Impact of Interaction-induced body movement on Cybersickness in Interactive Virtual Reality Environments

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***Abstract*—This paper investigates the impact of interaction-induced body movement on cybersickness in Virtual Reality (VR). Therefore we designed a controlled VR environment with three interaction conditions of increasing movement complexity. Data from 24 participants, combining subjective measures and motion-derived features, show a consistent increase in cybersickness with higher movement demands, particularly in conditions involving vertical displacement and full-body interaction. Moreover, correlation analysis reveals a significant negative relationship between the coefficient of variation of head velocity and cybersickness. This suggests that more variable and adaptive motion may mitigate the discomfort. These findings highlight the importance of movement characteristics, beyond movement intensity alone, for designing full-body interactive VR experiences.**

I. Introduction

Virtual Reality (VR) systems increasingly support natural and full-body interaction to enhance immersion, embodiment, and user engagement [1]. Rather than relying solely on controller-based input, modern VR applications encourage users to perform diverse physical actions, including reaching, grasping, bending, and sport-like movements [2], [3]. These interaction paradigms can strengthen the sense of presence and embodiment [4], but they also introduce new challenges related to how the users move, interact, and experience comfort in immersive environments.

Body movement in VR is not a uniform phenomenon. Interaction techniques can differ substantially in their spatial, temporal, and biomechanical characteristics, ranging from small hand gestures to horizontal navigation and vertical full-body actions. These differences may affect user experience in multiple ways, including perceived effort, presence, time perception, postural control, and cybersickness. In particular, while cybersickness remains a major barrier to VR adoption, its relationship with interaction-induced body movement is still not fully understood [5].

Prior work has extensively studied cybersickness in relation to visual motion and locomotion techniques. However, less attention has been given to how specific forms of physical interaction shape both discomfort and broader experiential outcomes, especially in scenarios requiring full-body engagement. In particular, existing studies often treat movement as a general factor, overlooking how horizontal and vertical movement demands, motion variability, and interaction context may contribute differently to the user experience [6].

This work addresses this gap by investigating how different interaction-induced body movement demands impact user perception. To this end, we designed an interactive VR environment with three progressive interaction levels. These increase movement demands while preserving a consistent task structure. Data from 24 participants combine subjective measures of cybersickness, presence, perceived time, and interaction quality with synchronized recordings of head and full-body movement. We examine differences between horizontal and vertical interaction demands, the role of motion characteristics such as head dynamics and vertical displacement, and how presence, perceived time, and cybersickness relate across interaction contexts. The remainder of this paper presents the methodology, evaluation, results, and conclusions.

II. Methodology

A. VR environment and user study

To examine movement and interaction effects, we designed a VR experiment that varies movement demands while keeping the task consistent across conditions. The overall experimental workflow and level structure are depicted in Figure 1. To create an engaging scenario, participants prepared customer orders in a fast-food workshop simulation. Participants follow instructions to prepare fries, soda, and sauces before delivering them on a tray. They complete a multi-step order preparation task designed to introduce controlled variations in movement. Each order requires selecting ingredients, preparing them, such as chopping or frying, and assembling the items before delivery, prompting users to move across the workspace and interact with different objects. Interactions use distinct hand gestures, requiring users to switch modalities while remaining consistent across conditions. Additionally, the interaction sequences require continuous engagement (e.g., holding inputs to activate machines), which encourages active participation and keeps users moving throughout each trial.

We introduced three levels with progressively increasing motion requirements (see Figure 1). First, *Tutorial*, serves

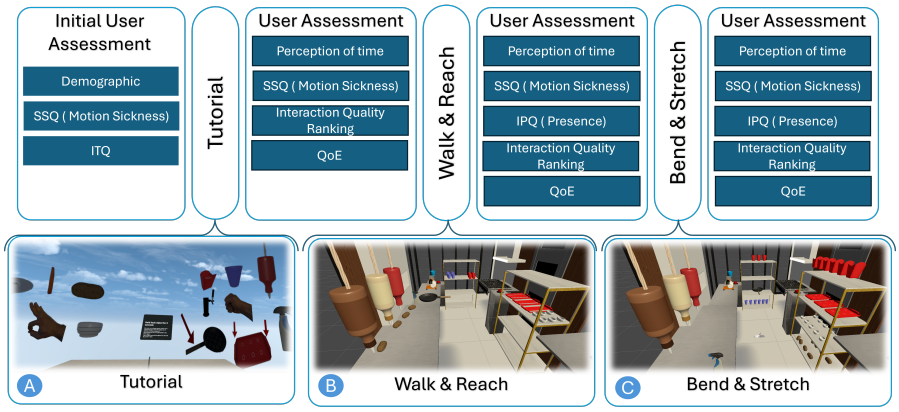


Fig. 1: Overview of the experimental VR design, including assessment timeline and the three interaction levels (Tutorial, Walk & Reach (W&R), Bend & Stretch (B&S)).

as both a baseline and control condition. Participants remain stationary behind a table and interact with objects appearing directly in front of them. They are instructed to hold each object for five seconds, with no requirement for reaching far or bending. The second and third levels build upon the same task structure but systematically increase movement demands through the spatial arrangement of objects and tools. In *W&R*, interactive elements are distributed horizontally across the workspace, requiring participants to move laterally and reach across the environment while maintaining a relatively constant vertical posture. For example, users retrieve ingredients from different kitchen areas and carry them to processing stations. To encourage horizontal movement, objects dropped below a predefined height are reset to their original positions. Finally, *B&S* introduces vertical variation by placing objects at different heights, requiring participants to bend, squat, and stretch while performing the same preparation tasks. This increases full-body involvement by adding vertical movement to the interaction. For example, potatoes were placed at ground level, requiring users to bend down, while other items are positioned on high shelves, prompting them to stretch upward.

This design allows us to isolate the contribution of different movement components, ranging from minimal motion to full-body engagement, while maintaining a consistent task. Consequently, any observed differences in user experience or cybersickness can be more directly attributed to the level of physical interaction rather than task variation. After each of the levels, subjective assessments were collected, including Simulator Sickness Questionnaire (SSQ), perceived time, and interaction quality, allowing us to track how user experience evolves with increasing movement demands.

B. Data Analysis

To examine the relationship between movement characteristics and cybersickness, we analyzed motion data from both the Head-Mounted Display (HMD) and a motion capture (MoCap) system which was installed in the test physical environment, focusing on features that capture movement intensity, variability, and spatial displacement. From the HMD velocity signal, we extracted mean velocity to quantify motion intensity, the coefficient of variation (v_{coefvar}) to capture relative head-movement variability, and jerkiness, computed as the temporal derivative of velocity, to characterize motion abruptness. MoCap data complemented head-motion features by capturing full-body cumulative displacement along the three spatial axes. Horizontal displacement (X and Y) represents lateral and forward motion, while vertical displacement (Z) captures movements such as bending, squatting, and stretching, which are particularly prominent in the B&S condition. More details on the collected multimodal data can be found in [7].

These features capture key motion characteristics linked to cybersickness, including movement intensity, variability, and abruptness [8]. All extracted features were analyzed in relation to cybersickness scores obtained from the SSQ. Due to the sample size and distribution characteristics, non-parametric statistical methods were employed. Correlation analyses were conducted to assess associations between motion features and cybersickness, and Bonferroni correction was applied to account for multiple comparisons. This approach allowed us to evaluate not only the effect of movement intensity, but also how specific motion characteristics, such as variability and vertical displacement, contribute to user discomfort.

C. Participants

A total of 24 participants (16 male, 8 female) took part in the study (Figure 1). Participants were aged between 24 and 40 years (M = 29.0, SD = 4.59), with 19 right-handed and 5 left-handed individuals. Regarding technical proficiency, 13 participants reported high and 11 reported medium familiarity. Prior VR experience varied, with 3 very experienced users, 8 experienced users, 11 participants having tried VR once, and 2 with no prior experience.

III. Results

A. Movement and Interaction type

Cybersickness scores were analyzed across the three interaction levels. Descriptive statistics reveal a progressive increase in cybersickness as movement demands intensify. The Tutorial condition shows the lowest scores ($M = 2.79$, $SD = 2.78$), followed by W&R ($M = 3.54$, $SD = 3.56$), while B&S

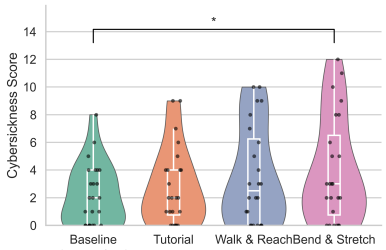


Fig. 2: Cybersickness scores across conditions

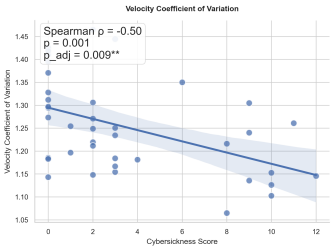


Fig. 3: Coefficient of variation vs Cybersickness

exhibits the highest values ($M = 3.96$, $SD = 3.83$). In addition to higher mean scores, the B&S condition also presents greater variability and higher maximum values.

To evaluate differences across conditions, a Friedman test was conducted. The analysis did not reveal a statistically significant main effect of condition ($\chi^2(2) = 6.84$, $p = 0.07$), but indicate a trend toward differences across movement levels. Further pairwise comparisons using Wilcoxon signed-rank tests show that cybersickness in the B&S condition is significantly higher than in the baseline ($p = 0.03$). The comparison between W&R and B&S does not reach statistical significance, although higher scores are consistently observed in the vertical movement. These results highlight a consistent pattern, as movement becomes more vertically demanding, cybersickness and feeling of discomfort tends to increase.

B. Motion Dynamics

To better understand how movement characteristics relate to cybersickness, we examined correlations between subjective scores and motion-derived features extracted from HMD and motion capture recordings. A notable finding emerges from the coefficient of variation of velocity (v_{coefvar}), which shows a moderate and statistically significant negative correlation with cybersickness ($r = -0.50$, $p < 0.01$, Bonferroni-corrected) (see Figure 3). In contrast, mean velocity exhibits a weak positive correlation with cybersickness ($r = 0.29$, $p = 0.33$), and the proportion of time spent actively moving follows a similar trend, although neither reaches statistical significance after correction. Taken together, these patterns point toward a more nuanced relationship between motion and discomfort. Rather than sheer movement intensity, it appears that how users move. Specifically, whether their motion is flexible and adaptive may play a more important role. One possible interpretation is that users who vary their motion can better regulate sensory input, thereby reducing sensory conflict. At the same time, this effect should be interpreted with caution, as the coefficient of variation is inherently influenced by mean velocity. Lower average speeds can inflate variability measures, suggesting that slower, less consistent motion may also contribute to reduced cybersickness.

Directional MoCap features showed a small, non-significant positive correlation between vertical displacement and cybersickness ($r = 0.20$, $p = 0.19$), while horizontal displacement showed negligible associations. Although not statistically significant, this trend hints that vertical motion, more prevalent in physically demanding interactions such as bending and squatting, may contribute to discomfort.

C. Presence and Cybersickness

Additional analyses were conducted to explore relationships involving presence and individual differences. No significant correlation is observed between presence and cybersickness in the W&R condition ($r = 0.111$, $p = 0.605$). In contrast, a moderate positive relationship is observed in the B&S condition ($r = 0.368$, $p = 0.077$), although this does not reach statistical significance, suggesting a context-dependent trend. Furthermore, we explored the correlation between immersive tendencies Immersive Tendency Questionnaire (ITQ) and presence ($r = 0.337$, $p = 0.019$), indicating that individuals with higher predisposition to immersion report stronger presence further proving earlier findings [9], [10]. However, immersive tendencies are not significantly associated with cybersickness ($r = 0.160$, $p = 0.278$). These findings suggest that presence and individual differences may influence user experience, but do not directly explain variations in cybersickness, reinforcing the primary role of movement characteristics.

D. Perception of Time

We analyzed perceived time in relation to cybersickness and Quality-of-Experience (QoE) across conditions. The results show that perceived time was linked to different aspects of experience depending on the interaction type. In the W&R condition, perceived duration was positively correlated with cybersickness ($r = 0.64$, $p < 0.05$, Bonferroni-corrected), suggesting that participants who felt more discomfort also perceived the task as longer. In the B&S condition, perceived duration was instead positively correlated with QoE ($r = 0.65$, $p < 0.05$), indicating that during more physically engaging full-body interaction, time perception may be more closely tied to experience quality than discomfort. No significant correlations were found in the Tutorial condition. Overall, these findings suggest that perceived time is context-dependent, reflecting discomfort in horizontal movement and engagement in more complex full-body interaction.

IV. Conclusion

This paper emphasizes the role of interaction-induced body movement in cybersickness and user experience within immersive VR. Cybersickness increases with movement complexity, especially with vertical displacement and full-body engagement. Key factors such as head motion dynamics and movement type contribute to discomfort, with smoother movements helping to reduce symptoms. These findings highlight the need for considering movement characteristics in VR design to enhance user comfort in full-body interactive environments.

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