Sitting or Standing in VR: About Comfort, Conflicts, and Hazards

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***Abstract*—This article examines the choices between sitting and standing in virtual reality (VR) experiences, addressing conflicts, challenges, and opportunities. It explores issues such as the risk of motion sickness in stationary users and virtual rotations, the formation of mental models, consistent authoring, affordances, and the integration of embodied interfaces for enhanced interactions. Furthermore, it delves into the significance of multi-sensory integration and the impact of postural mismatches on immersion and acceptance in VR. Ultimately, the article underscores the importance of aligning postural choices and embodied interfaces with the goals of VR applications, be it for entertainment or simulation, to enhance user experiences.**

WHY SIT?

In 2018, *"Oculus' Vice President of Content Jason Rubin claim[ed] that a "significant percentage" of Oculus Rift headset owners would rather sit down to enjoy virtual reality rather than take advantage of room-scale motion detection"*[1].

Are we simply lazy, maybe too lazy for exciting experiences in VR? Are the available experiences not exciting enough? Or are there more reasons to sit while consuming VR? The answer to all three questions is: yes and no. This article aims to illustrate the multifaceted nature of this phenomenon.

Sitting clearly is more comfortable regarding ergonomics and fatigue [1], [2], especially for long-term experiences. This comfort may be further enhanced by increased robustness against cybersickness [3], [4] and by the feeling of safety generated by the certainty of not being able to fall, run into a wall, or trip over a cat (see Figure 1). Furthermore, while we occasionally move our furniture for a game night or party with friends, we do not do so on a daily basis. The same is true for the overall technical complexity,

Figure 1. *"The Cat Problem"*: A user immersed in a VR experience can quickly forget the potentially dynamic physical world around them.

[1] https://www.digitaltrends.com/computing/oculus-rift-owners-want-to-sit-for-vr-experiences/

Figure 2. Standing in VR experiences without any purpose feels like standing in a line.

i.e., hardware and its setup. While inside-out tracking gets more reliable and applicable, much VR hardware for room-scale experiences requires substantial restructuring of your living room or office. VR is becoming a part of our lives, but its impact might not be high enough to justify these costs, and it is at least questionable whether future houses and flats will have a separate room for VR entertainment. Instead, technology has and will adapt to our lives, which opens up another crucial point. Sitting is accessible. Experiences that are usable while sitting are more inclusive (cf. [5], [6]).

Why Stand?

Is there a compelling reason to choose a standing posture while experiencing VR applications? The answer to this question is twofold. Firstly, there are no good reasons to stand without a purpose [7]. In other words, standing in VR should be purpose-driven, leveraging the potential benefits of an upright posture, such as an extended hand/interaction reach and the ability to step, duck, or hop. Standing aimlessly has been shown in various contexts, not just in VR, to be both boring and exhausting [8] (see Figure 2). Unfortunately, many VR applications still fall into this category.

On the other hand, standing in VR offers a distinct advantage. It goes beyond posture, granting the user a greater freedom of movement. With sufficient physical space, a standing user can even walk through the room, a concept known as room-scale VR. This environment enables a wide range of natural interactions and engagement opportunities, making it an attractive choice for developers. In contrast, maintaining user engagement is a significant challenge in seated VR scenarios [1].

Some of the advantages of sitting are inherent, while others are a result of suboptimal application design or the challenges associated with room-scale VR. These challenges include safety issues and the seamless integration of VR into living spaces, considering the available footprint and potential obstacles. In the near future, there are intriguing possibilities for addressing these challenges and enhancing the VR experience. One approach is the concept of substitutional reality [9], [10], where real-world objects are reused as virtual counterparts of similar dimensions and shapes. Another promising strategy involves redirection techniques [11], which subtly manipulate perception to overcome physical space limitations and hazards. By incorporating advanced sensor technologies and real-time notifications, users can maintain awareness of their physical environment while immersed in virtual worlds [12]. This approach, known as ambient awareness, promotes safety and usability by preventing accidents and collisions in VR scenarios.

Mental Models & Conflicts

In our discussion of sitting and standing in virtual experiences, we have primarily focused on the physical postures, but we must also acknowledge the importance of the user's virtual body and posture within the virtual environment. This virtual posture can be defined by an avatar, dictated by the context (e.g., sitting while riding a horse or standing when running), or shaped by the mental model that each individual user constructs to create a plausible experience in the absence of clear mediators. On the basis of the freedom the user has to choose a mental model, i.e., virtual posture, we refer to the latter as unauthored experiences. Authoring becomes crucial when developers aim to create consistent immersive experiences. Even seemingly simple scenarios can present challenges in achieving this consistency. For example, we mentioned running as a straightforward context that should naturally lead users to adopt a virtual standing or upright posture. Teleportation, one of the most commonly used methods in applications for virtual travel, is completely unsuitable for giving the user the feeling of walking. But which general applicable cues should be provided with continuous virtual travel methods such that users beyond a doubt believe that they are running and not hovering on a board or driving a vehicle in VR? One might argue that, in the absence of auditory or visual cues suggesting vehicle usage, the most plausible mental model for perceiving continuous self-motion is running. But what happens when virtual experiences transport users to a future that features noiseless hoverboards or movement speeds exceeding what is plausible for running?

Authoring

In a recent experiment of ours [13], participants who were physically seated had to perform an informed search task using different virtual travel techniques while maintaining an unaltered viewpoint height with jogging speed. At the end of the study, participants were asked to select one of several options regarding their perception of movement: 10 out of 19 participants reported feeling like they were hovering in a seated position, 4 felt like they were hovering while standing, 2 described the sensation of being walking dwarfs, and 3 felt like they were regularly walking in their minds. Whether or not these participants had a conscious model of their virtual movement before being questioned remains unanswered in this case (cf. [14]). However, it may not always be relevant for a developer to know whether a user perceives walking or hovering. Feeling like a dwarf, on the other hand, can have unintended consequences, such as a distorted perception of distances and sizes.

The latter experiment is an arbitrary example and when authoring is important there are some solutions to it [15]: This starts with appropriately adapting movement speed and camera height, catering to the dominant visual sense. Additionally, proprioceptive cues can be provided by utilizing related motion sequences for virtual travel, such as walking-in-place, which is also applicable in sitting scenarios (cf. [16]). Tactile stimulation is an option, achieved by modulating vibrations to match the movement metaphor or by adding artificial airflow to enhance the sense of vection, i.e., the perception of self-motion [17]. Lastly, acoustic cues, like footsteps or motor sounds, which are often easy to implement, can have a significant impact on users' mental models [18].

Multi-sensory integration

The above-mentioned experiment and its results illustrate that the virtual posture can differ from the physical one, either by design or as part of an individual's smallest set of acceptable conflicts towards a coherent and plausible, and thus entertaining, illusion. This concept alludes to a theory of theater known as the "(willing) suspension of disbelief", which explains the acceptance of the obviously untrue or unreal in exchange for greater entertainment.

At first glance, one might argue that this conflict is neither new nor of significant importance. After all, no one seems to complain about sitting while playing first-person video games for three decades. In fact, I personally remember players vividly describing their experiences, such as "running around that damn corner and getting caught," without questioning the contradiction. However, the degree of immersion in VR, compared to a desktop experience, significantly impacts vection, cybersickness, and body ownership illusions.

Vection refers to the embodied sensation of self-motion in stationary participants when presented with optic flow [19]. Cybersickness encompasses negative symptoms that mainly occur when perceiving virtual ego-motion that does not align with physical motion [20]. Body ownership illusion involves accepting another body, potentially virtual, as one's own due to synchronous multi-modal stimulation [21]. These phenomena manifest differently in individuals and become more pronounced with higher levels of immersion, leading to non-veridical yet plausible multi-sensory integration. It is reasonable to assume that postural mismatches also become more pronounced with increased immersion.

Obviously, a postural conflict itself is detrimental towards a multi-sensory integration, i.e., a plausible illusion, but the question is whether or not and in which cases an (artificial) solution to the conflict and thus a perceptual shift is not only sufficient but rated necessary by our brain. Can we willingly or unconsciously accept the virtual body or ego-motion of a horseman as our own, even when physically standing, as long as the the rest of the multi-modal stimulation matches perfectly? These questions lead deep into perceptual research and models like the Bayesian Causal Inference of Body Ownership [22].

Two interesting observations emerge: First, acceptance in the context of phenomena like vection, cybersickness, and body ownership illusion appears to operate on a more subconscious and less controllable level than the (willing) suspension of disbelief Acceptance is subconscious and also not controllable/revertable. This at least suggests that there can be also a degree of multimodal walking simulation that leaves the user without a choice about their movement perception.

Second, it seems that movement models are learnable to some extent. Drivers of cars often do not experience motion sickness, while their passengers sometimes do. This suggests that our ability to avoid motion sickness while walking, which may be attributed to genetic factors, does not transfer to the context of being a passenger. This raises questions about whether driving a car is more similar to physical walking than simply having greater control [23]. Control is something we can grant to users, even over virtual and implausible scenarios. Investigating this question could help create convincing illusions within a pool of conflicts.

While postural conflicts in VR are prevalent, they remain largely unexplored empirically. An interesting follow-up question is the role that the direction of the conflict plays. Does physically standing while virtually sitting have different consequences than virtually sitting while physically standing? Is one of these conflicts easier to resolve than the other? These are questions we aim to address in future research.

Entertainment vs. Simulation

When evaluating the potential impact of postural mismatches on a VR experience and whether they warrant our attention, the primary consideration is the overall goal of the application.

In the case of first-person video games, the primary objective is entertainment. Beyond intriguing basic research questions, the product's success primarily hinges on its ability to entertain. While a conflicting posture may marginally reduce the overall experience, it is just one of many variables at play in the entertainment context.

However, VR applications have a broader spectrum of use. In professional workflows, the user's posture becomes significant for two reasons. First, ergonomics take center stage when users may be exposed to VR for extended periods. Prolonged usage without considering ergonomics can negatively impact productivity. For instance, a direct comparison of postures revealed lower emotional arousal in participants seated during an HMD-projected quality assessment task [24].

Second, a distinct branch of professional applications focuses on realism, such as architectural walkthroughs, design reviews, and professional training, including safety-critical scenarios [25]. In these contexts, a postural mismatch is not the only concern but can have a substantial impact on the success of the training. In cases where cost reduction is a primary driver, other aspects may take precedence over an accurate simulation.

Consider a hypothetical scenario where a VR bicycle simulator is designed for security training. The simulator, for cost-saving reasons, overlooks the aspect of sideways leaning during cycling. In such a scenario, trainees might develop an unwarranted sense of confidence, potentially jeopardizing their preparedness for real-world security scenarios.

Now, imagine a debate surrounding the inclusion of object weight in the simulation of height work safety in a VR environment. Height is conveniently visualized in VR, raising the question of whether it is feasible to omit the consideration of object weight due to the inherent challenges in replicating this aspect accurately in VR.

In situations like those described above, we should not compromise the precision and completeness of the simulation, including postural conflicts, on the cost of security as long as we do know that little about our perception. This perspective leads us to the final section, where we explore the negative consequences and drawbacks of sitting in VR.

Why not to Sit?

The negative health consequences of prolonged sitting are well-documented and an omnipresent topic for many people today [26]. The risks of prolonged sitting should be taken seriously, also in the context of VR usage. Awareness of these issues is vital to encourage individuals to adopt healthier sitting habits and incorporate regular movement breaks into their VR expe-

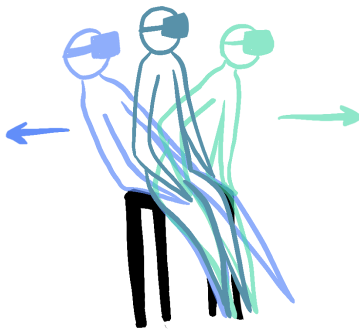

Figure 3. General idea of a human-joystick/leaning interface: the user moves in the direction of their body inclination and/or their movement speed is related to the amount of inclination. Implementations exist in various combinations and parametrizations.

riences. Understanding the risks, we can strive to find a balance between the immersive virtual world and our physical well-being. However, as a VR researcher and/or designer, it is particularly challenging to navigate between one's own responsibility and the risk of patronizing the user. The only thing we can state with certainty without getting into a philosophical discussion at this point is that it is equally important not to unjustifiably force the user into a seated posture, just as it is the other way around with standing. As discussed earlier, standing is much more likely to be accepted by the user if it serves a purpose or is simply enjoyable. When a person sits, they quickly assume a passive role, consuming content or taking a break. This expectation is often in contrast with what a UX designer intends: VR is about interaction.

The Human Joystick

Leaning interfaces represent a distinct form of locomotion interface that consistently yields positive results in terms of interactivity, enjoyment, and engagement [9], [13], [16], [27]. These interfaces draw inspiration from the concept of a human joystick, akin to an analog stick on a game controller, where (upper) body or head movements directly translate into virtual movement in the corresponding direction and/or speed of travel (see Figure 3). The inherent need to shift the body's center of gravity makes leaning interfaces particularly well-suited and safe for use while seated rather than standing.

In implementations with upright use, the user is usually either secured in or by an apparatus [27] or it is more of a stepping interface [28], i.e., the user steps out from a pivot point to set the direction of the movement instead of actually bending or tilting parts of the body. Across various implementations, leaning interfaces consistently demonstrate a positive impact on enjoyment, engagement, and performance when compared to standard controller-based input methods [13], [16], [27].

Furthermore, traditional controllers can pose a barrier, especially for individuals without prior experience with technology. Based on our ongoing qualitative study involving in-depth semi-structured interviews and focusing on the interaction with these interfaces among individuals with no prior experience, we have observed that people often display resistance towards devices featuring numerous buttons and blinking lights. This resistance is often rooted in their apprehension about their ability to operate such devices. Interestingly, these reservations are not mirrored with body-based interfaces, which we provide to individuals without additional instructions. Participants readily put on a VR headset without much hesitation, initially assuming they are just going to look around with little potential for anything to happen. This initial hurdle is overcome once they become immersed in an unexpected and engaging world, and they are more than eager to take on an active role and move. When they discover they can use their bodies for interaction, their enthusiasm knows no bounds.

Affordances

However, part of this advantage arises from a limitation of body-based interfaces, particularly when individuals are seated. Naturally, sitting is inherently associated with passivity and lacks affordances for movement and leaning, in contrast to a traditional controller where each button and joystick serves a distinct purpose. While the subsequent reaction to a button press may be surprising, users quickly explore the potential interaction space, at least when it is not used for wild gestures or button combos. An unguided user can also learn to activate a leaning interface but it could be by swimming breaststroke, as we have

Figure 4. A hoverboard metaphor is a good example of how to provide the user with easy to grasp and convincing mental model of what they are experiencing when locomoting with a (seated) leaning interface.

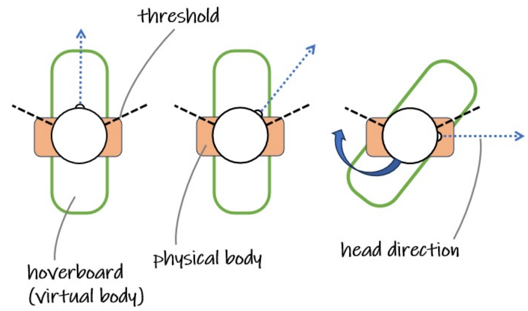

Figure 5. Scrolling from a bird's eye: A virtual yaw rotation that is initiated when the user's head direction exceeds a defined offset threshold with respect to the orientation of their body (here torso), i.e. is looking around [16]. It is important to note that for illustration purposes the virtual hoverboard is indicated to start turning in reaction to the user looking to the right, which is not accurate: The virtual (hoverboard) and user's physical body stay always aligned but the virtual world around them is turning, or they are together turning in the virtual world, which differs only from the point of reference.

observed in the aforementioned study. Here, the researcher and/or developer have a significantly greater responsibility to create artificial affordances [29]. However, once someone has been told to lean forward, seen someone else do it, or experimented with different postures, anyone can use a leaning interface.

One solution to create affordances and foster streamlined mental models is to employ strong and convincing metaphors. An example frequently used in conjunction with leaning interfaces, which has shown to work well even while seated, is the concept of hoverboards [30] (see Figure 4). Influenced by films and television, users immediately recognize the distinctive sound associated with a hovering vehicle, inviting them to lean and naturally engage with the interface. This metaphor, however, may not be universally applicable, and specific solutions must be tailored to the unique requirements of each application.

Virtual Rotation

Metaphors and interfaces have their boundaries, and in the realm of 3D user interfaces, these limitations can risk constraining users within an interaction environment that may not be ideal. A notable example of this is virtual rotation, which is essential not only for seated users but is more frequently required in this context due to restricted mobility. Seated users may encounter objects and obstacles while working at a desk, sitting on a sofa, or using public transportation.

Both leaning interfaces and the hoverboard metaphor have inherent limitations when it comes to accommodating rotations. In the case of leaning interfaces, the degrees of freedom provided by a bending body are not sufficient to control both translation and rotation simultaneously. To address this challenge, alternative concepts come into play, such as scrolling, where a virtual rotation around the yaw axis occurs when the user surpasses a predefined threshold while physically looking to the left or right (see Figure 5). However, this approach restricts the user's ability to look around freely [13]. Additionally, the virtual rotation, contrary to expectations due to the fact that it at least partially corresponds to the physical head movement, does not seem to alleviate the user's discomfort.

As mentioned earlier, user discomfort often arises from conflicts between visual perception and the vestibular system. The frequent need for virtual movements in seated scenarios exacerbates the challenge of cybersickness. Circular vection, the perception of self-rotation, seems to have a more pronounced impact on motion sickness than vection resulting from translation [20]. Unfortunately, virtual rotation is more commonly required in seated scenarios than in standing ones, as physical rotation is often limited. This can nullify the previously mentioned advantage of sitting in reducing cybersickness.

Motivated by these circumstances, we are actively exploring implementations involving discrete and semi-continuous virtual rotation instead of continuous rotations [31], [32], along with methods of translational movement [33]. In this approach, the direction and speed of rotation and/or translation are continuously controlled by the user, but the viewpoint transitions are no longer continuous or only partially so; instead, the user ”jumps” between viewpoints. This behavior resembles teleportation techniques but with continuous control rather than discrete target selection. It mitigates the perception of self-motion, which would otherwise conflict with the vestibular system. While the solution may sound straightforward, it is not. We aim to provide users with a sense of motion without the negative consequences, striking a delicate balance between the advantages and disadvantages of different approaches. Achieving this balance requires careful consideration and evaluation of various factors, and it remains an open question whether a net benefit can be derived from this balancing act in the end.

Design Guidelines

Given the complexities surrounding the choices of sitting and standing in VR experiences, it is crucial to establish clear design guidelines that prioritize user comfort, inclusivity, and engagement. While fundamental questions persist within the scientific field, we aim to draw insights from the preceding discussions and present a set of early guidelines to assist designers and developers in crafting immersive VR experiences:

Consider User Comfort: When designing VR experiences, prioritize the comfort of users. Recognize that sitting can offer a more comfortable alternative than standing for extended periods, particularly in long-term experiences, and it is preferred by a significant portion of VR users.

Minimize Postural Conflicts: Be mindful of potential postural conflicts in VR and strive to minimize them. Avoid imposing arbitrary seated or standing postures on the user unless these postures serve a specific purpose within the experience. Ideally, design applications that allow users the freedom to choose between sitting and standing, facilitating seamless transitions while maintaining consistency in the user’s perception.

Use Strong Metaphors: Incorporate strong and convincing metaphors into your VR design to create affordances and streamline mental models for user interaction. Robust metaphors provide users with guidance on how to interact effectively with the virtual environment.

Leaning Interfaces: Consider leaning interfaces as a compelling alternative for seated travel, especially when engagement and enjoyment are the primary objectives. Leaning interfaces offer a natural and intuitive means of controlling VR experiences while seated. In cases where leaning interfaces may not be suitable, alternatives such as teleportation or pointing-directed steering can provide simple and efficient solutions.

Reducing Cybersickness: Explore methods to reduce cybersickness in seated VR experiences. Consider implementing semi-continuous rotations and discrete viewpoint transitions to mitigate the perception of self-motion. Recent research suggests that the mitigation of cybersickness is not solely about avoiding sensory conflicts but also entails addressing elements like preventing surprise [34] and conveying agency [20]. Strong metaphors continue to play a pivotal role in achieving these objectives.

Future Work

In conclusion, we outline several areas for future research and exploration that hold promise in addressing the challenges and opportunities associated with postural choices in VR.

The Role of Postural Conflicts: Investigate the implications of postural conflicts in VR, including whether the direction of the conflict plays a significant role. Determine how different postural conflicts (sitting while virtually standing and vice versa) affect the user experience and overall comfort. Understand the potential differences in user experience when the direction of the postural conflict is varied, as this remains one of the significant open questions in the field.

Multi-sensory Integration: Explore the complex relationship between postural conflicts and multi-sensory integration. Gain a deeper understanding of when and how users accept or reject postural mismatches in immersive VR experiences.

Perception of Self-Motion: Examine how various postural conflicts influence the perception of self-motion in VR. Understand the triggers for cybersickness and develop effective strategies to mitigate its effects.

Balance in VR Interaction: Continue to explore the delicate balance between user comfort, postural conflicts, and motion perception in VR. Strive to find solutions that provide engaging experiences while minimizing the negative consequences of postural mismatches.

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