Balancing Accuracy and Embodiment: A Hybrid Perspective for Complex Visuomotor Tasks in VR

Dennis Dietz
LMU Munich
Munich, Germany
dennis.dietz@ifi.lmu.de

Sebastian Walz
LMU Munich
Munich, Germany
sebastian.walz@campus.lmu.de

Sven Mayer
TU Dortmund University
Dortmund, Germany
Research Center Trustworthy Data Science and Security
Dortmund, Germany
info@sven-mayer.com

Andreas Butz
LMU Munich
Munich, Germany
butz@ifi.lmu.de

Matthias Hoppe
Keio University Graduate School of Media Design
Yokohama, Japan
matthias.hoppe@kmd.keio.ac.jp

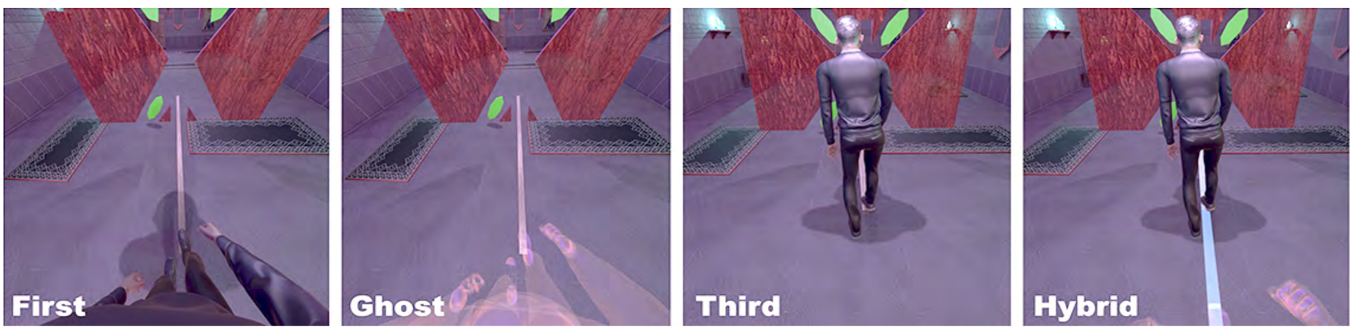

Figure 1: Overview of our four experimental perspective conditions. From left to right: The within-character views *First* and *Ghost* induced the strongest sense of presence and embodiment. In contrast, the out-of-character view *Third* provided a detached, strategic overview of the avatar. Our novel *Hybrid* perspective was ultimately the most preferred, as it combined the strategic overview of the *Third* view with the immediate limb feedback of a within-character view.

Abstract

Visual perspective is a crucial design factor in Virtual Reality (VR). Especially when complex motor tasks are involved, it can affect both objective performance and subjective experience. We compared four visual perspectives (First-Person view, translucent Ghost view, Third-Person view, and Hybrid view) in a user study (N=20) involving different difficulties in a balancing game. Our findings reveal complex tradeoffs between the sense of embodiment, performance, and preference: The preferred Hybrid perspective offered a significant stability advantage for low task difficulty. However, this benefit vanished with increasing physical demand, revealing a speed-accuracy trade-off where external views required longer completion times. Ego-centric perspectives (First and Ghost) induced a stronger sense of embodiment and presence, but were less preferred. Participants' choice was not determined by representational fidelity but by pragmatic considerations of perceived utility. As perceived effectiveness can overrule objective performance and subjective experience, the choice of perspective is an important factor for future training and rehabilitation applications in VR.

CCS Concepts

• **Human-centered computing** → **Virtual reality**; **Empirical studies in HCI**; • **Applied computing** → *Interactive learning environments.*

Keywords

Virtual Reality, Perspective Continuum, Hybrid Perspective, Embodiment, Avatars, Motor Control

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1 Introduction

Advancements in virtual reality (VR) technology have greatly improved the immersive features, such as 8k displays and full-body tracking, of current systems. This progress directs research in HCI to focus on the subtle psychological elements of user experience (UX) [5]. In VR, the user's visual viewpoint is essential in shaping the nature of embodied interaction. The usual method is to adopt a first-person perspective (1PP), based on the belief that imitating reality enhances the user's sense of presence and leads to better motor performance. However, this assumption raises questions. Our visual perception in VR is fundamentally different from the real world, due to technological limitations like narrow field of view and sensory conflicts [60]. These perceptual variations clearly lead to measurable performance problems, such as longer movement execution times and greater perceived difficulty of tasks, even for straightforward motor activities [47]. Consequently, the ability to transfer skills learned in VR to real-life situations is not guaranteed and could even be harmful under suboptimal design conditions [41]. This inconsistency necessitates a reevaluation: if the most 'natural' viewpoint isn't always the most efficient, what alternatives are available? This question arises not only from the challenges of simply mimicking reality but also from growing evidence that the true power of VR lies in going beyond it. Meta-analyses show that well-designed Virtual Reality Training can exceed traditional physical training for specific motor skills, particularly because VR allows for the structured application of motor learning principles in a controlled, immersive environment [36]. This exploration reveals a fundamental design challenge between the user's subjective experience of embodiment and their actual motor skills in the virtual environment, emphasizing the importance of investigating various perspectives.

This design conflict is rooted in the multifaceted nature of embodiment itself, the feeling of owning, controlling, and being located within a virtual avatar (ownership, agency, self-location) [30]. Since effective motor control relies heavily on a virtual body [47], embodiment has traditionally been linked strictly to the 1PP. However, this view is increasingly challenged by evidence that other viewpoints offer distinct advantages, such as improved spatial awareness in a third-person perspective (3PP) [20]. In this context, recent work suggests that users can maintain a high sense of agency over a 3PP avatar even without a strong sense of ownership, effectively treating it as a directly controlled tool rather than their own body [55]. This functional separation supports calls to prioritize utility over perfect simulation [17]. Following this logic, Hoppe et al. [23] postulate a perspective continuum ranging from within-character to out-of-character perspectives, that decouples technical viewpoints from subjective experience, offering a broader design space to explore alternative visual configurations beyond the traditional approaches.

This evolving understanding reveals a crucial research gap. It remains unclear how distinct visual configurations along this continuum, from standard 1PP to external views, impact the delicate balance between a user's subjective experience (e.g., embodiment) and their objective motor performance. While the successful transfer of skills to the real world remains a key objective [41], understanding this interplay within the virtual environment itself is fundamental. Specifically, we lack knowledge on how users themselves weight this trade-off: Do they prefer the immersion of 1PP or the functional clarity of external views when faced with a complex motor task? Therefore, a pressing need exists to systematically investigate how shifting perspectives affects both performance metrics and subjective perception. With this, we investigate this interplay with the following research questions:

RQ1 How does shifting visual perspective along a within-character to out-of-character perspective continuum impact a user's objective motor performance?

RQ2 How does this shift in perspective modulate the user's subjective experience?

RQ3 How do users balance objective performance against subjective UX when choosing a visual perspective for a complex VR motor task?

To answer these questions, we needed a motor task that is both a physical challenge and highly sensitive to manipulating the visual perspective. We have therefore opted for a balancing game in VR that combines postural stability with motor accuracy. The need to maintain balance while coordinating precise movements requires a constant integration of visual feedback and proprioceptive body perception and is, therefore, the ideal application for investigating the effects of different visual representations of one's own body. In this setting, we systematically compared four visual perspectives: a conventional ego-centric view (*First*), a view with a translucent ghost avatar (*Ghost*), also seen as a conventional ego-centric view, a classic exo-centric view (*Third*) and a novel hybrid view (*Hybrid*), which simultaneously combines elements from the both views. Crucially, all four conditions maintained an ego-centric control frame, where physical movements are directly mapped to the avatar, to ensure comparability across the perspective continuum. This approach allows us to measure the effects of these modalities on presence, task performance, enjoyment, and perceived workload, while interviews provided deeper insights into users' subjective preferences. The novelty of this work lies in the systematic investigation of these unconventional perspectives combined with a physically demanding whole-body interaction. In doing so, we contribute to understanding the perspective continuum postulated by Hoppe et al. [23] and its effects on UX in complex motor tasks.

Our results reveal a complex interplay between performance and experience: while traditional perspectives fostered the strongest sense of presence, users pragmatically preferred views that offered superior spatial information, even at the cost of immersion. Hence, we challenge the assumption that ego-centric views are inherently optimal for complex VR motor tasks. Our contributions are:

- **Design Space Exploration:** We introduce a novel *Hybrid* perspective that augments spatial overview with ego-centric limb feedback to bridge the gap between immersion and utility.
- **Empirical Evidence:** Results from a user study ($N = 20$) demonstrating a clear mismatch between embodiment and preference. Users prioritized the functional utility of external views (*Hybrid*, *Third*) over the higher immersion ratings of internal views (*First*, *Ghost*), deliberately sacrificing realism for better spatial information.

- **Implication for VR Training:** We demonstrate that in tasks requiring both stability and precision, the choice of perspective is not a binary one (Immersion vs. Overview) but a user-dependent trade-off. This highlights the necessity of flexible viewing options rather than a single "optimal" standard.

2 Related Work

To contextualize our research, we ground our work in three core areas of HCI and VR research that directly inform our study design and research questions. We begin by reviewing the state of the art in Visual Perspectives in VR, establishing the foundations of ego-centric and exo-centric views and the evolving concept of a perspective continuum. Subsequently, we examine the literature on Subjective UX in VR, focusing on key metrics such as presence, embodiment, and cognitive workload, which are essential for addressing our second and third research questions. Finally, to provide a solid basis for interpreting our objective performance data, we survey relevant work on Balance Training and Motor Control in VR, which explains the unique challenges and opportunities of using balance-related tasks for motor skill research.

2.1 Visual Perspectives in Virtual Reality

Traditionally, VR applications have predominantly adopted the ego-centric view, aligning with the natural human experience of the world through one's own eyes. This common practice fosters presence and embodiment, as the user's movements are directly mapped onto the virtual environment [23]. The ego-centric view is frequently favored for natural interactions and precise manipulations, proving effective particularly in static to moderately dynamic tasks [1]. Studies confirm that ego-centric view facilitates more accurate interactions [20] and is more efficient for navigation tasks [40, 58]. In contrast, the exo-centric view offers significant advantages in spatial awareness, providing a more comprehensive overview of the environment [20]. This can enhance the detection of peripheral objects and the strategic planning of movements [25]. Furthermore, it has been observed that exo-centric view can reduce simulator sickness in specific scenarios [45]. However, it is crucial to understand that the choice of the optimal perspective is heavily dependent on the specific task at hand [1, 31].

Current research and design practices of perspectives in games differ from perspectives in VR, largely due to the unique role of embodiment in immersive environments. While we have some basic understanding of these elements, a holistic understanding of their connection needs to be further developed and cannot be simply transferred from screen-based media [51]. Recent findings show that actively alternating between ego-centric and exo-centric views is compatible with a strong sense of embodiment [18], or that switching to an exo-centric view can even result in a higher sense of embodiment under certain conditions [39]. These findings indicate that the relationship between perspective and UX is not a binary choice between two extremes, but rather a nuanced gradient.

To better describe this spectrum, Hoppe et al. [23] challenge the traditional notion of strictly separating ego-centric and exo-centric views, instead proposing a perspective continuum in VR, that focuses the perception of the individual rather than discrete technical descriptions of the implementation of virtual camera positions. They suggest a precise terminology that decouples viewpoint from control, distinguishing between a **Within-Character view** (camera inside the avatar) and an **Out-of-Character view** (camera outside). This is further delineated from the control scheme, which can either be Within-Character (body-mapped movements) or Out-of-Character (e.g., gamepad control). This taxonomy provides a richer framework for analyzing UX, especially in cases where view and control do not align.

While our study builds on this continuum model, for the clarity of our experimental conditions, we use the terms *First*, *Ghost*, *Third*, and *Hybrid* to refer to specific points along the perspective continuum. Critically, while we vary the visual viewpoint, we hold the control scheme constant: all conditions in our study employ within-character (body-mapped) control to ensure comparable agency. This approach allows us to investigate the fundamental influence of perspective on embodiment and presence, both of which are integral components of a high-quality immersive VR experience [40, 45].

2.2 Subjective User Experience in VR

The subjective UX in VR encompasses crucial cognitive and emotional states, especially relevant for motor and balance tasks [4, 21]. Central to this experience are *embodiment*, the feeling of owning, controlling, and being located within a virtual body, and *presence*, the subjective sensation of "being there" [30, 52].

To understand the effects of perspective, it is crucial to distinguish between the three core components of embodiment: *Body Ownership* (the feeling that the body is one's own), *Agency* (the feeling of controlling it), and *Self-Location* (the volume in space where one feels located) [30, 48, 50]. Prior research identifies spatial co-location as a primary requirement for inducing strong body ownership and self-location [38]. Consequently, the unified sense of embodiment is traditionally linked to within-character views (1PP), which align all three components [20, 35].

In contrast, switching to an out-of-character view fundamentally challenges this unified understanding of embodiment. By spatially decoupling the physical body from the virtual avatar, out-of-character view inherently breaks *Self-Location* and significantly weakens *Body Ownership* [20, 38]. However, *Agency* remains robust, as it is primarily driven by visuomotor synchronicity rather than spatial alignment [43]. Smith et al. [55] demonstrated that users in out-of-character views can retain high agency by treating the avatar as a controlled tool, even as the other pillars of embodiment crumble. This functional separation supports calls to rethink the primacy of embodiment [13]. Forster et al. [17] argue that for many applications, the functional utility of the virtual body, its ability to support action, may be more critical than maintaining a strong sense of ownership. Nevertheless, since 1PP uniquely supports *all three* components simultaneously through spatial alignment, it remains the theoretical baseline for the strongest overall embodiment.

Regarding visual representation in within-character views, realism is not strictly required; Martini et al. [37] demonstrated that ownership is robust even for transparent limbs, provided visuomotor synchronicity is maintained. Similarly, Won and Zhou [62] found that self-resemblance of the user's avatar does not necessarily affect movement patterns, further suggesting that functional feedback might be more critical than visual fidelity. Expanding on this, Döllinger et al. [14] argue that highly salient opaque avatars in 1PP can sometimes even distract from internal body awareness, suggesting that a reduced visual dominance (e.g., translucency) might facilitate a stronger focus on the proprioceptive cues that are critical for motor tasks.

While embodiment describes the user's connection to the avatar, cognitive workload measures the mental cost of the interaction [22, 58]. This is particularly relevant for multi-perspective interfaces (MPI), where external views can increase cognitive demand due to spatial decoupling [2, 58]. Yet, recent work by Dufresne et al. [15] suggests that users can adapt to non-naturalistic avatar representations without breaking immersion, provided the visual feedback remains coherent with the functional affordances of the task.

Ultimately, the interplay of these factors determines enjoyment and engagement, often evaluated via the Games Experience Questionnaire (GEQ) [24] or the Physical Activity Enjoyment Scale (PACES) [27]. Perspectives play a key role: within-character views can foster awe and presence, whereas out-of-character views may reduce simulator sickness, improving overall comfort [45]. Despite these known links, current research frequently examines these elements in isolation [14]. A notable gap persists in comprehensively understanding the inherent trade-offs between embodiment, workload, and enjoyment in diverse VR interaction scenarios [23, 56].

Our study tries to bridge this gap by holistically evaluating a spectrum of subjective measures, including cognitive workload and enjoyment, in the context of varying visual perspectives.

2.3 Motor Accuracy and Postural Control in VR

VR has emerged as a promising tool for training precise motor control and balance, particularly in neurorehabilitation and fall prevention, by offering motivating and personalized therapeutic applications [3, 54, 57]. VR-based exergame protocols have significantly improved postural balance and transferred acquired skills to real-world locomotion [19, 32, 36]. Human postural control is a complex process, regulated by the interplay of vestibular, visual, and somatosensory systems [12]. VR environments can specifically manipulate this sensory integration, with visual input often leading to an increased reliance on visual information during balance tasks [19, 63]. The congruence of multimodal information, especially visuomotor synchronicity, is critical for enhancing motor performance [44, 57]. However, maintaining this congruence is challenging in non-standard perspectives. Research suggests that out-of-character views can dissociate visual flow from vestibular signals, potentially destabilizing postural control [20]. This makes the choice of perspective a critical variable for balance safety and precision. Accurate assessment of dynamic balance performance relies on comprehensive full-body tracking, which synchronizes virtual avatars with user movements [54, 57, 59]. Biomechanical metrics like foot placement accuracy, head and waist oscillations, and center of pressure (CoP) displacement are captured using technologies such as VR trackers and Azure Kinect DK [12, 19]. The visual representation of virtual feet is crucial for precise movements [32, 57]. VR-supported balance training often integrates complex motor tasks and dual-task paradigms to include cognitive load and simulate real-world challenges, with cognitive load known to affect gait parameters [49, 59]. In this context, the design of visual guidance is crucial; recent work shows that continuous visual cues specifically support better movement planning and reactivity in such exergames [26].

Despite the growing body of VR balance research, most studies traditionally employ within-character views [20, 23]. There is, however, limited research on how alternative visual perspectives, particularly the out-of-character views, affect postural control in complex tasks [10, 11, 54]. The universal recommendation for either within-character view or out-of-character view remains debated [11, 20], and a significant research gap exists regarding full-body coordination in tasks with perspective manipulation and its impact on motor performance and UX [23, 57]. Interestingly, some studies on movement guidance suggest that external and multi-view perspectives can lead to more accurate movements than within-character view across various complexities [16].

2.4 Summary and Hypotheses

While prior research has established the general trade-offs between first- and third-person perspectives, the interplay between these views and complex motor control remains under-explored. To address this gap, and complementary to the high-level Research Questions posed in the Introduction, we formulated three specific hypotheses. For each, we derive our prediction directly from the identified literature:

- **H1 Spatial Performance.** We hypothesize that perspectives affording an out-of-character view (*Third*, *Hybrid*) will lead to significantly fewer wall collisions compared to within-character views (*First*, *Ghost*). *Rationale:* As discussed in Section 2.1, out-of-character viewpoints provide a superior overview of the environment and the avatar's relation to it, enhancing the detection of peripheral obstacles and trajectory planning [20].
- **H2 Postural Stability.** We hypothesize that perspectives providing within-character visual feedback (*First*, *Ghost*) will result in superior postural stability (reduced oscillation) compared to the standard *Third* person view. *Rationale:* Following Section 2.3, out-of-character views can dissociate visual flow from vestibular signals, creating sensory conflict that increases the biomechanical cost of maintaining balance [6, 12]. Minimizing this conflict via within-character alignment should therefore stabilize posture.
- **H3 Embodiment.** We hypothesize that perspectives with a within-character viewpoint (*First*, *Ghost*) will elicit significantly higher ratings of Body Ownership, Agency, and Self-Location compared to detached viewpoints (*Third*, *Hybrid*). *Rationale:* Based on Section 2.2, spatial co-location is the primary requirement for inducing strong body ownership and self-location [38]. While agency can be maintained in external views, the unified alignment of all three components in within-character views is expected to yield the highest overall ratings.

Figure 2: The core gameplay of our VR balance game, inspired by the "Brain Wall" concept. From an out-of-character view, the participant controls an avatar that must adopt a specific body pose to fit through the X-shaped cutout in the approaching red wall, while simultaneously collecting the green orbs to successfully complete the trial.

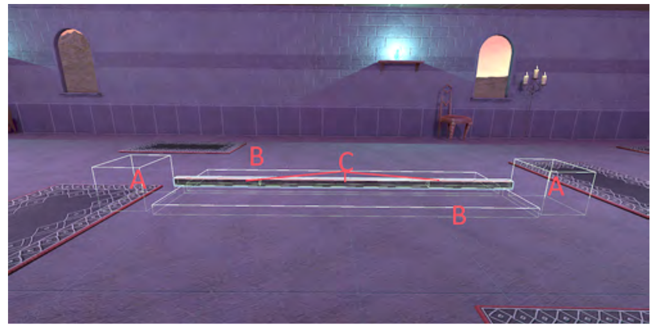

Figure 3: Virtual environment setup showing the collision detection system for the balance beam. Area A marks safe start and end platforms. Area C (active beam) is divided into a central gameplay zone flanked by two 25% stabilization zones. Area B detects step-offs via floor colliders.

3 Concept & User Study

To explore how visual perspective design can support both functional task performance (motor accuracy and postural control) and immersive UX, we conducted a user study in a novel VR balance game. Specifically, we investigated whether modifying traditional viewpoints to address limitations like occlusion in the *First* view and the lack of co-located hand and arm visualization feedback in the *Third* view could optimize the trade-off between performance and embodiment. Our study employed a **within-subjects 4 x 2 factorial design** manipulating two independent variables:

Perspective (4 levels). We compared four distinct viewpoints intended to represent points along the perspective continuum [23]: *First*, *Ghost*, *Third*, and *Hybrid*. The presentation order of these perspective blocks was counterbalanced using a 4×4 Latin square to mitigate learning and fatigue effects.

Difficulty (2 levels). Within each perspective block, we manipulated motor complexity by varying the number of required contact points (collectibles) per trial between an easy (*2-collectibles*) and a hard (*3-collectibles*) condition. The order of difficulty trials was systematically balanced (see Table 1). Measurements included in-game performance, motion-based balance measures, and subjective questionnaire data on presence, workload, and embodiment.

3.1 VR Game Adaptation of Brain Wall - Nokabe

The concept for our VR exercise game draws inspiration from the Japanese variety show component "Brain Wall" (also known in Japan as "Nokabe"). This format was selected because it inherently challenges spatial reasoning and precise full-body posture control within a continuous movement flow, which are mechanics that have been shown to be highly effective for immersive exergames [26]. We designed the virtual environment with a stylized, non-photorealistic aesthetic to ensure functional clarity and minimize visual distractions (see Figure 1). Key gameplay elements were color-coded for intuitive understanding: collectibles were rendered in bright green, while the hazardous parts of the approaching wall were rendered in red. To ensure the balance area was evenly lit while maintaining a consistent and naturalistic environment, the scene was illuminated by multiple point lights distributed along the room. This lighting setup casts dynamic shadows for all objects, including the avatar (except in the *Ghost* condition due to translucency). Even though the visual style was unique, we focused on realistic movements (matching avatar actions and physics) to ensure effective motor control. This also helped prevent the unsettling feeling of the uncanny valley, which arises from bodies that people struggle to relate to [53]. To further facilitate the user's connection with the co-located virtual body, participants could choose between two gender-matched avatars (male/female), both designed with a consistent stylized aesthetic to ensure comparable embodiment conditions across participants (see Figure 1 and Figure 2).

Our adaptation combines this concept with a balance task: Participants had to balance on a physical wooden beam, which adds a haptic feedback component, while being present in this VR game. The core challenge was to adapt their body poses to fit through specific, X-shaped cutouts in the approaching wall, which were designed to require distinct arm and leg positions. To drive motor complexity, we embedded green collectibles within these cutouts (see Figure 2). This design not only guided participants into the required poses but also provided a clear success metric. A trial was considered successfully passed if the participant collected all orbs without touching the surrounding wall. In this case, the wall would disappear, and the participant could proceed to the end of the beam to complete the round.

We defined clear failure conditions to ensure consistent measurement. If a participant touched the wall, this was counted as a *walltouch*. After three *wall touches*, the trial was considered failed, the wall disappeared, and the participant was instructed to finish the walk to the other side. Similarly, if a participant stepped off the physical beam to regain balance while the wall was approaching, the wall would reset to its starting position and begin its approach again after a 1.5-second pause. This ensured that the pose could only be performed while maintaining balance.

3.2 Perspectives

Our selection of the four Perspective conditions was driven by specific perceptual challenges and trade-offs (e.g., spatial awareness vs. ownership) identified in prior literature [20, 23]. We aimed to test design interventions that address the inherent limitations of traditional viewpoints while spanning the continuum from within-character to out-of-character views. For the within-character view (*First*), the primary limitation is visual occlusion of the environment by the user's own body. To address this, we introduced the *Ghost* condition (translucency) to improve environmental visibility while maintaining spatial co-location [14]. For the out-of-character view (*Third*), the primary limitation is the loss of immediate proprioceptive connection. To address this, we designed the *Hybrid* condition, which augments the external view with proximal limb feedback. Crucially, we rendered these proximal limbs translucent (as in *Ghost*) rather than opaque to provide this additional feedback without introducing new visual clutter, leveraging the finding that transparency does not necessarily break ownership [37]. All conditions maintained a consistent *within-character control scheme* (direct mapping of movements), differing only in their visual feedback. They are defined as follows:

First-Person Perspective (First): This condition represents the standard *within-character viewpoint*, where the camera is located at the avatar's eye level and a fully rendered, opaque body is visible. We included this condition as the ecological baseline for embodiment, as prior research consistently identifies high-fidelity 1PP as the optimal viewpoint for inducing body ownership and agency [38]. Additionally, 1PP typically affords superior precision for close-range interactions compared to external views [20]. However, this perspective inherently introduces visual occlusion, where the user's own virtual body can obstruct task-relevant information (e.g., the balance beam), a limitation our other conditions explicitly aim to address.

Translucent-Avatar Perspective (Ghost): The *Ghost* condition maintained the *within-character viewpoint* (camera at eye level) but rendered the avatar translucent. We selected this design to mitigate the visual obstruction of the balance beam while maintaining a spatial reference for the body. This approach leverages the robustness of body ownership for transparent limbs and aligns with the finding that non-naturalistic representations can effectively support embodied interaction if functionally coherent [15, 37]. By rendering the avatar translucent, we aimed to reduce visual dominance, preserving sufficient cues for limb positioning without occluding the task environment [12].

Third-Person Perspective (Third): This condition implemented a classic *out-of-character viewpoint* by positioning the camera two meters behind and slightly above the avatar. The camera position was rigidly linked to the user's head orientation (following camera), ensuring that the user's gaze direction consistently controlled the view vector, similar to the "alternating" setup described by Galvan Debarba et al. [18]. The avatar itself remained fully opaque. This created a clear spatial separation between the user's point of view and the controlled body. Gorisse et al. [20] showed that 3PP significantly improves spatial awareness and trajectory estimation compared to *First*, which is advantageous for anticipating the approaching wall in our task. However, this comes at the cost of reduced precision for fine motor interactions, as the user must mentally map their physical limbs to the distant avatar [20].

Third-Person Hybrid with Ghost Hands and Feet (Hybrid): Our novel *Hybrid* perspective presents both an Out-of-Character view (identical to the *Third* condition's following camera) of the main avatar and a *Within-Character view* simultaneously. The user's single set of body movements concurrently drives both the third-person avatar and a set of translucent ghost hands and feet rendered in the immediate foreground. This design combines the superior spatial awareness of the *Out-of-Character view* with the direct, first-person limb feedback of a *Within-Character view* [20]. We specifically superimposed translucent 'ghost' hands and feet because prior work indicates that foot visibility is critical for accurate self-motion perception and that the embodiment of virtual feet is directly correlated with motor performance in balance tasks [33, 57]. This dual-representation scheme provides both an external body reference and proximal cues for the balance beam without the visual clutter of a full first-person body. By aligning the visual feedback directly with the task's affordances (balance and collision avoidance), we leverage the finding that users can maintain coherent interaction even with non-naturalistic avatar representations [15]. We developed each of these perspectives to provide distinct experiential insights and to enable a systematic comparison in our VR setup (see Figure 1).

3.3 Task Difficulty

To evaluate performance under varying motor demands, we manipulated task Difficulty by varying the number of required contact points (collectibles). We defined four distinct limb configurations, labeled a–d:

Easy (2-Collectibles): Required the user to reach two target locations simultaneously. This allowed two limbs to remain free for stabilizing the body on the balance beam.
a: Right Hand + Left Foot (RH+LF)
b: Left Hand + Right Foot (LH+RF)

Hard (3-Collectibles): Required reaching three targets simultaneously. This constrained the upper body completely and left only one leg free for balance corrections, significantly increasing the postural demand.
c: Both Hands + Left Foot (BH+LF)
d: Both Hands + Right Foot (BH+RF)

3.4 Trial Structure & Counterbalancing

To mitigate order effects, the presentation order of the four Perspective blocks was counterbalanced across participants using a 4×4 Latin Square. Within each Perspective block, participants completed four distinct trials (two Easy, two Hard). Thereby each participant completed a total of 16 measured trials (4 Perspectives × 4 Trials). The sequence of these four limb combinations was fixed for each perspective but systematically shifted to ensure that every limb configuration appeared in every trial position (1st, 2nd, 3rd, 4th) across the study. Table 1 shows the specific sequences.

Table 1: Latin square counterbalancing *Perspective* and *Difficulty* as well as limb combinations.

Persp.	1st trial	2nd trial	3rd trial	4th trial
First	Easy (RH+LF)	Easy (LH+RF)	Hard (BH+RF)	Hard (BH+LF)
Ghost	Easy (LH+RF)	Hard (BH+LF)	Easy (RH+LF)	Hard (BH+RF)
Third	Hard (BH+LF)	Hard (BH+RF)	Easy (LH+RF)	Easy (RH+LF)
Hybrid	Hard (BH+RF)	Easy (RH+LF)	Hard (BH+LF)	Easy (LH+RF)

3.5 Apparatus

The study was conducted using a high-end desktop PC with an Intel Core i9-12900 (5.0GHz), 32GB RAM, and an Nvidia RTX 3070 to render the VR scene. The central piece of physical equipment was a wooden balance beam (4 m long, 10 cm wide, 5 cm high), which was positioned in the center of a tracking area managed by a SteamVR base station 2.0 [8] system. To ensure precise spatial alignment between the physical and virtual environments, two Vive Trackers (3.0) [7] were mounted on the ends of the balance beam. This setup enabled continuous, real-time tracking of the beam's position and orientation, allowing the system to dynamically update the virtual beam to compensate for any potential micro-shifts during the experiment. Furthermore, the physical beam was secured to the floor with heavy-duty tape to minimize such movements and ensure a stable, safe surface for balancing. Participants were equipped with a Valve Index Head-Mounted Display, two Valve Index Controllers [9] for their hands, and Tundra Trackers [34] attached to their feet and waist to enable full-body motion capture.

Our VR application was developed using the Unity engine (version 2022.3.7f1) on a Universal Render Pipeline (URP) project. The system utilized OpenXR for hardware integration, specifically using the Valve Index Controller and HTC Vive Tracker profiles (there is no separate profile for the Tundra trackers). To manage the complex tracking setup, a custom tracker manager component was developed using scriptable objects, allowing for flexible assignment of tracker roles. This system was essential as it enabled us to have multiple, code-managed in-game tracking objects for the same physical tracker. This was necessary to drive the two separate IK Avatars in the scene, each with a different camera distance from the avatar's head. One avatar was configured for the within-character views (*First*, *Ghost*) with the camera at zero distance, while the other was set for the out-of-character views (*Third*, *Hybrid*) with the camera positioned at an offset behind the avatar. This setup was required to render the different perspectives.

To manage the gameplay sequence and provide sensory feedback, we implemented two key systems. First, a custom game manager, built as a state machine, which controlled all transitions and logged gameplay events. It triggered the wall approach only after traversing the first 25% (stabilization zone) on the active beam (Zone C). Safe start/end platforms (Zone A) and lower floor colliders for step off detection (Zone B) completed the setup in Figure 3. Second, complementary sound effects for the approaching wall, collecting orbs, or touching the wall provided participants with continuous auditory feedback on their performance.

3.6 Procedure

After welcoming the participants, an informed consent was given, and an onboarding phase was conducted to familiarize participants with the balance task (without VR). We asked participants to balance over the beam while trying not to step off for two passes (back and forth). This was followed by a comprehensive introduction to the hardware and safety guidelines.

Participants then underwent a dedicated calibration phase in a neutral virtual environment. First, they selected one of two stylized, humanoid avatar models that best matched their self-perception. During this process, they could see themselves embodied in the chosen avatar via a virtual mirror. To ensure an accurate physical representation, participants then used a virtual slider interface to manually adjust the avatar's limb lengths (arms and feet) until they matched their perceived real-world dimensions. Following this calibration, participants were presented with a selection panel displaying the four experimental perspectives (*First*, *Ghost*, *Third*, *Hybrid*). They were required to actively select and experience each perspective briefly to familiarize themselves with the camera behavior and visual feedback of each condition before proceeding.

After this familiarization, participants were forwarded to the main scene, where we demonstrated the virtual balance beam and the approaching walls. We specifically explained the task of collecting the green orbs embedded in the wall's cutouts. This ensured all participants understood game mechanics and objectives before the first condition began. Finally, to ensure consistent difficulty across varying body sizes, the scale of the approaching walls (and their corresponding cutouts) was dynamically adjusted based on the participant's calibrated height. This normalization ensured that every collectible was equally reachable for every participant, preventing biomechanical advantages or disadvantages due to body size.

Once confirmed that the system was functioning correctly, participants started the main experimental blocks. Participants completed the four perspective blocks in the counterbalanced order assigned to them. Within each block, they performed the four specific trials (2 Easy, 2 Hard). After completing each perspective block, participants removed the VR headset and controllers to complete the UX questionnaires (detailed in Section 3.8) on a laptop. To ensure safety, we conducted verbal well-being checks at this stage; participants were explicitly asked to report their current state and whether they experienced any discomfort or symptoms of motion sickness. Once ready, participants resumed the experiment for the next condition.

After completing all four conditions, participants removed the tracking hardware and proceeded with the semi-structured interview. Finally, we thanked the participants and compensated them. The entire session lasted approximately 60 minutes per participant, of which around 12 minutes were spent inside the VR environment.

3.7 Participants

The study involved 20 participants: 18 students, one research assistant and one PostDoc with a mean age of 26.15 years (SD = 3.05, $range = 21 - 33$; 11 female, 9 male). Everyone had normal or corrected-to-normal eyesight. Participants' prior engagement with video games and VR varied, with most having used VR for gaming and participating in other user studies. Compensation for participants was either €5 per half hour or a corresponding credit towards their study modules. The study was approved by the institution's ethics review board. All 20 participants successfully completed the full experimental procedure, with no withdrawals or reports of simulator sickness or adverse effects.

3.8 Measurements & Data Preprocessing

We adopted a mixed-methods approach combining objective in-game performance analytics, motion-based balance metrics derived from six on-body tracking, and standardized questionnaires. The dependent variables were: (I) balance performance, comprising oscillations of key body segments (head, waist, hands), (II) in-game performance (success rate, wall touches, step-offs, task duration), and (III) subjective measures, including the sense of presence with the Igroup Presence Questionnaire (IPQ) [52], embodiment subscales using the questionnaire by Gorisse et al. [20], a perspective continuum visual analogue scale (VAS) by Hoppe et al. [23], perceived workload using NASA-TLX [22] and enjoyment with the Physical Activity Enjoyment Scale (PACES) [27]; and (IV) qualitative feedback and perspective ranking which were collected via semi-structured interviews.

3.8.1 Game Performance. To evaluate game performance (*success rate*, *wall touches*, *step-offs*, *task duration*), we automatically logged game events and derived four metrics: 1) ***success rate***: binary; coded 1 if all orbs were collected within up to three wall appearances, 0 otherwise. 2) ***wall touches***: count of wall contacts per trial by the participant, capped at three by game logic. 3) ***step-offs***: count of beam step-offs per trial; multiple events within a two-second grace window were consolidated into a single event. 4) ***task duration***: The time in seconds from the moment the participant exited the start zone until they entered the designated end zone on the opposite side of the beam.

3.8.2 Balance Performance. According to Paillard [46], postural balance characterizes the ability to maintain a particular segmental organization without falling. We evaluated postural balance from six on-body position trackers (head, left/right hand, left/right foot, waist). For each trial, tracker position time series were resampled to a consistent length (e.g., 500 samples) via linear interpolation between beam start and end markers in the horizontal plane (A beam centerline). Segment oscillations were quantified by calculating the per-sample Euclidean distance (drift) of each tracker to this centerline. These time series of drift values were then aggregated per trial into their mean (μ) and standard deviation (σ). 1) **Head Oscillation** ($\mathcal{H}$, μ and σ): mean and standard deviation of head drift; 2) **Waist Oscillation** ($\mathcal{W}$, μ and σ): mean and standard deviation of waist drift; 3) **Hand Balance Angle** (α, μ and σ): mean and standard deviation of the inter-hand angle defined by the vectors from head to left hand and from head to right hand (radians); 4) **Body Lean** (β, μ and σ): mean and standard deviation of the angle between the head to waist vector and the vertical axis (radians). We report per-metric analyses in Figure 5 and Figure 6.

3.8.3 Questionnaires. After each perspective block, participants completed a battery of standardized questionnaires to assess their subjective experience. We measured the sense of presence with the **Igroup Presence Questionnaire (IPQ)**, for which we analyzed the total score and its three subscales (Spatial Presence, Involvement, Experienced Realism) [52]. To capture the sense of embodiment, we used the **Embodiment Questionnaire** by Gorisse et al. [20] and analyzed its five subscales (Environmental Location, Possible Actions, Self-Location, Agency, Ownership). Additionally, we assessed participants' subjective positioning on the **perspective continuum** introduced by Hoppe et al. [23] using a Visual Analogue Scale (VAS), where 0 represented a fully body-centered (within-character view) experience and 100 an external (out-of-character view) viewpoint. Our goal was not to test for the existence of a continuum itself, but to empirically quantify where participants would situate our four distinct perspective designs within this conceptual space. The perceived workload was assessed using the **raw NASA-TLX** [22]. Finally, enjoyment was measured with the **Physical Activity Enjoyment Scale (PACES)** [27].

3.8.4 Semi-structured Interview and Ranking. After all four conditions were completed, a brief semi-structured interview was conducted to gather **qualitative feedback** on the UX and to understand the reasoning behind participants' preferences. As a final part of the interview, participants were asked to rank the four perspectives from most to least preferred. To aggregate preference rankings, we applied a pre-defined scoring system. For each perspective, a total score was calculated as the sum of each rank (1-4) multiplied by the frequency with which it was selected. Illustrative quotes from the interview are reported in the Discussion to contextualize the quantitative findings.

4 Results

Our analysis is structured into three main parts, mirroring our research objectives. We begin by presenting the objective performance data, first detailing the **in-game performance** (success, errors, duration) and then the **balance performance** derived from the motion tracking data. Following this, we report on the **subjective UX**, analyzing the results from the standardized questionnaires on workload, presence, and embodiment. Finally, we conclude with the participants' explicit **perspective rankings** gathered from the semi-structured interview. This three-part structure allows us to systematically investigate the relationship between objective performance (i.e., task and balance metrics), subjective experience (i.e., presence and embodiment), and explicit user preference, thereby exploring the trade-offs between different aspects on the perspective continuum.

Statistical analysis was performed in R (v4.3.1). We first assessed the normality of all dependent variables using the Shapiro-Wilk test [42]. Based on these results, we selected the appropriate statistical tests individually for each variable. We prioritized this distinct distribution-fitting approach over applying a uniform test across constructs to avoid information loss in normally distributed metrics and to maximize statistical power. For the 4×2 factorial data (game and balance performance), we employed parametric repeated-measures ANOVAs for normally distributed data, and non-parametric Aligned Rank Transform (ART) ANOVAs [61] using the *ARTool* library otherwise. For parametric ANOVAs, Greenhouse-Geisser corrections were applied where the assumption of sphericity was violated. For the questionnaire data, which were analyzed by perspective, we used one-way repeated-measures ANOVAs or the non-parametric Friedman test. All significant effects were explored using appropriate post-hoc tests (e.g., Tukey's HSD or Wilcoxon signed-rank tests) with Bonferroni correction for multiple comparisons. Descriptive statistics and a summary of all questionnaire analyses are provided in Table 3 and Table 4, respectively.

4.1 Game Performance

To assess overall task performance, we analyzed task duration, step-offs, wall touches, and success rate. Due to the non-normal distribution of these metrics, confirmed by Shapiro-Wilk tests, all analyses were conducted using non-parametric ART ANOVAs.

For task duration, the analysis revealed a significant main effect of Perspective ($F_{3,293} = 8.12, p < .001, \eta_p^2 = .077$) and a significant interaction between Perspective and Difficulty ($F_{3,293} = 3.15, p = .026, \eta_p^2 = .031$). Post-hoc tests on the interaction showed that while there were no differences in the easy condition, in the hard condition (3-collectibles), participants were significantly slower in the *Third* and *Hybrid* views compared to the within-character views *First* and *Ghost*. This indicates a speed-accuracy trade-off, where more demanding perspectives required more time to complete the task safely under high cognitive load.

The error metrics step-offs, wall touches, and success rate, present no significant main or interaction effects (all $p > .41$). This suggests that participants successfully maintained a high level of accuracy and a low error rate across all conditions, compensating for increased difficulty by adjusting their completion time (see Figure 4). A complete overview of all ANOVA results is provided in Table 2.

4.2 Balance Performance

To assess balance performance, we analyzed two types of metrics: spatial stability and postural strategy. We calculated the mean and standard deviation of spatial oscillations (drift from center) for the head ($\mathcal{H}$) and waist ($\mathcal{W}$), measured in meters. Additionally, we analyzed postural angles for the hands (α, inter-hand angle) and the upper body (β, lean angle), measured in radians. The statistical method was chosen for each metric individually based on the results of Shapiro-Wilk normality tests. For normally distributed data, we employed parametric repeated-measures ANOVAs, while for non-normally distributed data, we used non-parametric ART ANOVAs.

The analyses of mean head oscillation ($\mu_{\mathcal{H}}$) and mean waist oscillation ($\mu_{\mathcal{W}}$) revealed highly significant interaction effects between Perspective and Difficulty (for $\mu_{\mathcal{H}}$: $F_{2.68,50.95} = 16.88, p < .001$; for $\mu_{\mathcal{W}}$: $F_{2.76,52.39} = 19.19, p < .001$). Post-hoc tests showed that these effects were driven exclusively by the easy condition (2-collectibles). In this condition, the *Hybrid* perspective led to significantly smaller oscillations (i.e., higher stability) compared to the within-character views *First* and *Ghost*, which in turn showed different patterns of stability. In the hard condition (3-collectibles), these differences vanished, indicating that the task's difficulty became the dominant factor influencing balance.

A different pattern emerged for the body lean (β). Both the mean angle (μ_β) and its standard deviation (σ_β) were not normally distributed. The ART ANOVAs revealed a significant main effect of Perspective on both metrics (for μ_β: $F_{3,293} = 15.20, p < .001$; for σ_β: $F_{3,293} = 16.87, p < .001$), but no interaction with difficulty.

Post-hoc Wilcoxon tests showed that the *Third* perspective consistently led to a significantly more upright and stable posture. Specifically, the mean angle was significantly lower in the *Third* perspective compared to all other conditions (all $p_{adj} < .001$), indicating a less pronounced forward lean. Similarly, the standard deviation was significantly lower, demonstrating a more rigid and less variable posture (all $p_{adj} < .001$ against *First*, *Ghost*, and *Hybrid*). This pattern held true across both difficulty levels.

Finally, the remaining metrics, including hand angle ($\mu_\alpha, \sigma_\alpha$) and waist oscillation variability ($\sigma_{\mathcal{W}}$), did not reveal any significant main or interaction effects (all $p > .057$). This suggests that arm posture and the consistency of waist movement were robust strategies not significantly affected by our experimental conditions. A complete overview of all ANOVA results is provided in Table 2. For visualizations of these effects, see Figure 5 and Figure 6.

4.3 Questionnaires

To understand the subjective dimension of the UX, we analyzed data from our standardized questionnaires. We now report on how the four visual perspectives influenced the participants' sense of presence and embodiment (IPQ, Embodiment Questionnaire, and VAS scale), followed by the analysis of perceived workload (NASA-TLX) and their overall enjoyment of the physical task (PACES).

4.3.1 Presence. Our analysis of the subjective questionnaires revealed a clear pattern regarding the sense of presence. A Friedman test on the overall IPQ score showed that participants felt significantly more immersed in the within-character views ($\chi^2(3) = 27.88, p < .001$). Post-hoc tests revealed that the *Ghost* perspective ($M = 3.76, SD = 0.46$) was rated significantly higher than both *Hybrid* ($M = 3.35, SD = 0.50$) and *Third* ($M = 3.26, SD = 0.61$) (both $p_{adj} \leq .007$). The *First* perspective ($M = 3.62, SD = 0.43$) also outperformed the *Third* perspective ($p_{adj} = .006$), while the difference to *Hybrid* was marginally non-significant ($p_{adj} = .057$).

This general pattern was reflected in the IPQ subscales. Significant main effects were found for *Spatial Presence* ($F(2.08, 39.52) = 5.03$, $p = .011$) and *Involvement* ($F(2.44, 46.28) = 7.88$, $p < .001$). While post-hoc tests for *Spatial Presence* did not yield significant pairwise differences after correction (highest rating for *Ghost*: $M = 4.13$, lowest for *Third*: $M = 3.58$), tests on *Involvement* confirmed that the *Ghost* perspective ($M = 3.88, SD = 0.80$) was rated significantly more involving than both external views (*Third*: $M = 3.30$, *Hybrid*: $M = 3.38$) ($p_{adj} \leq .008$). For *Experienced Realism*, a significant main effect was found ($\chi^2(3) = 9.34, p = .025$), but pairwise comparisons remained non-significant (see Figure 7).

4.3.2 Embodiment. Regarding embodiment, we observed a profound divide between within-character and external views. The sense of *Self-Location*, the feeling of being located inside the virtual body, differed highly significantly across perspectives ($\chi^2(3) = 38.77, p < .001$). Post-hoc tests confirmed that both *First* and *Ghost* provided a significantly stronger feeling of self-location than *Third* and *Hybrid* (all $p_{adj} \leq .007$). Notably, *Hybrid* showed a trend towards higher ratings than *Third* ($p_{adj} = .073$), though this did not reach statistical significance. This finding was directly supported by the Perspective Continuum VAS ($\chi^2(3) = 27.4, p < .001$). The analysis revealed a clear bipolar pattern: participants rated the

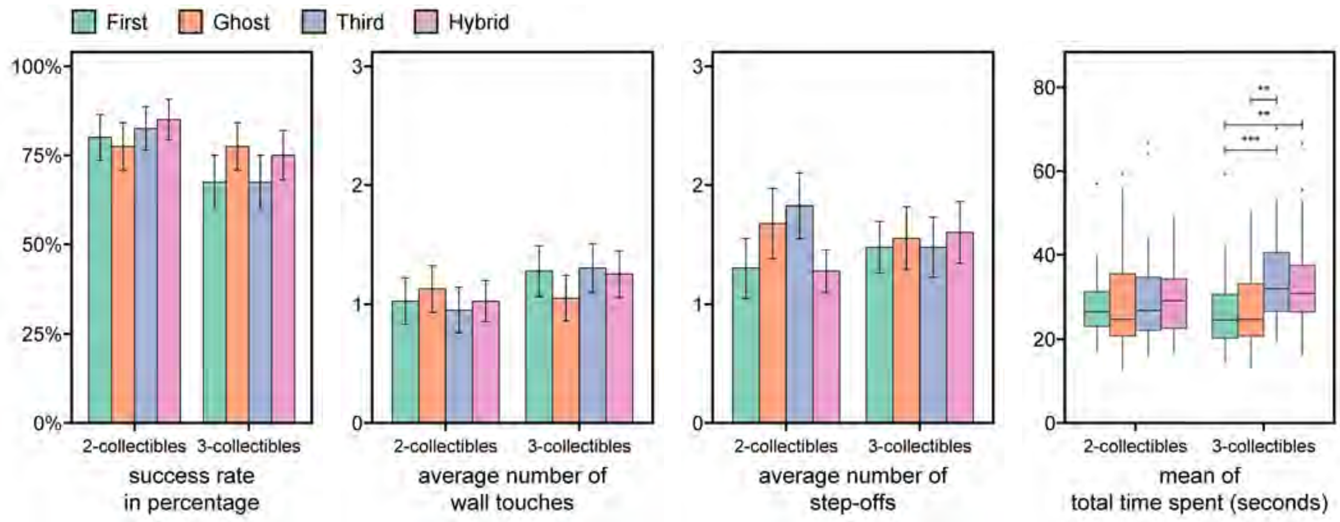

Figure 4: Averaged measures of game performance. While error rates (success, wall touches, step-offs) did not differ significantly, task duration shows a significant interaction effect, with participants being slower in the external perspectives (*Third*, *Hybrid*) in the hard condition. Error bars represent standard error of the mean (SE). Boxplots show median and quartiles. (A note on visualization choice: While we used box plots wherever possible, these would look degenerated in the first 3 diagrams above, since the underlying data is binary (success) or very small integers (wall touches + step-offs). Hence we chose bar graphs in the same color scheme with whiskers expressing standard deviation.)

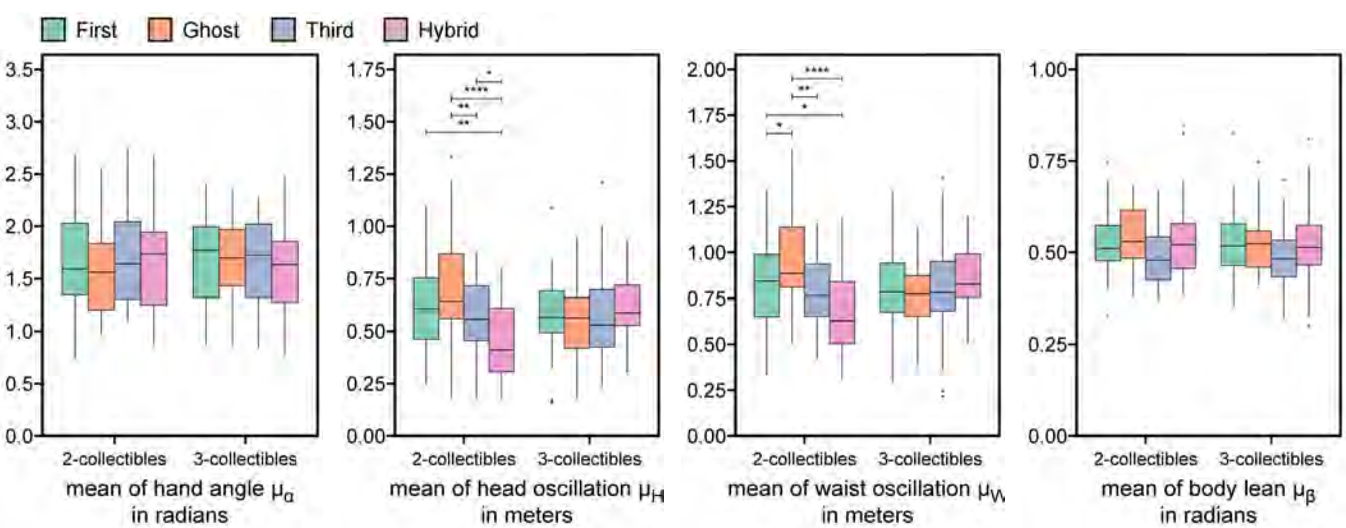

Figure 5: Mean values for postural control metrics. For head ($\mu_{\mathcal{H}}$) and waist ($\mu_{\mathcal{W}}$) oscillation, a significant interaction effect ($p < .01$) was driven primarily by differences within the 2-collectibles condition. For the body lean (μ_{β}), a highly significant main effect of perspective ($p < .001$) was found, consistent across both difficulty levels. Post-hoc tests revealed that the *Third* perspective resulted in a significantly more upright posture compared to all other conditions. No significant effects were found for hand oscillation (μ_{α}).

within-character views (*First*, *Ghost*) as significantly more body-centered than the external views (*Third*, *Hybrid*). Furthermore, a significant main effect was found for *Ownership* ($F(1.87, 35.58) = 3.88$, $p = .032$), although post-hoc tests did not isolate specific pairwise differences, suggesting a more diffuse effect. Crucially, the sense of *Agency* (the feeling of being in control of the avatar's actions) did

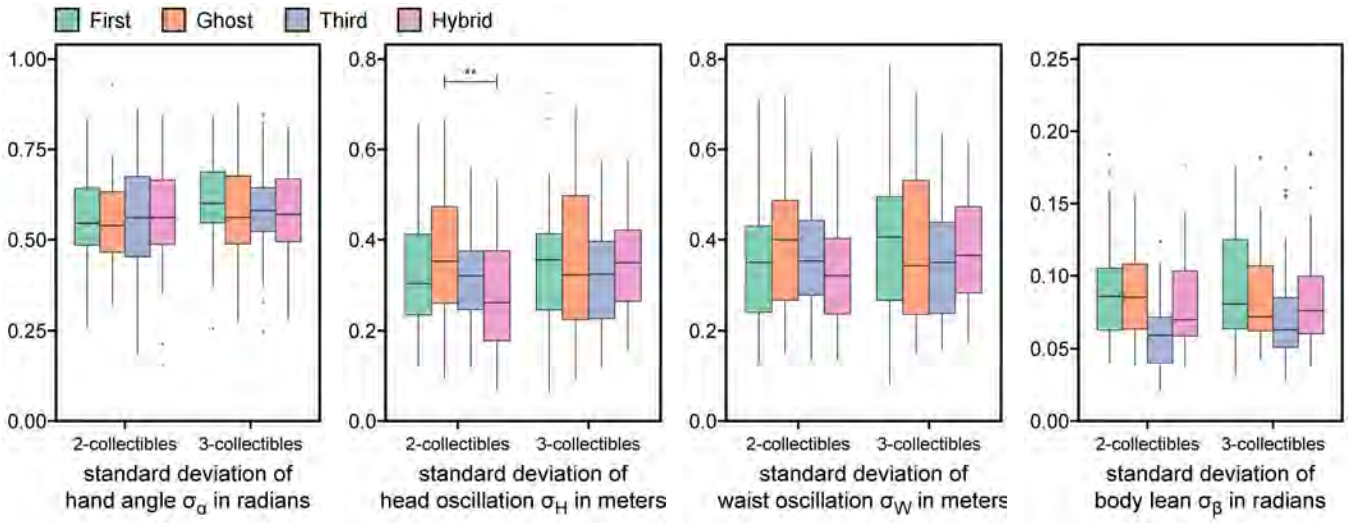

Figure 6: Standard deviation of oscillations, indicating movement consistency. For head consistency ($\sigma_{\mathcal{H}}$), a significant interaction effect ($p = .009$) was driven by differences within the 2-collectibles condition. For upper body consistency (σ_{β}), a significant main effect of perspective ($p < .001$) was found across both difficulty levels, with the Third perspective resulting in a significantly more stable (less variable) posture compared to the other conditions. No significant effects were observed for waist ($\sigma_{\mathcal{W}}$) or hand consistency (σ_{α}).

Table 2: Overview of all analyzed objective performance measures from within the virtual scene. Results using two-way ANOVAs (parametric or non-parametric ART). Significant results are highlighted in bold. Effect sizes are reported as partial Eta-Squared.

	Perspective				Difficulty				Interaction			
	df	*F*	*p*	η_p^2	*df*	*F*	*p*	η_p^2	*df*	*F*	*p*	η_p^2
Game Performance												
Success rate	3,293	0.90	.443	.009	1,293	0.52	.472	.002	3,293	0.94	.421	.010
Wall touches	3,293	0.07	.975	.001	1,293	0.58	.446	.002	3,293	0.44	.723	.005
Step-offs	3,293	0.51	.674	.005	1,293	0.00	.976	.000	3,293	0.96	.412	.010
Duration	3,293	8.12	**<.001**	.077	1,293	1.96	.162	.007	3,293	3.15	**.026**	.031
Balance Performance												
$\mu_{\mathcal{H}}$	2.64,50.21	4.66	**.008**	.038	1,19	0.00	.991	.000	2.68,50.95	16.88	**<.001**	.102
$\sigma_{\mathcal{H}}$	2.28,43.28	2.83	.064	.031	1,19	1.23	.281	.004	2.64,50.16	4.50	**.009**	.024
$\mu_{\mathcal{W}}$	2.89,54.89	3.96	**.014**	.042	1,19	0.41	.529	.001	2.76,52.39	19.19	**<.001**	.129
$\sigma_{\mathcal{W}}$	3,293	1.31	.271	.013	1,293	0.86	.354	.003	3,293	1.64	.181	.016
μ_{α}	2.12,40.30	0.16	.863	.001	1,19	0.25	.620	.000	2.41,45.76	2.88	.057	.007
σ_{α}	2.67,50.76	0.36	.758	.004	1,19	3.99	.060	.008	2.50,47.41	0.29	.799	.001
μ_{β}	3,293	15.20	**<.001**	.135	1,293	1.50	.222	.005	3,293	0.81	.491	.008
σ_{β}	3,293	16.87	**<.001**	.147	1,293	2.29	.132	.008	3,293	1.24	.296	.013

not differ significantly across perspectives, indicating that our control scheme was implemented robustly and felt equally responsive in all conditions (see Figure 8).

4.3.3 Perceived Workload. A Shapiro-Wilk normality test was conducted to assess the normality of the NASA TLX scores. All levels of Perspective passed the Shapiro-Wilk test for normality ($p > .05$). The NASA-TLX scores were analyzed using a one-way ANOVA with Perspective as the independent variable. The analysis revealed no significant differences in overall workload between the different levels, ($F_{2.32,44.07} = 0.63$, $p = .561$), although descriptive statistics suggested that *First* had the lowest workload (Mean = 43.5), while *Third* had the highest (Mean = 46.2). Subscale analyses showed that *Mental Demand* was rated highest for *Third* (Mean = 46.8) and lowest for *First* (Mean = 32.6). In addition, the *Frustration*

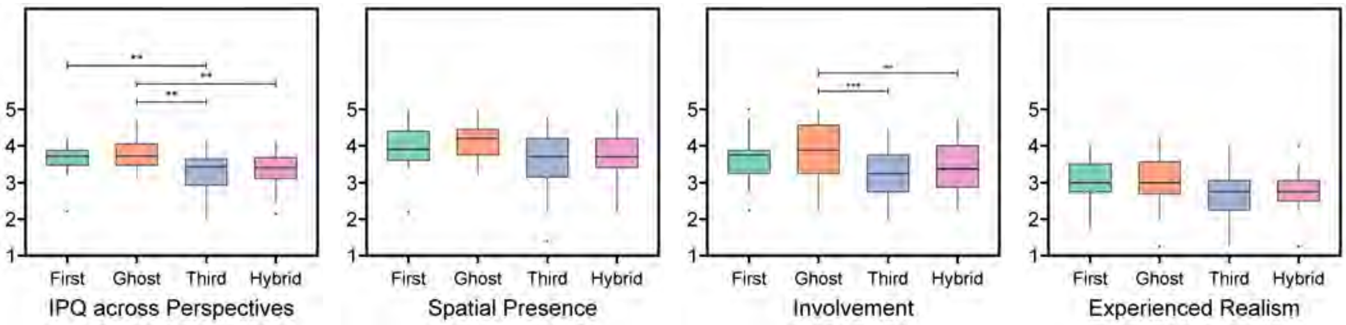

Figure 7: Measures of the IPQ, including subscales, demonstrating significant differences between within-character views (*First*, *Ghost*) and out-of-character views (*Third, Hybrid*).

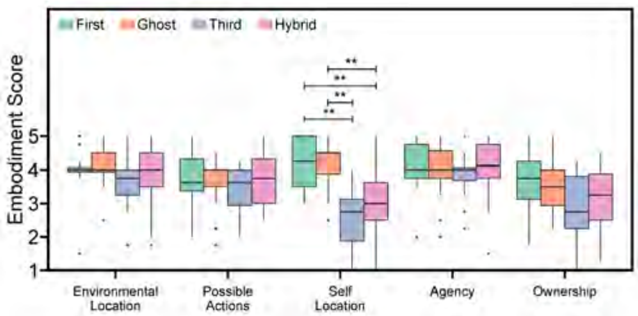

Figure 8: Averaged scores for the five subscales of the Embodiment questionnaire, grouped by the four perspective conditions. Significant differences were most pronounced in the 'Self-Location' subscale, where within-character views (*First* and *Ghost*) scored significantly higher than external views (*Third* and *Hybrid*). Note: Although *Ownership* and *Environmental Location* showed significant main effects, post-hoc tests revealed no specific pairwise differences.

scale showed the highest frustration levels for *Ghost* (Mean = 38.7) and lowest for *First* (Mean = 31.6).

Although no significant differences were found in overall workload, descriptive trends suggest that *First* and *Ghost* are less mentally demanding and frustrating compared to *Third* (see Figure 9).

4.3.4 Physical Activity Enjoyment Scale. The PACES scores were analyzed using a one-way ANOVA with Perspective as the independent variable. Normality testing indicated that all levels passed the Shapiro-Wilk test for normality ($p > .05$). The analysis revealed no significant differences in *enjoyment* between different levels of Perspective ($F_{2.43,46.21} = 1.21$, $p = .313$); however, descriptive statistics suggested that *Third* had the highest enjoyment ratings (Mean = 3.82), followed by *Hybrid* (Mean = 3.72), *Ghost* (Mean = 3.69) and *First* (Mean = 3.66), as visualized in Figure 10.

4.4 Condition Ranking

At the end of the semi-structured interview, participants were asked to rank the four perspectives from most preferred (1st) to least preferred (4th). To quantify overall preference, we applied a ranked scoring system where a 1st place rank was assigned 1 point and a 4th place rank was assigned 4 points (lowest score indicates highest preference). This analysis revealed that the *Hybrid* perspective was the most preferred (Score = 45), followed by the *Third* perspective (Score = 51). The within-character views *Ghost* and *First* were tied for the least preferred positions (Score = 52). A detailed breakdown of the rankings is provided in Table 5.

5 Discussion

In this study, we investigated how different visual perspectives in a VR-based balance game affect objective performance, subjective experience, and user preference. Our findings reveal a central mismatch that shows that the perspectives that the participants found most useful and preferred were not the ones that provided the highest level of perceived presence. In the following, we interpret these findings systematically by addressing our three research questions and evaluating the support for our specific hypotheses. We first discuss the trade-offs in objective performance (RQ1), addressing our predictions on spatial planning (H1) and postural stability (H2). We then analyze the subjective UX (RQ2), specifically testing our prediction on embodiment (H3). Finally, we synthesize these aspects to explore the complex link between performance, experience, and user preference (RQ3).

5.1 Objective Performance Reflects a Trade-Off Shaped by Task Demands.

Our first research question explored how shifting the visual perspective affects objective motor performance. Regarding our specific predictions, the results provide a nuanced picture for H1 (Spatial Planning) and H2 (Postural Stability), indicating a complex interaction between perspective and task difficulty. We could not confirm our prediction for H1, suggesting that out-of-character views will lead to less wall touches. We found no significant differences in error rates (success rate, wall touches, step-offs), suggesting that participants prioritized accuracy regardless of the viewpoint. However, this accuracy came at a cost to speed. In the harder condition, task duration was significantly longer in the out-of-character views

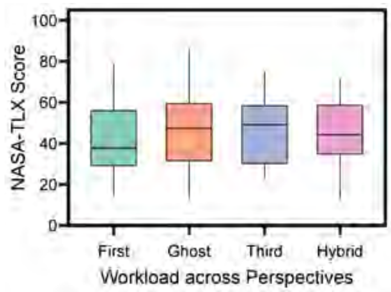

Figure 9: NASA-TLX total workload ratings for all four perspectives. Despite minor descriptive variation, the overlapping box plots suggest that perceived workload did not differ significantly between conditions.

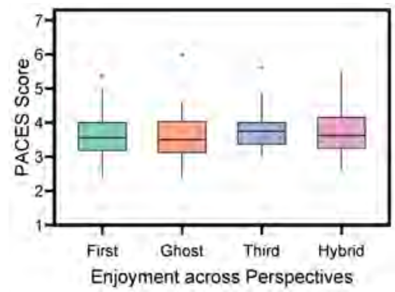

Figure 10: Physical Activity Enjoyment Scale (PACES) results for all four perspectives. Despite minor descriptive variation, the overlapping distributions indicate no statistically significant differences in enjoyment between conditions.

Table 3: Summary of statistical analyses for all questionnaire data. Depending on the violation of normality assumptions, either a parametric repeated-measures ANOVA (reporting F-values) or a non-parametric Friedman test (reporting χ^2-values) was used. Significant results ($p < .05$) are highlighted in bold. Effect sizes are reported as generalized Eta-Squared (η^2_G) for parametric tests and Kendall's W for Friedman tests.

Questionnaire	Subscale / Item	Test Statistic	df	p-value	Effect Size
NASA-TLX [22]	Overall Score	$F = 0.63$	2.32, 44.07	.561	$\eta^2_G = .005$
	Mental Demand	$\chi^2 = 7.61$	3	.055	$W = .127$
	Physical Demand	$F = 0.70$	2.32, 44.00	.520	$\eta^2_G = .009$
	Temporal Demand	$\chi^2 = 0.47$	3	.926	$W = .008$
	Performance	$F = 1.71$	2.32, 44.14	.189	$\eta^2_G = .034$
	Effort	$F = 0.61$	2.36, 44.86	.575	$\eta^2_G = .012$
	Frustration	$F = 1.01$	2.46, 46.83	.384	$\eta^2_G = .013$
IPQ [52]	Overall Score	$\chi^2 = 27.88$	3	**<.001**	$W = .465$
	Spatial Presence	$F = 5.03$	2.08, 39.52	**.011**	$\eta^2_G = .083$
	Involvement	$F = 7.88$	2.44, 46.28	**<.001**	$\eta^2_G = .095$
	Experienced Realism	$\chi^2 = 9.34$	3	**.025**	$W = .156$
Embodiment [20]	Environmental Location	$\chi^2 = 12.64$	3	**.005**	$W = .222$
	Possible Actions	$\chi^2 = 6.37$	3	.095	$W = .112$
	Self-Location	$\chi^2 = 38.77$	3	**<.001**	$W = .680$
	Agency	$\chi^2 = 4.81$	3	.186	$W = .084$
	Ownership	$F = 3.88$	1.87, 35.58	**.032**	$\eta^2_G = .099$
VAS Scale	Perspective Continuum	$\chi^2 = 27.40$	3	**<.001**	$W = 0.457$
PACES [27]	Overall Score	$F = 1.21$	2.43, 46.21	.313	$\eta^2_G = .011$

(*Third* and *Hybrid*). This suggests a classic speed-accuracy trade-off, where the increased spatial information of an external view required more time for cognitive processing and movement planning to maintain a low error rate. Users adapted their pacing to handle the demands of the less familiar viewpoints, a finding that aligns with research showing 1PP enables more accurate interactions while 3PP enhances spatial awareness [20]. This was reflected in participant feedback, with P6 noting that the *Third* condition was "harder to see what's going on" and harder to time movements because of the virtual distance. Furthermore, the results regarding H2 (Postural Stability) were more complex and did not fully align with our prediction that within-character views would be strictly superior. In the easy condition, our novel *Hybrid* perspective resulted in significantly lower head and waist oscillations compared to the within-character views. This indicates that the combination of a out-of-character overview with within-character view limb feedback provided a tangible benefit for postural stability when the cognitive load was manageable (2-collectible). This finding aligns with Elsayed et al. [16], who demonstrated that multi-view guidance can enhance movement precision by resolving spatial ambiguities. However, this advantage disappeared in the harder condition, suggesting that the cognitive effort required to integrate these dual viewpoints may have outweighed its benefits when the primary task became more demanding [12].

Table 4: Descriptive statistics (Mean and Standard Deviation) for all questionnaire data, grouped by perspective. This table includes results for the raw NASA-TLX, the Igroup Presence Questionnaire (IPQ), the Embodiment Questionnaire, and the Physical Activity Enjoyment Scale (PACES).

		First		*Ghost*		*Third*		*Hybrid*	
	Range	Mean	SD	Mean	SD	Mean	SD	Mean	SD
NASA-TLX [22]	0-100	43.50	18.50	47.50	20.50	46.20	16.80	45.00	17.30
Mental Demand	0-100	32.60	22.80	38.70	23.70	46.80	22.80	35.40	24.00
Physical Demand	0-100	39.40	24.90	39.20	25.80	37.80	22.10	41.40	24.10
Temporal Demand	0-100	36.60	24.60	37.80	23.00	37.00	21.40	38.40	23.10
Performance	0-100	68.60	20.70	69.60	22.00	63.20	21.20	67.20	20.00
Effort	0-100	52.20	24.80	56.20	24.60	52.00	21.90	52.60	22.40
Frustration	0-100	31.60	25.00	43.40	28.20	40.40	27.60	35.00	24.50
IPQ [52]	1-5	3.62	0.43	3.76	0.46	3.26	0.61	3.35	0.50
Spatial Presence	1-5	3.98	0.62	4.13	0.51	3.58	0.89	3.77	0.76
Involvement	1-5	3.66	0.69	3.88	0.80	3.30	0.70	3.38	0.73
Experienced Realism	1-5	2.95	0.68	3.02	0.77	2.72	0.59	2.70	0.69
Embodiment [20]									
Environmental Location	1-5	4.03	0.81	4.10	0.67	3.64	0.89	3.86	0.96
Possible Actions	1-5	3.66	1.07	3.65	1.00	3.41	1.03	3.72	1.07
Self-Location	1-5	4.28	1.01	4.15	0.98	2.55	1.26	2.98	1.46
Agency	1-5	4.08	0.78	4.01	0.86	3.82	0.82	4.09	1.00
Ownership	1-5	3.59	1.28	3.51	1.22	2.86	1.33	3.16	1.30
PACES [27]	1-7	3.66	0.76	3.69	0.81	3.82	0.66	3.72	0.71

Table 5: Summary of participants' preference rankings for perspectives. A lower total score, calculated from the frequency of each rank, indicates a higher preference. The results show a clear preference for the *Hybrid* perspective, followed by the *Third* perspective.

Perspective	1st	2nd	3rd	4th	Total Score	Rank
Hybrid	5	6	8	1	45	1
Third	6	5	1	8	51	2
Ghost	4	5	6	5	52	Tied-3
First	5	4	5	6	52	Tied-3

In addition, a distinct postural strategy emerged in the *Third* condition. Participants consistently adopted a significantly reduced body lean. This suggests a shift in control strategy from relying primarily on internal, proprioceptive feedback to utilizing the out-of-character view reference of the full-body avatar. By observing their entire body from the outside, users seemed to adopt a more cautious and rigid posture to ensure they fit through the wall cutout. This is consistent with studies showing that users can maintain a high sense of agency over an out-of-character view avatar without a strong sense of ownership, effectively treating the avatar as a directly controlled tool rather than their own body [35, 55]. This sentiment was echoed by participant 4 who described the experience as "playing with a doll rather than being a real person".

5.2 Within-Character View Maximizes Subjectively Perceived Presence and Embodiment Without Impairing Control.

Our second research question addressed how the shift in perspective modulates the user's subjective experience. Our results provide **mixed support for H3**. Regarding **Self-Location**, the hypothesis was confirmed: the within-character perspectives elicited significantly higher ratings, demonstrating that spatial co-location is the primary driver for feeling "in" the virtual environment. Regarding **Body Ownership**, the pattern pointed in the same direction (Within > Detached), aligning with Maselli and Slater [38], though the statistical strength of this effect was less robust than for Self-Location. This suggests that while perspective influences ownership, other factors (like the abstract avatar appearance) may have dampened the effect. Moreover, this aligns with recent findings that users in complex motor tasks may prioritize functional control cues over strict body ownership, potentially allocating less cognitive resource to validating the feeling of possession [17]. Regarding **Agency**, the hypothesis was rejected. Ratings remained consistently high across all conditions with no significant main effect of perspective. This critical null result replicates Gorisse et al. [20] and indicates a functional dissociation: users maintained a strong sense of control even when spatial presence (Self-Location) was significantly reduced.

Beyond the core hypothesis, the strong Self-Location in within-character views translated to significantly higher scores in Environmental Location (only main effect) and overall Presence (IPQ).

Participants described the experience as more "natural" and "connected," a finding further validated by the clear bipolar clustering on the Perspective Continuum scale [23]. Further nuances emerged in the specific designs. First, the *Ghost* perspective's high presence scores are noteworthy. Its translucent representation likely struck an optimal balance: providing sufficient visual feedback for embodiment while reducing visual dominance to allow for better integration of environmental cues. This supports the trade-off highlighted by Döllinger et al. [14], suggesting that reducing the salience of the virtual body can actually facilitate a stronger proprioceptive focus. Second, although the *Hybrid* perspective shared the detached camera position with the *Third* view, the trend towards higher Self-Location (p_{adj} = .073) suggests that users successfully integrated the multi-scale feedback (global view + proximal limbs). As theorized by Dufresne et al. [15], this implies that non-naturalistic avatar representations can be accepted if they offer coherent functional affordances. Proximal cues like translucent ghost limbs appear to partially bridge the spatial gap. While not restoring full ownership, they provide a critical visuomotor anchor that reinforces the sense of agency, effectively implementing a functional transparency that supports control without requiring full spatial coherence.

This entire pattern of, robust agency combined with varying degrees of presence, demonstrates that subjective experience in VR is modular. Users can feel "in control" (Agency) without necessarily feeling "inside" (Self-Location), confirming a functional dissociation [55]. Ultimately, these results highlight a complex relationship where the highest degree of embodiment does not automatically translate to the best user preference, a paradox we will explore in the next section.

5.3 In Complex VR Motor Tasks, Users Pragmatically Prefer the Perspective That Offers Them the Greatest Usefulness, Even If It Means Less Presence.

Our third research question asked how users balance objective performance against subjective experience when choosing a perspective. The final preference ranking reveals a mismatch that forms the core of our contribution. The most surprising finding was the clear contradiction between embodiment scores and user preference. The *Hybrid* and *Third* views, those that scored lowest on presence and self-location, were ranked as the most preferred. Conversely, the most "embodied" perspectives, *First* and *Ghost*, were ranked last. This demonstrates that for a task that demands precision and spatial awareness, users prioritize pragmatic utility over the subjective feeling of immersion. The reason for this preference likely lies in the functional benefits of the external views. An out-of-character view provides a complete overview of the avatar's body in relation to the environment (i.e., the approaching wall), which is a significant strategic advantage for planning and executing the correct pose. Participants were willing to sacrifice the "natural" feeling of a within-character view in exchange for information that helped them succeed in the task [20]. This aligns with recent theoretical arguments that users value functional utility over embodiment when task demands increase [17].

The fact that our novel *Hybrid* view was ranked as the most preferred overall suggests that users are not only open to, but may even favor unconventional perspectives that go beyond simply mimicking reality. The *Hybrid* view offered the "best of both worlds". It used the strategic overview of the *Third* perspective combined with the immediate limb feedback of a within-character view. P16 stated it "provided a good balance between self-visualization for balance and task execution," while P20 found it provided a "more comprehensive visual and sensory experience, aiding task performance". This preference for comprehensive visual feedback mirrors findings by Elsayed et al. [16], where users explicitly favored multi-view configurations for complex tasks to resolve spatial ambiguities. This indicates a desire for designs that leverage the unique capabilities of VR to provide optimal information for the task at hand, reinforcing the idea that the true power of VR lies not in replicating reality, but in augmenting it [23, 35, 55].

A core challenge in this augmentation process is the deliberate control of visual information, filtering between wanted and unwanted visual cues. Our handling of dynamic shadows illustrates this nuance. We are aware that shadows can serve as powerful depth cues, potentially confounding the comparison between perspectives. Fortunately, however, our data indicates that their actual influence was negligible. First, the *Ghost* condition (lacking perceptible shadows) yielded results nearly identical to the *First* view (with shadows), proving that users did not rely on them in within-character view (see Figure 1). Second, regarding the preferred out-of-character views (*Third*, *Hybrid*), while shadows were present, their utility was likely redundant. The out-of-character viewpoint inherently solves the spatial problem by allowing users to directly perceive the distance between the avatar and the wall. Thus, the primary geometric advantage of the external perspective rendered auxiliary cues like shadows superfluous.

6 Limitations & Future Work

Our study is subject to several limitations that guide future research directions. Firstly, the generalizability of our findings is constrained by our **small (N=20) and homogeneous student sample**. We did not conduct an *a priori* power analysis but relied on sample sizes consistent with related work in the field. As our related work identifies VR as a promising tool for neurorehabilitation and fall prevention, future work must extend our investigation to these target clinical populations, including older adults and patients with vestibular or neurological disorders, to validate the therapeutic applicability of our findings.

Secondly, our use of a **single, specialized motor task** ("Brain Wall") does not allow us to exclude that the observed perspective-performance trade-offs may be task-dependent. We deliberately chose this task over established paradigms like object carrying [57] to minimize confounding factors such as object occlusion and secondary manipulation demands, keeping the focus strictly on postural control and body schema. Consequently, it remains an open question whether the pragmatic preference for the *Hybrid* view would persist in tasks with different attentional or biomechanical demands. Future research should systematically examine these perspective effects across a variety of ecologically valid tasks, such as simulated daily activities and therapeutic exercises.

Third, by design, we investigated only **four discrete perspectives**. While this allowed for controlled comparison, it only samples a fraction of the "perspective continuum" we introduced in the beginning. Future work should explore this continuum more granularly, potentially through adaptive systems that dynamically adjust the viewpoint to personalize the experience and optimize motor learning.

Fourth, our protocol for **subjective measurement** aggregated the experience across different task difficulties. We collected questionnaire data after each perspective block, which included trials from both the easy and hard conditions. This methodological choice prevents us from analyzing how task difficulty might have interacted with subjective measures such as presence, embodiment, or workload. While our objective data revealed that performance advantages were modulated by difficulty, we cannot determine if a similar pattern exists for the subjective experience. Future studies should therefore collect subjective feedback after each difficulty level to disentangle these effects.

Fifth, our protocol was constrained by a **brief exposure duration** (12 minutes) and our reliance on kinematic data from on-body trackers. This prevents conclusions about long-term adaptation and may not capture all nuances of postural control. Future studies should employ longitudinal designs and integrate the comprehensive biomechanical assessments mentioned in our related work, such as **force plates to measure center of pressure** and EMG, to more robustly evaluate learning effects and the sustained impact of different perspectives.

Finally, while we ensured participant safety through regular verbal well-being checks, we did not employ a standardized quantitative instrument, such as the Simulator Sickness Questionnaire (SSQ), or the Fast MS Scale (FMS) to measure motion sickness [28, 29]. Although no participants reported discomfort or withdrew from the study, future work involving movements in out-of-character views should quantify potential adverse effects to better understand the physiological trade-offs of different perspectives.

7 Conclusion

In this work, we investigated the **trade-off between objective performance and subjective experience in VR** through a balance game. We systematically compared four distinct visual perspectives. Our findings reveal a critical paradox in VR design for complex motor tasks: The **perspectives that induce the strongest sense of embodiment and presence are not the most preferred.** While traditional within-character views (*First* and *Ghost*) **maximized the sense of being "in" the virtual body (Self-Location and Ownership)**, they were ultimately **ranked lower** by users. Instead, participants pragmatically favored our **novel *Hybrid* perspective**, which users felt **provided the best support for balancing performance and perception**, although the objective data showed a cost to speed in demanding scenarios. This preference was driven by perceived utility. It seemed to offer the "best of both worlds" through a strategic overview combined with direct limb feedback. Although this objective stability benefit was limited to lower difficulty conditions, the *Hybrid* view represented the most effective compromise for users. This demonstrates that **for demanding physical tasks, user preference can be dictated by pragmatic considerations of effectiveness rather than by the intensity of embodiment or presence**. Our findings extend the established trade-off, where out-of-character views provide superior spatial awareness at the cost of presence [20], by showing that users will actively choose this pragmatic advantage. This insight challenges the common assumption that maximizing subjective presence is the primary goal for all VR applications. For designers of future VR training, rehabilitation, and exergame systems, our results echo the notion that the optimal perspective is heavily task-dependent and that no universal recommendation exists [1, 20]. Consequently, the most effective "tool" for a motor task may be one that prioritizes function over representational fidelity, making the option to choose a perspective a crucial design element.

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Generative AI tools were used at the paragraph level to improve readability and style of text originally envisioned and written by the authors, and to adjust figures (e.g., improving clarity, layout, or labeling) based on author-created originals. The AI assistance was limited to copy-editing and visual refinement; all conceptual content, study design, analysis, and interpretation were created by the authors. All AI-assisted text and image adjustments were carefully reviewed, revised, and approved by the human authors, who remain fully responsible for the final manuscript. No confidential or proprietary data were provided to the AI system.

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