Immersive versus Non-Immersive Virtual Reality Environments: Comparing Different Visualization Modalities in a Cognitive-Motor Dual-Task

Marianna Pizzo[a], Matteo Martini[b], Fabio Solari[c] and Manuela Chessa[d]
Department of Informatics, Bioengineering, Robotics and Systems Engineering,
University of Genoa, Genoa, Italy
{marianna.pizzo, matteo.martini}@edu.unige.it, {fabio.solari, manuela.chessa}@unige.it

Keywords: Perspective Visualization, Orthographic Visualization, Reaching Task, Counting Task, Presence in VR, Usability in VR, Cognitive Load.

Abstract: In fields like cognitive and physical rehabilitation, adopting immersive visualization devices can be unfeasible. In these cases, the main challenge is to develop Virtual Reality (VR) scenarios that still provide a strong sense of presence, usability, and user agency, even without full immersion. This paper explores a cognitive-motor dual-task in VR, consisting in counting and reaching, comparing three non-immersive visualization methods on a 2D screen (tracked perspective camera, fixed perspective camera, fixed orthographic camera) with the immersive experience provided by a head-mounted display. The comparison focused on factors like sense of presence, usability, cognitive load, and task accuracy. Results show, as expected, that immersive VR provides a higher sense of presence and better usability with respect to the non-immersive visualization methods. Unexpectedly, the implemented 2D visualization based on a tracked perspective camera seems not to be the best approximation of immersive VR. Finally, the two fixed camera conditions showed no significant differences in performance based on the type of projection.

1 INTRODUCTION

Immersive Virtual Reality (VR) technology has expanded beyond gaming and entertainment into fields such as education, training, medical simulation, and rehabilitation. However, transitioning VR into clinical practice remains challenging due to financial constraints, resistance to change, privacy concerns, and gaps in staff training.

Clinicians have recently shown growing interest in *serious games* and *exergames* for rehabilitation (Lee et al., 2024; Ehioghae et al., 2024; Ren et al., 2024; Garzotto et al., 2024). Nevertheless, immersive VR is not always suitable for every rehabilitation protocol due to the unique needs of patients. For instance, it may be unusable in cases of severe cognitive impairment, epilepsy, or simply when clinicians opt for non-immersive VR based on the patient's condition. Another limitation is the lack of sufficient data on the use of head-mounted displays (HMDs) for rare conditions, though this gap is gradually narrowing (Malihi et al., 2020).

Exergames and serious games in clinical settings are often delivered via non-immersive VR on 2D screens, but the lack of depth cues reduces movement precision, increases cognitive strain (Wenk et al., 2022), and limits the immersive benefits of VR (Rao et al., 2023). Moreover, the use of perspective cameras in 3D virtual environments can distort object proportions on 2D screens. To address this issue, clinicians often require to downgrade exergames to 2D scenarios; although these are easier to manage, they lose foundamental advantages of 3D environments, such as depth perception, spatial representation, and improved eye-hand coordination. A potential solution to these issues is the adoption of orthographic camera visualization for non-immersive VR.

In all these cases where immersive VR is not feasible, developers of such systems who collaborate with clinicians, must know which is the best non-immersive alternative to it. For this reason, in this paper, we aim to evaluate which non-immersive visualization modality can provide a user experience

---

[a] https://orcid.org/0009-0004-8653-4018
[b] https://orcid.org/0009-0006-3929-5055
[c] https://orcid.org/0000-0002-8111-0409
[d] https://orcid.org/0000-0003-3098-5894

Pizzo, M., Martini, M., Solari, F. and Chessa, M.
Immersive versus Non-Immersive Virtual Reality Environments: Comparing Different Visualization Modalities in a Cognitive-Motor Dual-Task.
DOI: 10.5220/0013133600003912

In *Proceedings of the 20th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications (VISIGRAPP 2025) - Volume 1: GRAPP, HUCAPP and IVAPP*, pages 561-568
ISBN: 978-989-758-728-3; ISSN: 2184-4321

that most closely resembles immersive VR. Specifically, we aim to understand if a non-immersive perspective visualization (onto a 2D screen), continuously updated by considering the tracked user's actual pose (in this paper referred to as point-of-view, POV), could be a valid substitution for immersive VR. Moreover, we aim to analyze the differences between non-immersive fixed (i.e., without tracking the users' head pose) perspective and orthographic visualization (PERSP and ORTHO, respectively). The following hypotheses are formulated:

- **H1.** The non-immersive tracked perspective visualization (POV modality) is the best approximation of immersive VR, thus showing (a) a higher sense of presence, (b) better usability, and (c) a lower cognitive load compared to PERSP and ORTHO modalities.
- **H2.** The non-immersive perspective (PERSP modality) and orthographic visualization (ORTHO modality) provide comparable (a) sense of presence, (b) usability, and (c) cognitive load.
- **H3.** As a control hypothesis, the experimental setup confirms the finding of previous work (Pallavicini et al., 2019; Boyd, 1997; Wenk et al., 2022) that demonstrated the advantages of immersive VR with respect to non-immersive visualisation modalities, particularly in terms of (a) a higher sense of presence, (b) better usability, and (c) reduced cognitive load.

To compare the different visualization modalities, we consider a cognitive-motor dual-task: subjects are asked to count specific objects appearing in the virtual scene (cognitive task) while reaching specific targets (motor task). This approach is widely used in the literature to evaluate the cognitive load in different conditions (Baumeister et al., 2017; Souchet et al., 2022).

2 RELATED WORK

Serious games and exergames are interactive computer-based games designed for purposes beyond entertainment, such as education, skill enhancement, and behaviour change. Both are examples of gamification, which applies game elements in non-game contexts (Landers, 2014). Gamification is widely used in fields like education, healthcare, and wellness, often integrating VR to enhance immersion and user experience through realistic, ecological 3D environments (Carlier et al., 2020).

According to (Bassano et al., 2022), VR setups can be classified into non-immersive, semi-immersive, and immersive categories. Non-immersive systems use screens that do not occlude the user's field of view (FOV), allowing a persistent sense of the real world. Semi-immersive systems, such as driving simulators based on multi-monitor configurations or like the CAVEs, provide partial virtual environments and do not block external sensorial stimulations, whereas immersive systems, e.g., the Meta Quest 3[1] or HTC Vive[2], fully immerse the user in the virtual environment.

Despite the benefits of immersive VR in enhancing presence, most exergames and serious games still rely on non-immersive setups due to their accessibility, affordability, and portability (Bassano et al., 2022). Even with advancements in affordable HMDs with high performance, non-immersive VR remains the most widely used visualization technology, followed by immersive VR. Recent findings in (Sudár and Csapó, 2024) also show that cognitive load in 2D tasks using standard UIs and non-immersive 3D environments is comparable.

In their systematic review and meta-analysis, (Ren et al., 2024) examined the impact of VR-based rehabilitation on patients with mild cognitive impairment or dementia, highlighting the benefits of immersive over non-immersive VR. Immersive VR showed significant improvements in cognition and motor function compared to non-immersive setups, due to the transfer of cognitive skills from the game to reality, enhancing real-world performance.

In (Wenk et al., 2019), the impact of visualization technologies on movement quality and cognitive load was assessed by comparing (i) an immersive VR HMD, (ii) an Augmented Reality (AR) HMD, (iii) and a computer screen. Participants performed goal-oriented reaching motions (measured with an HTC Vive controller) while completing a concurrent counting task to assess cognitive load. Compared to screen displays, VR improved motor performance, which is likely due to the more direct mapping between virtual representation and physical movement. On the other hand, there was not a noticeable impact of the display mode on cognitive load.

The same authors repeated the experiment with twenty elderly participants and five subacute brain-injured patients (Wenk et al., 2022) to evaluate the effects of different visualization technologies on movement quality and cognitive load. Results for 3D reaching movements mirrored the first study, but HMDs appeared to reduce cognitive load. Participants also rated HMDs as highly usable, supporting their use in future VR-based rehabilitation.

These findings were further confirmed in a sub-

---

[1] https://www.meta.com/it/quest/quest-3

[2] https://www.vive.com/eu/

sequent study (Wenk et al., 2023), where twenty healthy participants performed the same task under the same conditions and completed questionnaires to assess cognitive load, motivation, usability, and embodiment. While cognitive load remained unaffected across technologies, VR was rated as more motivating and usable than AR and 2D screens. Additionally, VR and AR achieved higher levels of embodiment compared to the 2D screen.

These studies align with our control hypothesis H3 suggesting that immersive HMDs are better suited for training 3D movements in VR-based therapy compared to conventional 2D screens, and also have a positive effect on system's usability and cognitive load. However, as highlighted in the introduction, HMDs are not always a feasible option. This motivates the need to further evaluate the effects on users of different non-immersive visualization modalities. Notably, no other studies have specifically addressed the impact of visualization modalities on user experience in virtual environments.

3 EXPERIMENT

3.1 Participants

Participants were recruited voluntarily from the University of Genoa for a within-subject study evaluating the effects of four visualization modalities on participants' cognitive load, sense of presence, and usability. Twenty-four healthy participants (8 female, 16 male), aged 20 to 56 years (26.71 ± 8.10), with no known motor, cognitive disorders, or color blindness took part. Most had little to no prior experience with HMDs, and no compensation was provided. The study complied with the Declaration of Helsinki.

3.2 Visualization Modalities

In this study, we evaluated four visualization modalities (see Figure 1):

- VR: immersive VR using HMD;
- POV: non-immersive VR on 2D screen with tracked perspective camera;
- PERSP: non-immersive VR on 2D screen with fixed perspective camera;
- ORTHO: non-immersive VR on 2D screen with fixed orthographic camera.

In the VR condition, participants used a fully immersive HMD: the Meta Quest 2[3]. Hand movements were tracked using the XR Hands[4] Unity package, while the body animation was handled with the Final IK[5] plugin.

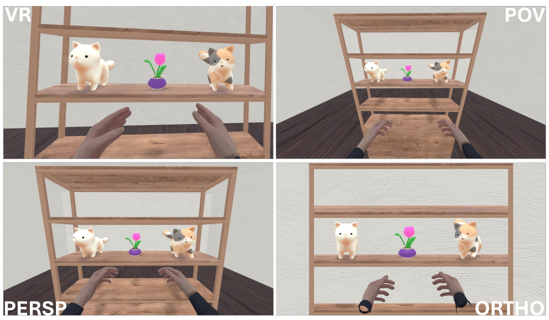

Figure 1: The four visualization modalities considered in the cognitive-motor dual-task.

In the POV condition, participants experienced the virtual environment (VE) on a 47" LG 47LM615S screen (1920x1080 resolution) placed 155 cm away, while seated on a fixed chair 112 cm from the screen center (consistent across all non-immersive conditions). In between the participant and the screen, a ZED Mini depth camera[6] is positioned 35 cm ahead of the monitor and tracks the user's 3D pose, including 38 body joints. In this way, the avatar's arms and the virtual rendering camera can move in sync with the user's arm and head movements, tracked by the ZED device. A virtual perspective camera with a vertical FOV of 75° is used in this condition, and its 6 degrees of freedom (6DOF) pose is updated with respect to the tracked 6DOF position of the users' head.

In the PERSP condition, the same screen and ZED setup were used, but the virtual perspective camera was fixed with a 7° downward tilt to ensure all shelves were in view. Arm movements were tracked and replicated into the virtual scene.

In the ORTHO condition, participants used the same screen and setup, but in this condition, we use an orthographic camera with a viewport size set so that all the shelves are in the field of view. Again, only arm movements were tracked and replicated.

In all conditions, a gender-neutral, light-skinned full-body avatar downloaded from Adobe Mixamo[7] was used to match participants' demographics. The virtual environment (VE) featured light grey walls and a wooden floor to minimize distractions.

---

[3] https://www.meta.com/it/quest/products/quest-2

[4] https://docs.unity3d.com/Packages/com.unity.xr.hands@1.5

[5] http://root-motion.com/#final-ik

[6] https://store.stereolabs.com/en-it/products/zed-mini

[7] https://www.mixamo.com

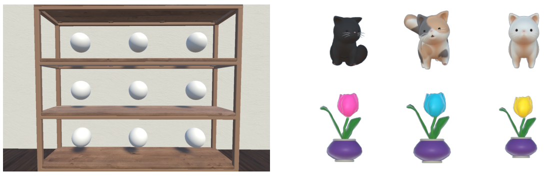

Figure 2: The shelving unit (left) and the types of cats and flowers shown during the cognitive-motor task (right). The white spheres (not shown during the experiment) on the shelving highlight the position where objects were spawned.

3.3 Experimental Setup

The experiment was conducted in a room with controllable artificial lighting. The ZED Mini depth camera was used across all visualization modalities to record upper body movement data (head, trunk, and arms) consistently.

The VE was developed using the Unity 3D game engine (version 2022.3.23F_1, Unity Technologies, USA). The ZED plugin version 4.1 for Unity 3D handled motion tracking. The avatar was animated using the IMMERSE framework (Viola et al., 2024) which requires a brief calibration phase at the start of the VR session to adapt the avatar to participants' body proportions.

The workstation operated on Windows 11 Home 64-bit (Microsoft, USA), equipped with an AMD Ryzen 9 5900X processor (12 cores/32 threads) and an NVIDIA RTX 3080 Ti graphics card.

3.4 The Dual Cognitive-Motor Task

Participants performed the same dual-task across different visualization modalities. A shelving unit with nine fixed positions, arranged in a 3x3 square layout at equal depth, was placed centrally in front of them (see Figure 2). To exclude depth estimation cues, all objects were positioned equidistant from the user. Objects included three types of cats (white, black, tabby) and three types of flowers (pink, blue, yellow), all of the same size (see Figure 2).

For the motor task, participants were instructed to reach for pink flowers using their bare hands, tracked and displayed in the virtual environment. Reaching could be executed with either hand without specific arm positioning instructions, though most rested their arms on their laps. Successfully reaching an item made it disappear with a pop sound for auditory feedback. For the cognitive task, participants counted aloud the cats appearing on the shelves.

The items were presented in four blocks of increasing difficulty: Block 1 had one item per trial, Block 2 had two, Block 3 had three, and Block 4 had four items. Each block consisted of 7 trials (so for each modality, users are exposed to 28 trials), including a final randomized trial added to vary the cat count. Each trial lasted 5 seconds or ended earlier if all items were reached. Trials within each block were randomized, while block order remained sequential to ensure progressive difficulty.

3.5 Procedure

A demo video of the experiment is shown here[8]. A researcher was present throughout the experiment. After a briefing on the task objectives, participants completed a brief training session to confirm their understanding. They then performed the dual cognitive-motor task in VR, followed by the three non-immersive modalities (POV, PERSP, ORTHO) in a randomized order. The six possible modality orders were evenly distributed among participants (four per order).

At the start of each condition, participants were informed of the current visualization modality. Before the VR task, a calibration phase ensured the shelving unit was positioned at shoulder height and equidistant from the user by having participants hold their arms up at shoulder level, palms down.

After VR, the system automatically calibrated the avatar's position to align with the shelving and camera for the subsequent non-immersive modality. At the end of each condition, participants completed self-assessment questionnaires on sense of presence, usability, and perceived cognitive load. Finally, participants ranked the visualization modalities in a tier list based on their preference.

3.6 Instruments

To assess participants' sense of presence, we used the Igroup Presence Questionnaire (IPQ) (Schubert et al., 2001), a 14-question tool on a 7-point Likert scale (0–6) measuring three key aspects:

- *Spatial Presence (SP)*, the sense of being physically present in the virtual environment;
- *Involvement (INV)*, measuring attention and engagement with the virtual environment;
- *Experienced Realism (REAL)*, assessing the perceived realism of the virtual environment.

Additionally, one item evaluates the general sense of *"being there" (PRES)*, which encompasses spatial presence, emotional engagement, and cognitive involvement, along with the illusion of ownership over

---

[8] https://youtu.be/k1AMaxmxgAM

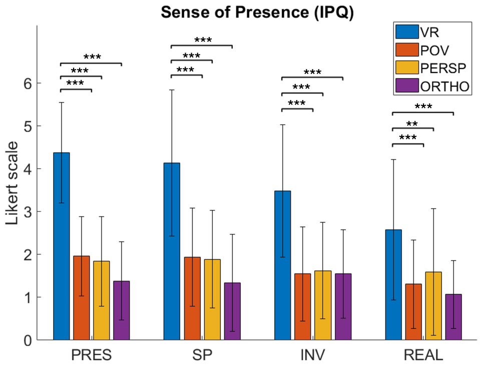

Figure 3: The IPQ results are reported for the three subscales: spatial presence (SP), involvement (INV), and experienced realism (REAL). Lastly, PRES refers to the additional item for the general sense of "being there".

a virtual body (Slater et al., 2022; Hartmann et al., 2015).

To evaluate usability, we employed the System Usability Scale (SUS) (Brooke et al., 1996), a 10-question, 5-point Likert scale. Raw scores are rescaled to a 1–100 range, where 68 is the average score:

- Below 51 indicates serious usability issues;
- Scores around 68 suggest room for improvement;
- Above 80.3 signifies excellent usability.

This scoring is the result of a statistical analysis of three different datasets of SUS questionnaires, encompassing nearly 450 studies.

For cognitive load, we combined task performance scores with the Raw Task Load Index (RTLX) (Hart, 2006), a shortened version of the NASA Task Load Index (Hart and Staveland, 1988). The RTLX uses six sub-scales to measure mental, physical, and temporal demand, as well as performance, effort, and frustration, with responses rated on a 100-point Likert scale.

4 RESULTS

Figure 3 shows the results of the IPQ. A one-way repeated measures ANOVA was conducted to examine variations in IPQ subjective reports across different modalities. The significance threshold was set at $\alpha = 0.05$, with post-hoc analysis performed where necessary to identify differences between specific conditions. The VR condition demonstrated higher IPQ scores across all considered aspects. In the corresponding figure, asterisks indicate the presence of statistically significant difference, and their number represents its level: one asterisk for $p \leq 0.05$, two for $p \leq 10^{-2}$, and three for $p \leq 10^{-3}$.

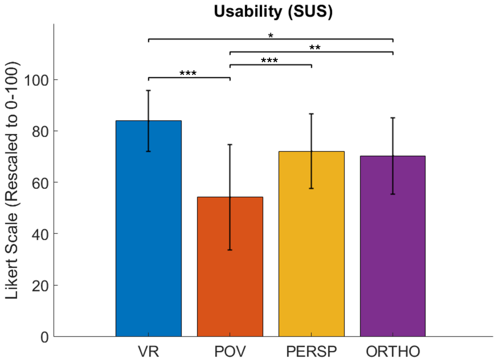

Figure 4: The SUS questionnaire results.

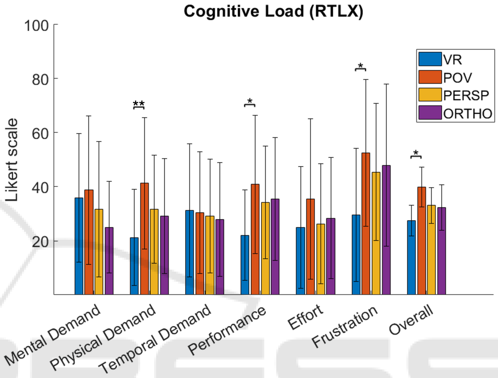

Figure 5: The RTLX questionnaire results.

ANOVA was conducted to analyze differences among visualization modalities in usability and to explore variations in SUS subjective reports. As shown in Figure 4, the VR modality achieved an average usability score of 83.85, indicating optimal usability and ranking first among the four modalities. PERSP and ORTHO, with scores of 72.08 and 70.31 respectively, demonstrated usability slightly above the passing grade. Lastly, POV is below the usability threshold, with a SUS score of 54.17: following the literature results, it is not unusable but does have some usability issues. Asterisks indicate the presence of significant difference following the same rules as those used for the IPQ score.

As shown in Figure 5, for the cognitive load, VR and POV modalities showed statistically significant differences, through ANOVA analysis, in the physical demand, performance, and frustration sub-scales individually and in the overall score. Also here, the asterisks indicate a significant difference emerged from the post-hoc analysis, following the same conventions described previously.

In Figure 6, we present the errors made by par-

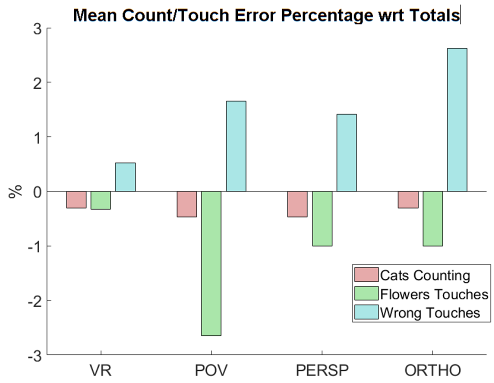

Figure 6: Mean percentage errors in the cognitive-motor task. In particular, we have: the amount of miscounted cats with respect to the total amount of shown cats (in pink); the mean percentage error for the reaching task, i.e., the number of untouched target flowers with respect to the total amount of target shown flowers (in green); and the mean percentage of wrongly touched objects (objects that should not be touched but were, in blue).

ticipants during the cognitive-motor task experiment. Specifically, we calculate the mean percentage error for the cognitive task (miscounted cats relative to the total shown), the reaching task (untouched target flowers relative to the total shown), and the percentage of wrongly touched objects (cats or non-target flowers).

The number of miscounted cats (pink) can theoretically be positive or negative, as users might overestimate or underestimate the count. However, the graph shows negative values, reflecting a general tendency to underestimate. The number of untouched target flowers (green) is inherently negative, indicating failures to touch required flowers. Lastly, the percentage of wrongly touched objects (blue) is always positive, as it measures incorrect touches relative to the total displayed.

5 DISCUSSION

Among the three non-immersive visualization modalities, the POV condition is, in principle, the most similar to immersive VR. Indeed, in this modality, the virtual camera pose is continuously updated according to the tracked user position, as it happens in HMDs. The PERSP and ORTHO conditions do not update the pose of the virtual camera, and they are often preferred in order to avoid discomfort. The PERSP condition allows us to maintain depth cues, like perspective, but it could generate distortions due to the fact that the projection plane and the virtual camera parameters are different with respect to the observer's ones. To this aim, sometimes people prefer not to have these distortions, thus using the ORTHO condition, in which perspective division is no longer present and depth cues are eliminated.

Firstly, the results support our control hypothesis H3 about the superiority of the immersive condition with respect to other modalities both in terms of presence and usability, with IPQ scores and SUS scores significantly higher. While no significant differences in cognitive load (RTLX) were found between VR and ORTHO or PERSP, immersive VR showed lower cognitive load than POV and achieved the lowest error rates in the motor task (0.5% wrong targets, 0.3% missed flowers), confirming its advantage in motor tasks. These findings align with the previous result. The absence of a significant difference in cognitive load between the immersive and non-immersive conditions might be due to the task itself.

Then, we aimed to understand whether POV visualization is the best approximation of immersive VR. Our results seem to reject the H1 hypothesis. Indeed, POV visualization does not provide a better sense of presence, better usability, or a lower cognitive load. Regarding presence, the POV condition, like other non-immersive conditions, shows significant differences compared to immersive VR, but no significant differences were found between POV and the other non-immersive conditions. For usability, the score was 54.17, significantly lower than all other modalities, which exceeded the usability threshold of 68 mentioned in 3.6. This is reflected in the RTLX results, which show significant differences from the immersive condition in physical demand, performance, frustration, and overall experience. Additionally, the reaching task results indicate more errors in the POV condition, with 1.6% of wrongly touched targets and 2.5% of missed pink flowers. This usability issue may be due to the specific implementation of the POV visualization technique. As shown in Figure 7 (left), the frustum follows the tracked head position, causing the projection of a virtual object *O* to shift left on the screen during rightward head movement, unlike real-world perception. An ecological implementation (Figure 7, right) uses an asymmetric frustum with the focal plane aligned to the screen, making the projection shift right, as in the real world. It is worth noting that, given the setup and the task required of the participants, the amount of head rotation observed during the experiments was quite limited. As a result, their perception was not significantly different from what they would have experienced with the ecological implementation. However, a focal plane at a different position would still cause incorrect motion (see (Solari et al., 2013) for the stereoscopic case).

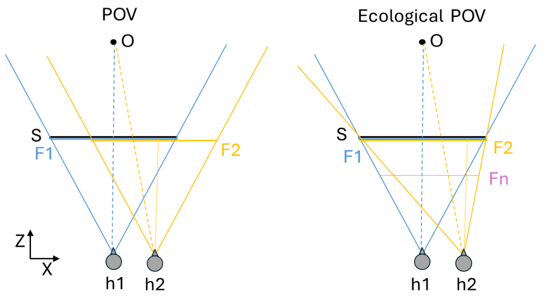

Figure 7: A sketch of the geometry for the POV visualization technique: a view from above (X-Z plane). Two head positions (h_1 and h_2) and a virtual object (O) are considered. The screen (S) and the frustum with the relative focal plane (F_1) are also drawn: specifically, F_1 and dark blue for h_1, and F_2 and orange for h_2 (dashed lines denote the projection rays). (left) The current implementation of the POV: the frustum follows the tracked head. (right) An ecological implementation of the POV (the purple F_n shows a focal plane in a different position).

Finally, our results confirm that the PERSP and ORTHO visualization modalities are characterized by a comparable sense of presence, usability, and cognitive load (H2 accepted). Looking at the results, it is worth noting that the PERSP modality shows higher (though not significant) values of the presence and spatial presence factors in the IPQ. Moreover, though the percentage of errors in the counting task and in the pink flower reaching task are comparable between the two modalities, the ORTHO visualization shows a slightly higher percentage of wrongly touched objects. These results may confirm the added value of perspective cues in 2D visualization.

At the end of the experiments, we also asked the participants to provide a ranking of the visualization modalities. Their choices allowed us to have the following ranking: 1) immersive VR, 2) PERSP, 3) ORTHO, and finally, 4) POV. This ranking maps exactly to the obtained quantitative results.

6 CONCLUSION AND FUTURE WORK

In this paper, we have compared four visualization techniques considering a cognitive-motor dual task. This work is motivated by the fact that in some specific contexts, such as healthcare, immersive visualization is not possible and for this reason we aimed to provide a guidance on non-immersive visualization modalities to developers working in this field.

Results shows that immersive VR (HMD) outperforms the non-immersive visualization modalities. Although there are few statistically significant differences between immersive VR and non-immersive methods, immersive VR excelled in cognitive (counting) and motor (reaching) tasks. Furthermore, immersive VR significantly surpassed the non-immersive conditions in terms of users' sense of presence and usability. Contrary to our expectations, our implementation of a non-immersive visualization that accounts for users' head movements does not outperform the fixed non-immersive modalities (PERSP and ORTHO). Indeed, the implemented POV technique shows the worst results in terms of usability and cognitive load. Lastly, fixed non-immersive visualization techniques do not show significant differences with respect to the kind of projection (perspective or orthographic). However, perspective one is more appreciated and slightly better in terms of percentage errors.

Our analysis has several limitations. First, the POV implementation shows discrepancies in projections compared to the real world. An ecological POV with an asymmetric frustum, as shown in Figure 7, should be implemented to reassess H1. Additionally, the low error rates in cognitive and motor tasks suggest that a more complex dual-task could better highlight differences between modalities. We also observed qualitative differences in arm trajectories during the reaching task, warranting further analysis of potential non-natural behavior. Future work will incorporate an ecologically valid POV, investigate screen distance effects, and explore how different modalities impact movement naturalness. We also plan to evaluate the impact of these modalities on users' embodiment, using the embodiment questionnaire from (Gonzalez-Franco and Peck, 2018).

ACKNOWLEDGEMENTS

This work was supported by the Italian Ministry of Research, under the complementary actions to the NRRP "Fit4MedRob - Fit for Medical Robotics" Grant (# PNC0000007).

REFERENCES

Bassano, C., Chessa, M., and Solari, F. (2022). Visualization and interaction technologies in serious and exergames for cognitive assessment and training: A survey on available solutions and their validation. *IEEE Access*, 10:104295–104312.

Baumeister, J., Ssin, S. Y., ElSayed, N. A., Dorrian, J., Webb, D. P., Walsh, J. A., Simon, T. M., Irlitti, A., Smith, R. T., Kohler, M., et al. (2017). Cognitive cost of using augmented reality displays. *IEEE* *transactions on visualization and computer graphics*, 23(11):2378–2388.

Boyd, C. (1997). Does immersion make a virtual environment more usable? In *CHI'97 Extended Abstracts on Human Factors in Computing Systems*, pages 325–326.

Brooke, J. et al. (1996). Sus-a quick and dirty usability scale. *Usability evaluation in industry*, 189(194):4–7.

Carlier, S., Van der Paelt, S., Ongenae, F., De Backere, F., and De Turck, F. (2020). Empowering children with asd and their parents: design of a serious game for anxiety and stress reduction. *Sensors*, 20(4):966.

Ehioghae, M., Montoya, A., Keshav, R., Vippa, T. K., Manuk-Hakobyan, H., Hasoon, J., Kaye, A. D., and Urits, I. (2024). Effectiveness of virtual reality–based rehabilitation interventions in improving postoperative outcomes for orthopedic surgery patients. *Current Pain and Headache Reports*, 28(1):37–45.

Garzotto, F., Gianotti, M., Patti, A., Pentimalli, F., and Vona, F. (2024). Empowering persons with autism through cross-reality and conversational agents. *IEEE Transactions on Visualization and Computer Graphics*.

Gonzalez-Franco, M. and Peck, T. C. (2018). Avatar embodiment. towards a standardized questionnaire. *Frontiers in Robotics and AI*, 5:74.

Hart, S. G. (2006). Nasa-task load index (nasa-tlx); 20 years later. In *Proceedings of the human factors and ergonomics society annual meeting*, volume 50, pages 904–908. Sage publications Sage CA: Los Angeles, CA.

Hart, S. G. and Staveland, L. E. (1988). Development of nasa-tlx (task load index): Results of empirical and theoretical research. In *Advances in psychology*, volume 52, pages 139–183. Elsevier.

Hartmann, T., Wirth, W., Schramm, H., Klimmt, C., Vorderer, P., Gysbers, A., Böcking, S., Ravaja, N., Laarni, J., Saari, T., et al. (2015). The spatial presence experience scale (spes). *Journal of Media Psychology*.

Landers, R. N. (2014). Developing a theory of gamified learning: Linking serious games and gamification of learning. *Simulation & gaming*, 45(6):752–768.

Lee, J., Phu, S., Lord, S., and Okubo, Y. (2024). Effects of immersive virtual reality training on balance, gait and mobility in older adults: a systematic review and meta-analysis. *Gait & Posture*.

Malihi, M., Nguyen, J., Cardy, R. E., Eldon, S., Petta, C., and Kushki, A. (2020). Evaluating the safety and usability of head-mounted virtual reality compared to monitor-displayed video for children with autism spectrum disorder. *Autism*, 24(7):1924–1929.

Pallavicini, F., Pepe, A., and Minissi, M. E. (2019). Gaming in virtual reality: What changes in terms of usability, emotional response and sense of presence compared to non-immersive video games? *Simulation & Gaming*, 50(2):136–159.

Rao, A. K., Choudhary, G., Negi, R., and Dutt, V. (2023). Is virtual reality better than desktop-based cognitive training? A neurobehavioral evaluation of visual processing and transfer performance. In Bruder, G., Olivier, A., Cunningham, A., Peng, Y. E., Grubert, J., and Williams, I., editors, *IEEE International Symposium on Mixed and Augmented Reality Adjunct, ISMAR 2023, Sydney, Australia, October 16-20, 2023*, pages 308–314. IEEE.

Ren, Y., Wang, Q., Liu, H., Wang, G., and Lu, A. (2024). Effects of immersive and non-immersive virtual reality-based rehabilitation training on cognition, motor function, and daily functioning in patients with mild cognitive impairment or dementia: A systematic review and meta-analysis. *Clinical Rehabilitation*, 38(3):305–321.

Schubert, T., Friedmann, F., and Regenbrecht, H. (2001). The experience of presence: Factor analytic insights. *Presence: Teleoperators & Virtual Environments*, 10(3):266–281.

Slater, M., Banakou, D., Beacco, A., Gallego, J., Macia-Varela, F., and Oliva, R. (2022). A separate reality: An update on place illusion and plausibility in virtual reality. *Frontiers in virtual reality*, 3:914392.

Solari, F., Chessa, M., Garibotti, M., and Sabatini, S. P. (2013). Natural perception in dynamic stereoscopic augmented reality environments. *Displays*, 34(2):142–152.

Souchet, A. D., Diallo, M. L., and Lourdeaux, D. (2022). Cognitive load classification with a stroop task in virtual reality based on physiological data. In Duh, H. B. L., Williams, I., Grubert, J., Jones, J. A., and Zheng, J., editors, *IEEE International Symposium on Mixed and Augmented Reality, ISMAR 2022, Singapore, October 17-21, 2022*, pages 656–666. IEEE.

Sudár, A. and Csapó, Á. B. (2024). Comparing desktop 3d virtual reality with web 2.0 interfaces: Identifying key factors behind enhanced user capabilities. *Heliyon*.

Viola, E., Martini, M., Solari, F., and Chessa, M. (2024). Immerse: Immersive environment for representing self-avatar easily. In *2024 IEEE Gaming, Entertainment, and Media Conference (GEM)*, pages 1–6. IEEE.

Wenk, N., Buetler, K. A., Penalver-Andres, J., Müri, R. M., and Marchal-Crespo, L. (2022). Naturalistic visualization of reaching movements using head-mounted displays improves movement quality compared to conventional computer screens and proves high usability. *Journal of NeuroEngineering and Rehabilitation*, 19(1):137.

Wenk, N., Penalver-Andres, J., Buetler, K. A., Nef, T., Müri, R. M., and Marchal-Crespo, L. (2023). Effect of immersive visualization technologies on cognitive load, motivation, usability, and embodiment. *Virtual Reality*, 27(1):307–331.

Wenk, N., Penalver-Andres, J., Palma, R., Buetler, K. A., Müri, R., Nef, T., and Marchal-Crespo, L. (2019). Reaching in several realities: motor and cognitive benefits of different visualization technologies. In *2019 IEEE 16th International Conference on Rehabilitation Robotics (ICORR)*, pages 1037–1042. IEEE.