to my left") and are continuously updated during movement. These are essential for motor actions like reaching or avoiding obstacles in the direction of objects (Committeriet al., 2004). Allocentric representations code object locations independently of the observer, in relation to other objects or environmental landmarks (e.g., "the tea cup is behind the laptop") (Galati et al., 2000; Zheng et al., 2021). Moreover, the studies showed that egocentric frame of reference is not only limited to the head and overall body position but also associated with haptic perception as the hand and the arm. Importantly, the two systems are not mutually exclusive; they often operate in parallel and interact dynamically depending on task demands (Volcic & Kappers, 2008). There is growing interest in whether they are neurally distinct and how they influence not just spatial processing but also temporal perception.

NEURAL BASIS OF SPATIAL FRAMES

Neurophysiological evidence supports a dissociation between the dorsal and ventral visual streams, corresponding roughly to egocentric and allocentric processing, respectively (Milner & Goodale, 1992; Ruotolo et al., 2019). The dorsal stream, extending from the occipital to parietal cortex, facilitates sensorimotor transformations and egocentric representations. The ventral stream, projecting to the inferior temporal lobe, supports object recognition and allocentric coding.

Studies of lesion patients reinforce this division. For example:

- Patients with optic ataxia (dorsal damage) can recognize objects but have difficulty interacting with them.
- Patients with visual agnosia (ventral damage) show the opposite profile, preserving motor action but losing perceptual access to object identity Whitwell, Milner, & Goodale, 2014).

Functional imaging further demonstrates that egocentric spatial judgments recruit dorsal-frontal networks, while allocentric judgments engage ventral-frontal and medial temporal areas, including the hippocampus (Committeri et al., 2004; Zaehle et al., 2007).

TIME PERCEPTION AND ITS INTERACTION WITH SPACE

The perception of time is a fundamental component of cognition, influencing language, action, emotion, and memory. However, time perception is not purely abstract—it is shaped by sensory, spatial, and affective inputs (Wittmann, 2009; Burr & Morrone, 2006).

Neuroscientific models such as Scalar Expectancy Theory (SET) propose an internal timing system with a pacemaker–accumulator mechanism, modulated by attention and memory load (Di Lernia et al., 2018). Increased attentional engagement is thought to increase pulse accumulation, leading to overestimation of time intervals. Crucially, space and time are not processed in isolation. Numerous studies suggest that spatial context can modulate perceived duration (Bratzke et al., 2023; Whitaker et al., 2022). For example, scenes rich in movement or complexity are often perceived as longer and shifts in spatial perspective can alter subjective time estimates. This link may stem from overlapping neural mechanisms for spatial and temporal attention, particularly within frontoparietal and hippocampal circuits (Coull & Nobre, 1998). Clinical data further underscore this link: patients with spatial neglect often show temporal neglect, failing to represent past events on the "left side" of the mental timeline (Saj et al., 2013). These findings raise the possibility that spatial representations scaffold our experience of time. Despite growing evidence, many questions remain about the precise nature of the space–time interaction—particularly how spatial frames of reference influence temporal judgment. Virtual reality (VR) offers a promising experimental tool to disentangle these variables in controlled yet immersive settings; a topic explored in the next section.

TIME PERCEPTION AND ITS INTERACTION WITH SPACE

The perception of time is a fundamental component of cognition, influencing processes such as language, motor coordination, memory, and decision-making. However, time perception is not purely abstract—it is dynamically modulated by sensory input, emotional salience, and spatial context (Burr & Morrone, 2006; Wittmann, 2009).

Prominent models such as Scalar Expectancy Theory (SET) suggest the existence of an internal pacemaker–accumulator mechanism, wherein subjective time is estimated by counting accumulated pulses over an interval. This internal clock is sensitive to attentional resources and memory load: greater attentional focus increases pulse accumulation and leads to longer duration judgments (Di Lernia et al., 2018). Importantly, temporal perception does not operate in isolation from spatial cognition. A growing body of research highlights that spatial cues—such as motion, viewpoint, and environmental layout—can systematically distort time judgments (Bratzke et al., 2023; Whitaker et al., 2022). For example, complex or dynamic scenes are often judged as lasting longer than simpler, static ones. These perceptual distortions may result from shared mechanisms underlying spatial and temporal attention, particularly in frontoparietal and hippocampal circuits (Coull & Nobre, 1998).

Clinical studies further support this connection. Patients with left spatial neglect not only misrepresent visual space but also neglect the "left side" of time, underestimating events located on that part of their mental timeline (Saj et al., 2013). Such findings imply that spatial representations scaffold temporal cognition, and that disruptions in one domain may impair the other. Despite these insights, the precise nature of how spatial frames of reference (egocentric vs. allocentric) influence subjective time remains underexplored. Addressing this gap is particularly feasible through the use of virtual reality (VR) technologies, which allow precise manipulation of spatial perspective in immersive, ecologically valid environments.

METHODS

PARTICIPANTS

Seventy-nine participants (56 females, 23 males), aged 18 to 35 years (M = 22.91, SD = 3.66), were recruited for the study. Most participants had at least a bachelor's degree (57%), followed by master's degree holders (18%) and high school graduates (8.8%). The sample was recruited through university networks (primarily Eötvös Loránd University) and social media platforms (e.g., WhatsApp and Facebook student groups). Inclusion criteria required participants to be over 18, fluent in English, and free of any known neurological or psychiatric disorders. Ethical approval was granted prior to data collection by the ELTE Ethical Research Committee (approval number 2023/315). Participation was voluntary, and no financial compensation was provided; refreshments were offered post-session. Informed consent was obtained in accordance with institutional guidelines.

APPARATUS AND STIMULI

VIRTUAL REALITY SETUP

Stimuli were presented via Oculus Quest 2 head-mounted display and hand controllers, allowing full 360-degree immersive video playback. The headset and controllers were sanitized between uses. Volume levels were fixed at 70% for all videos.

STIMULI AND EXPERIMENTAL CONDITIONS

Four VR videos (sourced from publicly available YouTube 360° content) were selected in consultation with the research supervisor to manipulate two independent variables:

- *Spatial Frame of Reference*: Egocentric (1st-person perspective) vs. Allocentric (3rd-person perspective),
- *Content Eventfulness:* Eventful (dynamic narrative) vs. Uneventful (neutral or ambient scenes).

Table 1. *2 × 2 Within-subjects Design.*

Condition	*Allocentric (3rd person)*	*Egocentric (1st person)*
Eventful	Jailbreak (JA)	Jailbreak (JE)
Uneventful	Maldives (MA)	Liminal Spaces (LE)

The order of four videos was randomized and was shown for equal durations (1-minute-long), a fact that is unbeknown to the participants. The scenes are neutral with respect to any ethical, religious, or political views. The videos did not feature any sensitive media such as children, disease, or other stimuli that might trigger anxiety or phobia.

PROCEDURE

Each experimental session lasted approximately 25–30 minutes. Upon arrival, participants were welcomed, informed about the study, and asked to provide written or electronic informed consent. Following consent, participants were fitted with the VR headset and given brief familiarization time with the device and the testing environment. The study took place in a soundproof laboratory room, with a 2×2 meter clear space designated for safe movement. Participants remained standing during the video presentations and were encouraged to freely rotate, walk within the boundary, and make natural head and body turns to explore the 360-degree environments.

Participants viewed four 360° VR videos, each corresponding to a unique condition (Eventful–Allocentric, Eventful–Egocentric, Uneventful–Allocentric, Uneventful–Egocentric). The order of video presentation was randomized across subjects. All videos were matched in duration, but participants were not informed of this to minimize bias in duration estimation. To ensure fidelity, each video was mirrored onto a computer screen during playback, allowing the experimenter to monitor participant engagement and confirm exposure to all conditions. After each video, participants were asked to provide an overall spatial presence rating (Lombard et al., 2009) capturing their sense of immersion and interaction with the virtual environment. Upon completion of all four videos, participants were given sorting cards to rank the videos in descending order of perceived duration, from longest to shortest. Finally, participants completed a modified version of the Spatial Presence Questionnaire, adapted from the Temple Presence Inventory (Lombard et al., 2009) to assess perceived immersion across conditions.

TASK

SPATIAL PRESENCE ASSESSMENT

To assess participants' subjective sense of immersion and spatial presence in each VR condition, a modified version of the Temple Presence Inventory (Lombard et al., 2009) was administered. Spatial presence is critical for understanding perceptual distortions in immersive technologies and their implications for judgment, memory, decision-making, and behavior in virtual environments. The modified scale comprised six items, each targeting different aspects of spatial presence such as embodiment, sensory realism, and physical engagement with the environment. Items were rated on a *7-point Likert scale*, with anchors varying between frequency-based (1 = *never*, 7 = *always*) and intensity-based (1 = *not at all*, 7 = *very much*) depending on item wording.

The items were:

1. Object and People Presence: *"How much did it seem as if the objects and people you saw/heard had come to the place you were?"*
2. Object Presence (Avoidance Behavior): *"How often when an object seemed to be headed toward you did you want to move to get out of its way?"*
3. Overall Spatial Presence: *"To what extent did you experience a sense of 'being there' inside the environment you saw/heard?"*
4. Sound Localization: *"To what extent did it seem that sounds came from specific, different locations?"*
5. Touch Presence: *"How often did you want to or try to touch something you saw/heard?"*
6. Perceptual Framing (Movie vs. Window): *"Did the experience seem more like looking at the events/people on a movie screen or more like looking at the events/people through a window?"*
   (Higher scores indicated a more immersive, "window-like" experience.)

Participants completed this questionnaire after the entire session to reflect on their global experience across all four VR conditions.

DATA ANALYSIS

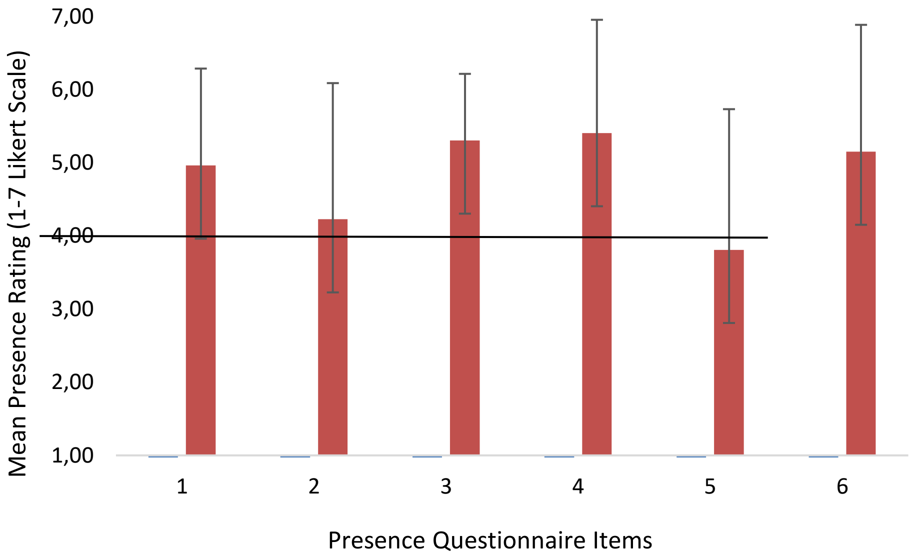
The data collected were analyzed using IBM SPSS Statistics. To explore participants' temporal judgments, frequency counts were used to assess the distribution of rankings for the perceived duration of each video (longest to shortest). To examine potential relationships between categorical variables, Chi-Square (X^2) tests of independence were conducted to determine whether there was a statistically significant association between content type (eventful vs. uneventful) and spatial frame of reference (egocentric vs. allocentric) in perceived duration judgments. In addition, Spearman's rank-order correlation was used to assess whether the order in which the videos were presented was associated with participants' ranked duration estimates, addressing possible order effects. Finally, a

Mann–Whitney U test was performed to compare spatial presence scores between participants with prior virtual reality (VR) experience and those without, as presence scores were not assumed to be normally distributed.

RESULTS

Mean ratings (± standard error) on a 7-point Likert scale for each spatial presence questionnaire item (N = 79). Items included perceptions of object/people presence (Item 1), avoidance reaction (Item 2), overall spatial presence (Item 3), sound localization (Item 4), desire to touch (Item 5), and perceived realism (Item 6).

Figure 1. *Mean Spatial Presence Ratings Across Questionnaire Items*

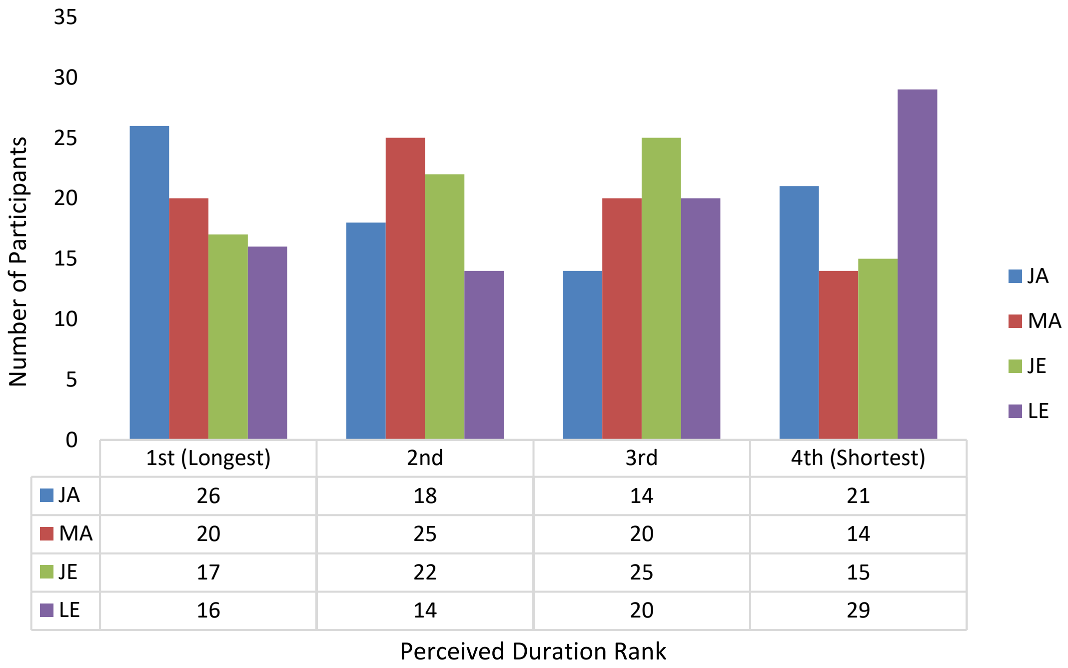


As shown in Figure 1, participants generally reported moderate to high levels of presence across most items, with several scores exceeding the median of 4.0 on the 7-point Likert scale. The horizontal line at 4.0 was added to facilitate interpretation of participant responses relative to the scale midpoint. Item 1 (Object and People Presence) received a mean score of M = 4.96 (SD = 1.32), with a median of 5.00, suggesting that participants perceived a relatively strong sense of co-presence with virtual people and objects. In contrast, Item 2 (Avoidance Reaction)—assessing participants' instinct to move away from approaching virtual objects—had a lower mean of M = 4.23 (SD = 1.86), with a median of 4.00, indicating a more moderate response.

Item 3 (Overall Spatial Presence) received one of the highest scores, M = 5.30 (SD = 0.91), with a median of 5.00, highlighting a strong subjective experience of "being there" within the VR environment. Notably, Item 4 (Sound Localization) had the highest mean rating of M = 5.41 (SD = 1.55), and a median of 6.00, suggesting that spatialized audio played a significant role in enhancing the immersive experience. Conversely, Item 5 (Desire to Touch) yielded the lowest mean rating, M = 3.81 (SD = 1.92), with a median of 4.00, indicating that participants felt relatively less inclined to physically interact with virtual objects. Finally, Item 6 (Window vs. Movie)—measuring perceived realism—was rated at M = 5.15 (SD = 1.73), with a median of 6.00, suggesting that participants experienced the VR content more as a "window into a real world" rather than simply watching a screen-based video.

Taken together, these findings demonstrate that participants reported a strong sense of spatial presence, particularly in terms of sound localization and overall presence. However, the lower tactile engagement (Item 5) indicates that virtual touch remains a limitation in immersive experiences like these.

Figure 2. *Frequencies of Each Video Across Four Perceived Duration Ranks from Longest (1st) to Shortest (4th).*



	1st (Longest)	2nd	3rd	4th (Shortest)
JA	26	18	14	21
MA	20	25	20	14
JE	17	22	25	15
LE	16	14	20	29

Figure 2 displays how frequently each of the four videos (JA, MA, JE, LE) was assigned to each perceived duration rank by participants (N = 79). As illustrated in the Figure 2, the video "JA" was most frequently ranked as the longest (1st position), while fewer participants placed it in the 2nd, 3rd, or 4th positions. The video "MA" showed a peak in the 2nd position, suggesting it was generally perceived as moderately long. The video "JE" was most commonly placed third, indicating a relatively balanced duration perception. In contrast, the video "LE" was most often ranked as the shortest (4th position), with the highest number of participants assigning it to this category. These patterns suggest that both content and spatial frame of reference may have influenced participants' subjective duration estimates.

Figure 3. *Number of Participants Selecting Each Content × Spatial Frame Condition as the Longest Perceived Video.*

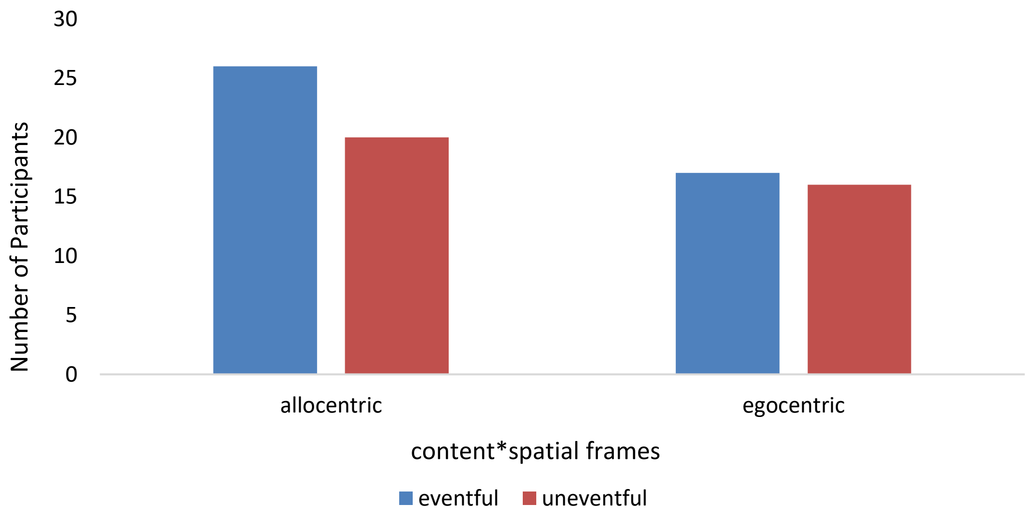


Figure 3 illustrates the number of participants who perceived videos as the longest based on their content (eventful vs. uneventful) and spatial reference frame (allocentric vs. egocentric). The distribution of participants' choices for the longest perceived video (N = 79) revealed that "JA" was selected most frequently, by 26 participants (32.9%), followed by "MA" with 20 participants (25.3%), "JE" with 17 participants (21.5%), and "LE" with 16 participants (20.3%). These values account for 100% of valid responses, excluding missing data, which comprised 16% of the total sample. A Chi-Square test of independence was conducted to examine the relationship between video content (eventful vs. uneventful) and spatial frame of reference (allocentric vs. egocentric) in relation to participants' rankings of the longest perceived video (N = 79). The results revealed no statistically significant association between content × spatial frame and participants' longest-duration judgments, $\chi^2(1, N = 79) = 0.194$, $p = .659$.

Figure 4. *Frequencies for Each Content × Spatial Frame Condition Selected as the Second Longest Video.*

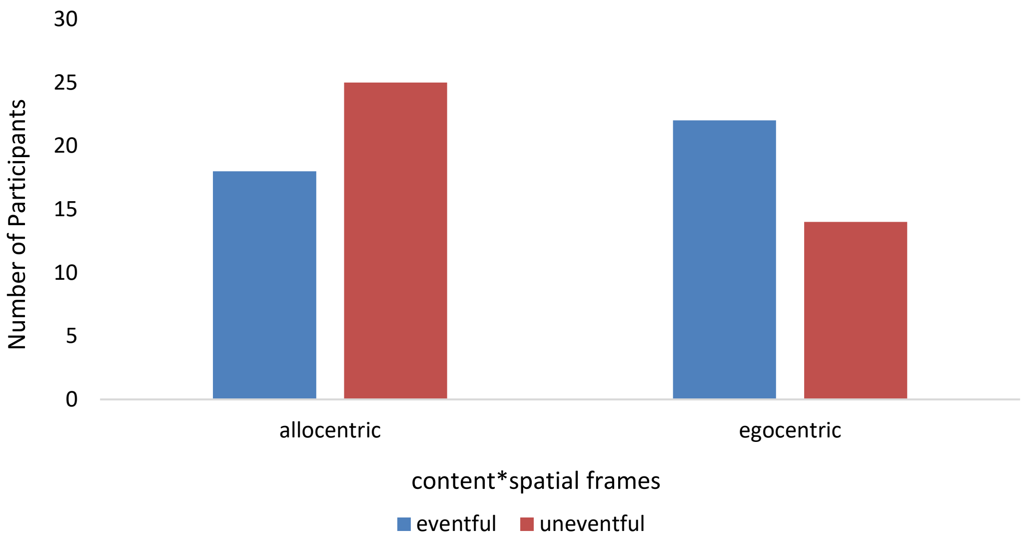


Figure 4 displays the number of participants who selected each content and spatial frame combination as the second longest in perceived video duration. Figure 4 illustrates a consistent trend in which allocentric videos were more frequently perceived as longer than egocentric ones, although the margin was narrower compared to first-order rankings. This suggests that allocentric spatial frames may generally contribute to an extended perception of time. In contrast, the influence of eventfulness in the content appeared less pronounced in second-order rankings. This may indicate that spatial framing exerts a more consistent effect on duration perception than content alone.

Descriptive analysis of participants' second-longest video choices (N = 79) revealed that "MA" was the most frequently selected, with 25 participants (31.6%), followed by "JE" with 22 participants (27.8%), "JA" with 18 participants (22.8%), and "LE" with 14 participants (17.7%). To explore the relationship between video content (eventful vs. uneventful) and spatial frame of reference (allocentric vs. egocentric) in participants' second-longest video selections, a Chi-Square test of independence was conducted (N = 79). The result indicated that there was no statistically significant association, $\chi^2(1, N = 79) = 2.91$, $p = .088$.

Although the result approached significance, it does not meet the conventional threshold of $p < .05$, suggesting only a marginal trend that may warrant further investigation with a larger sample.

Figure 5. *Frequencies for Each Content × Spatial Frame Condition Selected as the Third Longest Video*.

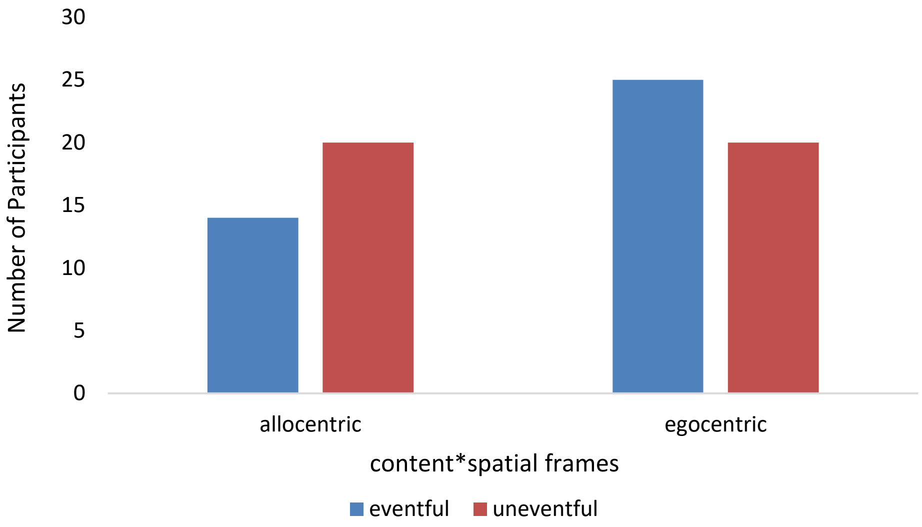


Figure 5 presents the frequency distribution of participants who perceived each video condition as the third longest in duration. The figure reveals a shift in perceived duration, with egocentric videos being more frequently associated with shorter durations compared to allocentric ones. In both eventful and uneventful conditions, participants tended to rank egocentric representations as shorter, with the egocentric–eventful condition receiving the highest frequency in the third-order ranking. This contrasts with earlier patterns, where allocentric frames were more dominant, suggesting a diminishing influence of allocentric perspectives on extended time perception in later rankings. Descriptive analysis of third-order rankings (N = 79) showed that "JE" was selected most often (n = 24, 30.4%), followed by "LE" (n = 21, 26.6%), "MA" (n = 20, 25.3%), and "JA" with the fewest selections (n = 14, 17.7%). To examine whether video content (eventful vs. uneventful) and spatial frame of reference (allocentric vs. egocentric) influenced participants' third-order video rankings, a Chi-Square test of independence was conducted (N = 79). The results showed no statistically significant association between content × spatial frame and third-order duration judgments, $\chi^2(1, N = 79) = 1.60$, $p = .206$.

Figure 6. *Distribution of Responses for Each Content × Spatial Frame Condition when Identifying the Shortest Video Perceived.*

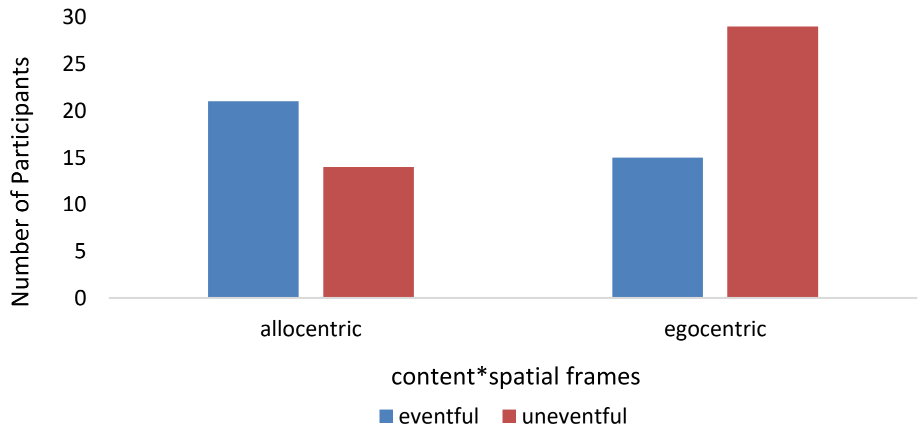


Figure 6 shows that the egocentric-uneventful condition was most frequently identified as the shortest in perceived duration. The figure illustrates a clear shift, with egocentric videos, particularly the egocentric–uneventful condition (LE), most frequently perceived as the shortest in duration. This pattern reflects a notable decline in the frequency of allocentric videos (both eventful and uneventful) from first to last rank, reinforcing the idea that egocentric perspectives may compress subjective time perception. Interestingly, LE, which had previously received fewer selections as the longest video, emerged as the most frequently selected as the shortest.

Descriptive analysis of the shortest video choices (N = 79) showed that LE was rated as the shortest by 29 participants (36.7%), followed by JA (n = 21, 26.5%), JE (n = 15, 18.9%), and MA (n = 14, 17.7%). This ranking pattern suggests a consistent perceptual bias toward shorter durations in egocentric–uneventful conditions, highlighting the impact of both spatial perspective and content sparsity. A Chi-Square test of independence was conducted to examine the relationship between video content (eventful vs. uneventful) and spatial frame of reference (allocentric vs. egocentric) in participants' selection of the shortest perceived video (N = 79). The result revealed a statistically significant association between content × spatial frame and shortest video perception, $\chi^2(1, N = 79) = 5.28$, $p = .022$. This finding suggests that the combination of content type and spatial reference frame had a meaningful impact on participants' judgments of which video felt shortest in duration.

Figure 7. *Distribution of Participants' Combined Video Ranking Orders*

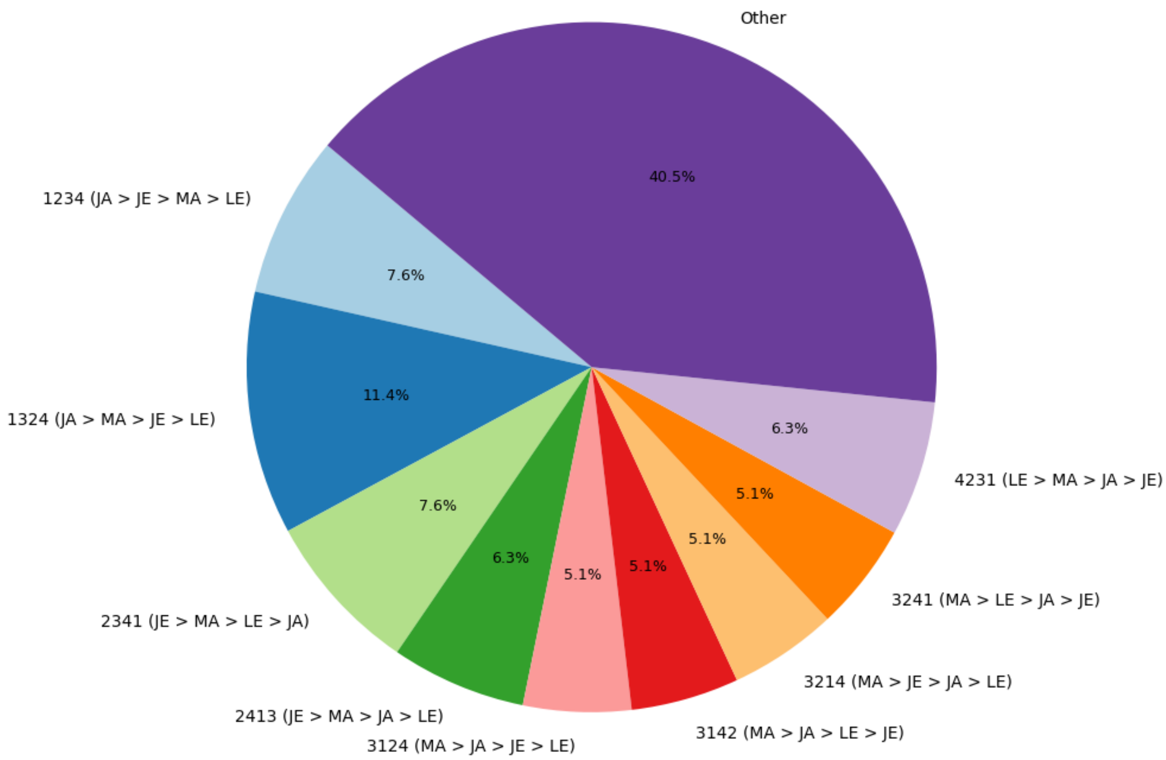


Figure 7 displays the percentage of participants who selected each unique ranking combination of the four videos. Only combinations endorsed by ≥5% of participants are individually labeled; the rest are grouped as "Other." The analysis revealed that the order "1324" (JA > MA > JE > LE) was the most frequently selected, representing 11.39% of participant responses. This was followed by "1234" (JA > JE > MA > LE) and "2341" (JE > MA > LE > JA), each chosen by 7.59% of participants. These orders suggest that participants tended to perceive the eventful-allocentric videos (e.g., JA) as longest and egocentric-uneventful videos (e.g., LE) as shortest.

Conversely, some ranking patterns such as "4213", "4123", and "3412" occurred in less than 2% of the sample and were grouped into the "Other" category, indicating these sequences were less preferred or more idiosyncratic. Overall, the combined ranking data supports the general trend that spatial framing—particularly allocentric perspectives—may contribute to the perception of extended duration, though individual differences in judgment remain evident.

RELATIONSHIP BETWEEN PRESENTATION ORDER AND PERCEIVED DURATION

To examine whether the presentation order of each video influenced how participants perceived their duration, Spearman's rank-order correlations were computed between the shown order and perceived rank order for each video (JA, MA, JE, and LE). Results are presented in Table 2.

Table 2. *Spearman's Rank-Order Correlations between Video Presentation Order and Perceived Rank*

Video	*ρ (rho)*	*N*	*p-value*
JA	0.124	79	.275
JE	0.043	79	.706
MA	0.114	79	.316
LE	0.144	79	.206

Table 2 presents the correlation coefficients (ρ), sample sizes (N), and associated p-values for each video. All correlations were weak and statistically non-significant, suggesting that the order in which a video was shown did not systematically affect participants' time judgments. These findings indicate that presentation sequence alone did not significantly influence participants' duration judgments, supporting the interpretation that other factors (e.g., content and spatial framing) may have played a more substantial role.

SPATIAL PRESENCE RATINGS AND PRIOR VR EXPERIENCE

To determine whether previous experience with virtual reality (VR) influenced participants' sense of spatial presence during the video viewing, a series of Mann–Whitney U tests were conducted comparing presence scores for each video between participants with and without prior VR experience. Presence ratings were derived from a modified version of the Temple Presence Inventory. Table 3 displays the test statistics (U and Z values) and associated p-values comparing presence scores between participants with and without prior VR experience for each video. Results in Table 3 indicated no statistically significant differences in perceived spatial presence between the two groups for any of the four videos.

Table 3. *The Effect of Previous Experiences with Virtual Reality (vr) on participants' Spatial Presence Perception while Watching Videos*

Video	*U*	*Z*	*p (2-tailed)*
JA	167	–0.063	.95
JE	152	–0.524	.60
MA	163.5	–0.170	.865
LE	125	–1.366	.172

These findings suggest that prior exposure to VR technology did not significantly influence participants' subjective feelings of spatial presence within the experimental virtual environments. This reinforces the robustness of the stimuli design in eliciting spatial immersion regardless of individual differences in VR familiarity.

DISCUSSION

This study investigated how spatial framing (egocentric vs. allocentric) and content type (eventful vs. uneventful) within virtual reality (VR) environments influence subjective duration judgments and the sense of spatial presence. Additionally, we evaluated how prior VR experience may modulate the perceived immersion using a modified version of the Temple Presence Inventory.

SPATIAL PRESENCE IN VR

Participants reported strong spatial presence across VR conditions, particularly in terms of object and people presence as well as auditory localization, confirming the effectiveness of the immersive setup. However, tactile presence received lower ratings, suggesting a sensory gap in current VR implementations. This finding is consistent with previous literature highlighting the importance of multi-sensory integration in generating presence (Slater & Wilbur, 1997). The lack of tactile stimuli likely limits full embodiment and highlights an important area for future development in VR technology. Enhanced haptic feedback may improve overall presence and affect temporal perception more robustly.

PERCEIVED DURATION AND SPATIAL FRAMING

Although the majority of statistical comparisons between conditions were non-significant, meaningful trends emerged. Videos framed allocentrically particularly those with eventful content were more likely to be perceived as longer, especially in first and second ranking orders. This aligns with prior findings suggesting that motion-rich and spatially complex scenes are associated with time dilation effects (Gorisse et al., 2017; Verde et al., 2019).

Interestingly, egocentric videos, especially those depicting uneventful content, were consistently perceived as shorter, and the egocentric–uneventful condition was the only one to produce a statistically significant result in terms of being selected as the shortest. This may be due to egocentric framing inducing a stronger sense of embodiment and immersion, thus diminishing awareness of time passage (Gorisse et al., 2017). Moreover, the perceived time difference diminished in later ranking orders (3rd and 4th), suggesting that the influence of spatial frame and content may attenuate with repeated exposure or cognitive fatigue, or that participants relied less on spatial cues and more on heuristic impressions as the task progressed.

INTERACTION OF PRESENTATION ORDER AND DURATION JUDGMENTS

A series of Spearman's rank-order correlations examined whether the order in which videos were presented influenced participants' perceived duration rankings. Across all four videos (JA, JE, MA, LE), correlations were weak and statistically non-significant. These results suggest that presentation order did not meaningfully affect temporal judgments, reinforcing the interpretation that content and spatial characteristics were more influential than sequence effects.

SPATIAL PRESENCE AND PRIOR VR EXPERIENCE

Contrary to expectations, a Mann–Whitney U test revealed no significant differences in spatial presence scores between participants with and without prior VR experience. Presence ratings remained comparably high across both groups, indicating that the immersive experience was effective regardless of participants' previous exposure to VR. This finding has practical implications: well-designed VR environments can elicit strong subjective presence even in novice users, supporting the use of VR for research and applications in populations without prior VR familiarity.

CONCLUSIONS AND FUTURE DIRECTIONS

This study contributes to our understanding of how spatial frames and content interact to shape time perception and spatial presence in VR. These findings offer important insights into the design and application of immersive technologies. For instance, allocentric framing and eventful content may be leveraged to enhance perceived duration, which could benefit training simulations where prolonged engagement or deeper memory encoding is desired (e.g., firefighting or surgical training). Conversely, egocentric–uneventful scenarios may serve to reduce the perceived length of an experience, which could be useful in therapeutic VR settings where prolonged exposure might otherwise feel overwhelming (e.g., exposure therapy for phobias or pain distraction protocols).

In addition, these findings may inform clinical and patient-centered applications. For example, patients undergoing lengthy medical treatments such as chemotherapy, dialysis, or physical rehabilitation often experience extended periods of discomfort or inactivity. Egocentric and calming VR content in these contexts may help reduce the subjective duration of such procedures, improving patient comfort and compliance. Conversely, when a sense of extended duration is desirable such as in cognitive training or mindfulness interventions allocentric and eventful VR content might help amplify perceived time, increasing the subjective richness of an experience without extending its actual duration. These insights highlight the potential for tailored VR content design in healthcare and therapy settings to enhance patient experience and engagement.

Furthermore, the finding that VR-naïve users reported comparable spatial presence supports the broader accessibility of VR technologies across age groups and populations unfamiliar with immersive systems. Designers developing content for cognitive training, education, or therapy can focus on spatial and narrative elements without requiring prior user expertise with VR interfaces. Although most statistical effects were not significant, emerging trends suggest:

- Allocentric framing and eventfulness may promote time dilation
- Egocentric framing may compress perceived duration, possibly through increased embodiment
- Content and spatial frame may influence time judgments independently of video order
- VR-naïve users can still experience strong spatial presence

LIMITATIONS

As a thesis study, the sample size was constrained by available resources, limiting generalizability. The use of pre-existing YouTube VR videos, rather than custom-designed stimuli, constrained experimental control. Additionally, temporal judgments were assessed behaviorally, without neurophysiological or physiological correlates.

RECOMMENDATIONS FOR FUTURE RESEARCH

Building on the current findings, future research should aim to refine and expand our understanding of how spatial framing and content modulate temporal perception and presence in VR. First, incorporating custom-designed VR content with tight control over pacing, camera movement, and visual complexity would allow for more precise manipulation of spatial and temporal variables. This would overcome limitations posed by using pre-existing videos and allow for experimental designs that directly isolate key features.

Second, increasing sample size and demographic diversity is essential to improve the generalizability of results, especially considering that factors such as age, gaming experience, or cognitive style may moderate VR-related effects. Larger datasets would also allow for more robust statistical testing and interaction modeling.

Third, integrating physiological and neurophysiological measures—such as EEG, galvanic skin response (GSR), or heart rate variability could provide insights into the underlying mechanisms of perceived time distortion and immersion. These methods would allow researchers to move beyond self-report and link subjective experience to objective neural and autonomic activity.

Additionally, future studies should explore how attentional load, memory encoding, and emotional salience interact with spatial framing to influence perceived duration. For instance, emotionally charged or cognitively demanding scenes might differentially affect time judgments depending on the viewer's spatial perspective. Finally, it would be valuable to disentangle the roles of individual sensory modalities—such as visual, auditory, and haptic input—in driving spatial presence and time estimation. Multisensory VR environments can enhance presence but understanding how each modality contributes will help tailor applications in domains like rehabilitation, cognitive training, and virtual storytelling.

FINAL REMARKS

This research underscores the importance of spatial framing and content in shaping temporal perception in immersive environments. These findings suggest that VR developers can manipulate user experience not only through narrative pacing but also through perspective and sensory immersion. By combining virtual reality with cognitive paradigms, we can better understand how humans construct internal representations of time and space—and how these constructions are modulated by technology. This has broad implications for fields ranging from education and rehabilitation to entertainment and mental health interventions, where time perception and immersion are critical components of effectiveness.

AUTHOR CONTRIBUTION

First author has made substantial contributions to conception and design, or acquisition of data, or analysis and interpretation of data. The second author, as the supervisor of the study, has been involved in drafting the manuscript or revising it critically for important intellectual content. Both authors have given final approval of the version to be published.

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