Does Perspective Matter? Understanding the Role of Viewpoints on User Performance in 3D Sketching

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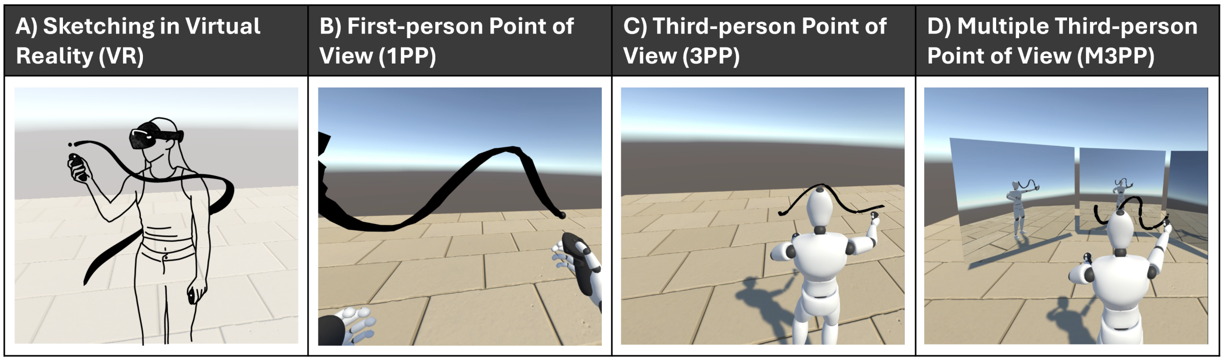

Figure 1: A) A person sketching in VR using a controller. B) The first-person point of view (1PP) is the standard view in VR. C) The third-person point of view (3PP) is a view traditionally used in action video games. D) The multiple third-person point of view (M3PP) is a non-natural view of the environment that allows users to see multiple perspectives at the same time.

Abstract

Most 3D sketching tools for Virtual Reality (VR) rely on traditional features, like scaling and translating the environment with the hands and viewing the environment using a first-person (1PP) point of view (POV). Yet, VR can enhance the artist's experience in ways impossible in the physical environment. These novel ways to perceive the sketch might influence users' behaviours, positively affecting the sketching quality and user experience. In a within-participants user study, we explore the possibilities of using different POVs for sketching by comparing three different perspectives, including first-person POV (1PP), third-person POV (3PP), and multiple third-person POV (M3PP). We collected data on their task performance and subjective experience to evaluate the impact of these perspectives on users' ability to sketch in VR. Our results reveal that POV notably affects user performance.

Index Terms: Virtual Reality, 3D Sketching, Spatial Cognition

1 Introduction

Thanks to the current wave of Virtual Reality (VR) head-mounted displays (HMDs), designers and artists can utilize this new medium for creation. Commercial applications like GravitySketch [38], ShapesXR [18] and OpenBrush [15] allow a broad range of tasks like freely sketching in space, building 3D models to assembling and testing virtual prototypes. Among these tasks, 3D sketching, also known as "3D pointing" or "3D drawing," is a popular choice for artists, designers, and laypeople to use, as it allows them to directly draw a stroke in 3D using their arm movements in space [4, 8]. In most 3D sketching applications, users see the world in a First-Person point of view (POV), using their dominant hand to hold the device that creates strokes, e.g., a controller or a pen, and utilize their non-dominant hand to hold a controller that emulates the palette. See Figure 1. Thus, current 3D sketching applications provide an experience that mimics painting or sketching in 2D. Yet, this approach limits the possibilities of VR as a place to go beyond reality and experience the process of art creation in ways impossible in the physical environment.

Past works have suggested using POVs different from First-Person in VR to enhance the user experience [3, 27]. For example, using POVs like Third-Person or Multiple Third-person positively affect the user, as they provide a better feeling of presence and spatial awareness [37], allow more precise maneuvering in VR [41], and enable users to follow a movement guidance better [19]. Other work has found that using an unnatural POV affects user performance in a navigation task [33]. Yet, it is still unclear what the benefits and challenges of using unnatural POV for 3D sketching are. This task depends on the user creativity [4] and the ability to make spatial relationships between objects in the scene [10], which might be affected by the POV.

This paper examines novel POV for 3D sketching applications. We aim to understand user's behaviours during sketching and identify the advantages and disadvantages of seeing the world in novel ways. Previous work on 3D sketching has focused on creating novel user interfaces or tools [31, 11, 7, 40, 44] and understanding the sketch activity [10, 35, 6]. However, all these past works utilize the First-Person POV and do not focus on exploring novel POV. By understanding users' behaviours during 3D sketching, our work extends previous work that analyzes the stroke creation process [6].

We investigate sketching performance, quality, and user experience in a user study using three different POVs and two sizes. We aimed to assess the relationship between POVs and size on time and accuracy, and better understand the user experience. The three POVs used in the study are: 1) First-Person POV (1PP), where the user's viewpoint is from inside their head and the only reference of their body is the arms or the floating controllers in space (Figure 1b); 2) Third-Person (3PP) POV that renders the viewpoint from a fixed distance behind and slightly above the user's head, allowing them to see part of the avatar (Figure 1c); and 3) Multiple Third-person (M3PP) POV that renders the viewpoint from the front of the avatar, allowing them to see all user actions but

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mirrored (Figure 1d). The two sizes are small, e.g., similar to a desk lamp, and large, e.g., similar to an armchair. Our results show that the POV affects how people sketch in VR, as there was a significant difference between shape likeness and stroke quality when using 1PP compared to 3PP and M3PP. These findings are relevant for future 3D sketching applications, as they inform the creation of novel interaction techniques that affect the user's POV and show their effect on user performance.

2 Related Work

2.1 3D Sketching

3D sketching is widely utilized in VR design tasks, as it brings users intuitive 3D visualization and rapid prototyping. Yet, it comes with unique challenges that do not exist in 2D sketching, such as high sensorimotor [42] and cognitive loads [10, 34]. Problems also exist in depth perception in stereo displays [9, 13, 12] and lack of physical assistance [5]. Prior research has explored the control and ergonomic aspects associated with midair sketching [5, 31] and the learnability of 3D sketching [10, 42] to determine the underlying causes of these issues. Yet, no other work has explored how different POVs affect users' cognitive and sensorimotor loads while sketching in VR.

Other previous research has introduced innovative devices and techniques to improve 3D sketching through beautification techniques [7, 21] or by employing novel metaphors for stroke creation [29, 30, 36]. Additionally, visual guides have been employed to enhance users' shape accuracy [11, 24, 45, 40]. While the approaches above focus on interaction and accuracy, there has been limited exploration of the relationship between POVs and 3D sketching performance. We aim to fill this gap by finding how different POVs influence users' perception of the virtual environment (VE) and further affect user experience.

2.2 Viewpoints in VR

1PP is the most common POV used in VR applications, as it mirrors the user's real-world experience by simulating their POV directly within the VE. Prior research has shown that 1PP is effective in enhancing task performance like navigation and locomotion in VR [33, 41, 22]. On the other hand, researchers tried to extend more possibilities with 3PP by positioning the camera behind or above the user's avatar, allowing users to view their character from an external POV [20, 19, 2, 33, 41]. Prior work has demonstrated that 3PP enhances spatial awareness and task performance in certain contexts [19], though it may reduce the sense of immersion compared to 1PP [33]. Besides traditional 1PP and 3PP, some studies explored novelties of VR POVs. For example, Elsayed et al. [19] proposed M3PP assist guidance systems. Ujkani et al. [41] compared a top-down view with other POVs in locomotion tasks. Finally, switching between 1PP and 3PP has been explored as a hybrid way to combine the strengths of both POVs and developed as locomotion interfaces [17, 23]. Furthermore, Hoppe et al. [28] proposed an innovative concept of continuous dimension in VR, offering broader flexibility in the design space of VR experiences. In this paper, we compared how different POVs affect spatial navigation and sketching performance in VR, providing insights into how each POV can support or hinder 3D design tasks.

3 Evaluated POVs

3.1 First-Person POV (1PP)

1PP is the standard VR perspective where users see the environment through their eyes. While most VR sketching apps (e.g., OpenBrush [15]) only show floating controllers, this study included a humanoid robot avatar across all POVs to maintain consistent body representation and spatial reference.

3.2 Third-Person POV (3PP)

3PP is mainly used in action and adventure video games, allowing players to see a more strongly characterized avatar [1]. Following previous work by Evin et al. [20], we utilized a third-person camera behind and above the avatar's position. The camera followed the head-mounted display's rotation at a fixed distance (1m) and height (0.5m above head) - parameters optimized through pilot testing to balance the field of view with motion sickness risk. A snap rotation feature allowed users to rotate the camera 45 degrees using the joystick to prevent the avatar from blocking their view while sketching.

3.3 Multiple Third-person POV (M3PP)

M3PP is the least standard of all, yet we based it on past conclusions by Elsayed et al. [19] that adding multiple views in VR was beneficial for accurate multi-limb movements. For the user study, we used three mirrors arranged in front of the user - one directly facing the avatar and two angled mirrors providing left-front and right-front views. The mirrors maintained a constant 3m from the user while rotating with the camera, allowing users to see their actions from multiple angles.

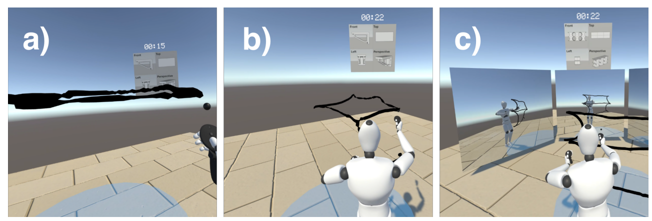

Figure 2: The different POV used in the study: a) 1PP, b) 3PP, c) M3PP

4 User Study

This study aims to identify how different POVs affect participants' experience and performance by correctly sketching VR objects from various viewpoints. This study was approved by Dalhousie Research Ethics Board.

4.1 Participants

We recruited twenty-four participants (10 female, 13 male, one prefers not to say) from Dalhousie University and Nova Scotia College of Art and Design. Their ages ranged between 19 and 33 ($M = 23.5, SD = 3.81$). All participants were right-handed except for one. Two participants reported no experience in First-Person POV video games, and three had zero experience in Third-Person POV video games. Six participants had never used VR, while three participants used VR monthly or more often. Four had experience in VR designing, including VR game development, participation in other research projects, etc.

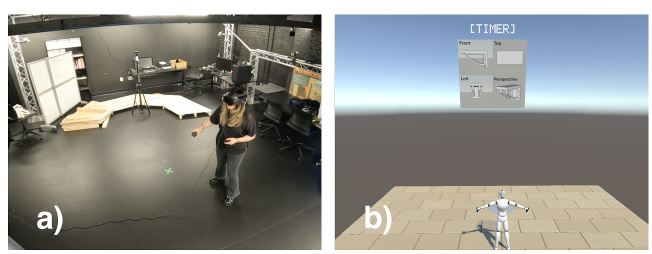

Figure 3: a) Physical experimental setup with walking area. b) 3D environment of the experiment

4.2 Apparatus

We ran the experiment with a 3.20 GHz Intel(R) Core(TM) i9-14900KF desktop PC with 32 GB RAM and an NVIDIA GeForce RTX 4090 graphics card. We developed the 3D scene in Unity3D 2022.3.15f1 and used the Oculus Quest Pro and two controllers connected via a USB 3.0 cable to connect to the PC. Participants were allowed to walk freely in a $3m \times 3m$ square area while sketching and used their dominant hand to draw the strokes, rotate the camera under 3PP and M3PP, and their non-dominant hand to start and finish each trial. Following past work by Barrera Machuca et al. [10], the sketching system only supported basic stroke creation features, with no additional features like colour, stroke width, or eraser, to avoid any possible distraction. There was an image of the required object (including a front, top, left, and perspective view) in front of the user. This image floated in midair and kept facing the participants wherever they turned. See Figure 3. A transparent blue platform would appear at the center of the sketching area to indicate the required sketch size - waist height for small designs (desk lamp size) or a 1.5m circular floor area for large designs (armchair size).

4.3 Experimental Design

The user study was a three-factor within-subject study with three POVs (1PP, 3PP, M3PP), two shapes (Shape 1 and Shape 2), and two task sizes (small and large). Each participant drew two shapes of two sizes under three POVs ($3_{POV} \times 2_{Shapes} \times 2_{Sizes} = 12 sketches$), resulting in 288 sketches ($12 sketches \times 24 participants = 288 sketches$). The order of conditions across POVs and task sizes was counter-balanced using a Latin Square, while the two shapes appeared in random order for each POV $\times$ Shape.

4.4 Procedure

Participants began by completing consent forms and demographic questionnaires asking about their gender, name, VR experience, and gaming experience under different POVs. After learning VR controller usage and sketching techniques, they practiced creating drawings of various sizes from three POVs in the VR environment. For each of the 12 trials, participants viewed a reference figure while using their dominant hand to create strokes by pressing and releasing the controller's trigger button, moving their body as needed. Participants received 5-minute breaks between sketches and completed VRSQ, SUS, and NASA-TLX questionnaires after each POV condition. The session ended with a comparative questionnaire and interview about their overall experience and POV rating, lasting approximately 120 minutes.

4.4.1 Shapes

Following past work in the area [10, 40], we chose two similar shapes for the sketching task. See Figure 4 for an image of the drawn shapes. *Shape 1* is a two-layer long, rectangular-like object with concave curves on its sides and four large circular holes running through its length. *Shape 2* is a shelf-like triangle support structure with diagonal bars underneath a right-angle structure. The second object has fewer curves but more details. With different focuses on each shape, we aim to comprehensively evaluate participants' sketching skills by presenting diverse challenges.

4.5 Evaluation Metrics

Following previous work by Barrera Machuca et al. [8], we collected their task performance and user experience. We analyzed participants' performance using the following measures:

Task Completion Time: The time from when the trial started until the participant finished sketching and pressed a button on the left controller to exit the scene.

Shape Likeness: The subjective metric used to evaluate the overall similarity of a 3D drawing to its reference 3D model. Rated on a scale from 1 (indicating no similarity) to 10 (indicating a high degree of resemblance) based on how closely it matches the reference model.

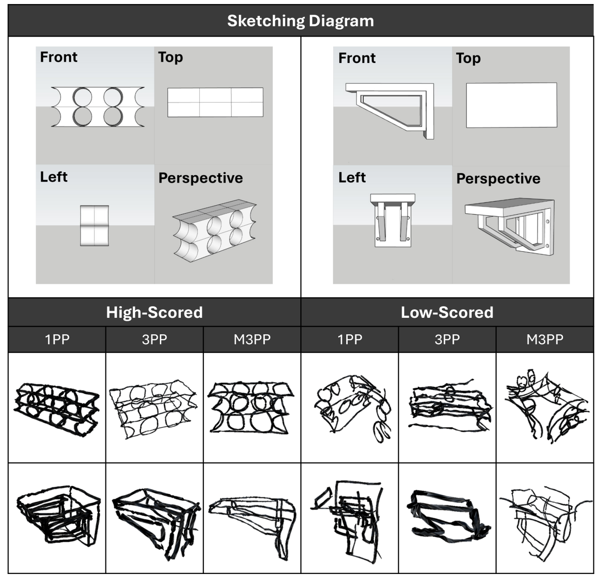

Figure 4: A diagram of target shapes to be drawn and examples of high-scored and low-scored sketches

Stroke Quality: We employed Wiese et al.'s [42] coding system, which examines four aspects of the strokes: (1) *Line Straightness*, how smooth the stroke is; (2) *Matching of Two Lines*, whether two strokes properly connect; (3) *Degree of Deviation*, how far two strokes from the same plane deviates from each other; (4) *Corrective Movements*, whether corrections are made at the end of a stroke to connect to another stroke. Each category is scored individually on a scale from 1 (very poor) to 3 (very good), adding up to 4-12 in total.

Three independent markers (unaffiliated with the study) scored each sketch on Shape Likeness and Stroke Quality. Marker 1 had a Computer Science and 3D gaming background. Marker 2 came from an art and animation background. Marker 3 was also from the Computer Science field, with marking experience in related sketching projects. We shuffled the sketches and removed the condition labels to prevent marker bias. First, markers scored independently for each participant, and then they performed a comparative analysis to calibrate their scoring across participants. Past work has used similar subjective shape-likeness scoring methods [10, 40, 39, 16].

User Experience: We used three standardized questionnaires: the Virtual Reality Sickness Questionnaire (VRSQ) [32], the System Usability Survey (SUS) [14], and the NASA Task Load Index (NASA-TLX) [26, 25].

5 Results

Results were analyzed using SPSS and plotted using JMP software. All the scores were not normally distributed, so we applied Aligned Rank Transform (ART) [43] to normalize the data before performing repeated measures (RM) ANOVA with $\alpha = 0.05$. Pairwise comparisons were conducted with Bonferroni corrections. Table 1 shows statistical results.

5.1 Task Completion Time

We did not find a statistically significant difference in *task completion time* for POV.

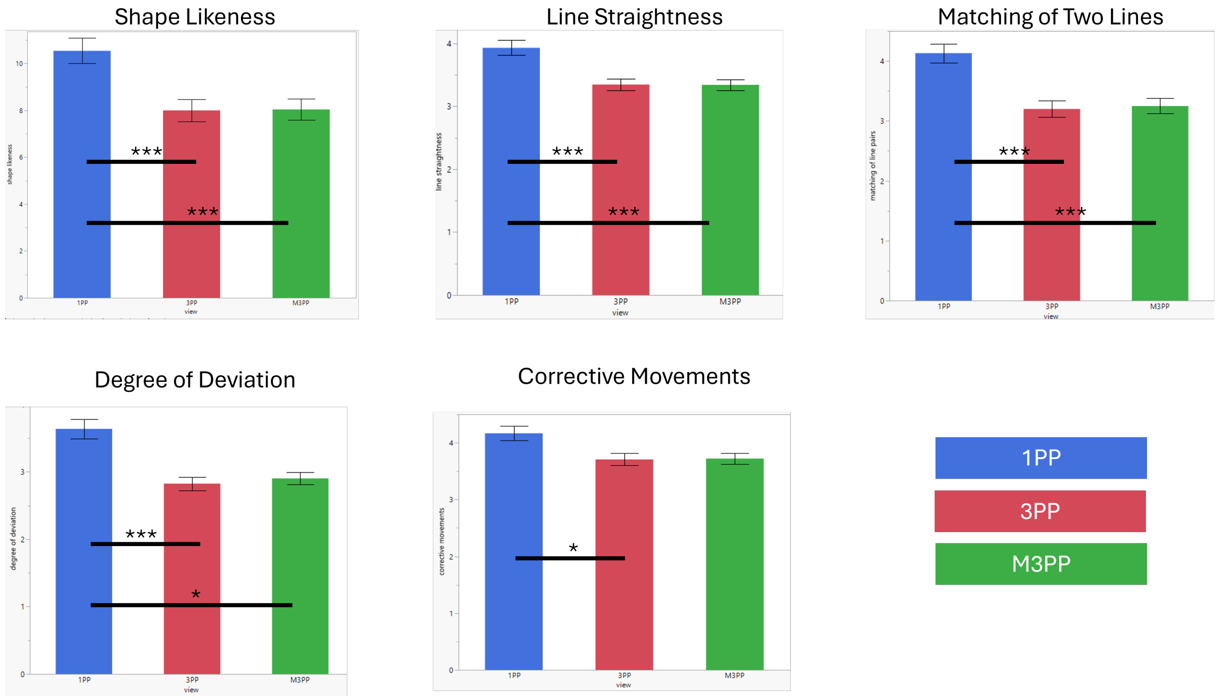

Figure 5: Score analysis results

5.2 Shape Likeness

There was a significant main effect of POVs on *Shape Likeness*. A post-hoc analysis revealed that participants got higher scores under 1PP than 3PP (p<0.001) and M3PP (p<0.001), while no significant differences were found between 3PP and M3PP. Task size did not have a significant effect on *Shape Likeness* either.

5.3 Stroke Quality

1PP sketches had higher *Stroke Quality* than 3PP and M3PP regarding *Line Straightness* (with both p<0.001), *Matching of Two Lines* (with both p<0.001), *Degree of Deviation* (p<0.001, $p = 0.002$ respectively), and *Overall Score* (with both p<0.001). For *Corrective Movements*, 1PP got a significantly higher score than 3PP ($p = 0.017$), while only nearly significant differences were found between 1PP and M3PP ($p = 0.053$). The pairwise comparisons did not detect any significant variation between 3PP and M3PP under all categories. As for task size, the post-hoc analysis identified that participants had better performance on *Line Straightness* ($p = 0.002$), *Matching of Two Lines* (p<0.001), and *Degree of Deviation* ($p = 0.012$). We also identified some interaction effects for *Matching of Two Lines* and *Degree of Deviation* for POV and size.

5.4 User Experience

Qualitative data from the questionnaires were analyzed using nonparametric Friedman's tests with POV as the only independent variable. Pairwise comparisons were conducted with Bonferroni corrections.

VRSQ: Friedman tests showed that POV has a significant main effect on oculomotor ($\chi^2_2 = 9.60, p = 0.008$) and total score ($\chi^2_2 = 6.74, p = 0.034$), while no significance was found on disorientation ($\chi^2_2 = 2.96, p = 0.23$). In particular, users suffered less oculomotor and disorientation under 1PP than M3PP ($p = 0.025, p = 0.045$ respectively).

SUS: Friedman test revealed significant differences among POVs on system usability ($\chi^2_2 = 7.00, p = 0.03$), user satisfaction ($\chi^2_2 = 14.60, p = 0.001$), and system helpfulness ($\chi^2_2 = 18.95, p = 0.000$). Although pairwise tests did not yield significance on system usability ($p = 0.08$), we observed that 1PP got better scores than 3PP/M3PP on user satisfaction ($p = 0.009, p = 0.021$) and system helpfulness ($p = 0.003, p = 0.001$).

NASA-TLX: Analysis with the Friedman test showed that the differences were statistically significant on mental demand ($\chi^2_2 = 12.00, p = 0.002$), temporal demand ($\chi^2_2 = 9.12, p = 0.01$), performance ($\chi^2_2 = 6.24, p = 0.044$), effort ($\chi^2_2 = 6.66, p = 0.036$), and

Table 1: Statistical results of sketching performance. Statistically significant factors are shown in bold.

	POV	**Size**	**POV × Size**
Completion Time	F(2, 46) = 2.58 p = 0.086	F(1, 23) = 0.88 p = 0.357	F(2, 46) = 1.33 p = 0.274
Shape Likeness	**F(2, 46) = 14.99** **p < 0.001**	F(1, 23) = 0.18 p = 0.67	F(2, 46) = 1.77 p = 0.18
Line Straightness	**F(2, 46) = 17.98** **p < 0.001**	**F(1, 23) = 11.55** **p = 0.002**	F(2, 46) = 0.73 p = 0.49
Matching of Two Lines	**F(2, 46) = 22.98** **p < 0.001**	**F(1, 23) = 15.69** **p < 0.001**	**F(2, 46) = 22.00** **p = 0.042**
Degree of Deviation	**F(2, 46) = 15.53** **p < 0.001**	**F(1, 23) = 7.36** **p = 0.012**	**F(2, 46) = 3.37** **p = 0.043**
Corrective Movements	**F(2, 46) = 5.46** **p = 0.007**	F(1, 23) = 0.89 p = 0.36	F(2, 46) = 0.17 p = 0.84
Overall Score	**F(2, 46) = 20.60** **p < 0.001**	F(1, 23) = 3.88 p = 0.06	F(2, 46) = 2.62 p = 0.83

frustration ($\chi^2_2 = 11.10, p = 0.004$). No significant variation was detected in physical demand ($\chi^2_2 = 3.59, p = 0.17$). Results from pairwise comparisons revealed that 1PP led to lower mental demand than 3PP ($p = 0.007$) and caused less frustration than M3PP ($p = 0.025$). The performance of 1PP was better than that of M3PP with a difference approaching significance ($p = 0.055$). No other significant pairwise differences were found among the POVs.

Subjective Ranking: 19 participants chose 1PP as their favourite POV. The number of participants was relatively even in their second favourite POV (9 for 3PP, 8 for M3PP) and the least favourite ones (9 for 3PP, 10 for M3PP). Regarding accuracy, 21 participants ranked 1PP the first, while the remaining 3 voted for M3PP. 8 and 11 participants ranked 3PP and M3PP as the second, respectively. Half (12) of the participants thought 3PP was the least accurate POV, compared to 6 who found M3PP to be the least accurate.

6 Discussion

For user performance, our results indicate that different POVs significantly influence the quality of 3D sketching. No significant differences were found in task completion time across POVs, as we observed that task completion time does not fully reflect participants' efficiency. Under 3PP or M3PP, a participant reported finishing the sketch faster to avoid motion sickness and thus ended up with lower quality sketches. Regarding Stroke Quality, 1PP sketches consistently outperformed those from 3PP and M3PP across all categories, including Line Straightness, Matching of Two Lines, and Degree of Deviation. These results suggest that users in 1PP had more precise control over their strokes, possibly due to the more direct mapping of hand movements and visual feedback and less occlusion. Interestingly, participants showed greater corrective movements under 1PP than 3PP, suggesting that the immersive nature of 1PP might encourage users to refine their sketches more frequently, further improving quality.

As for subjective user experience, the results showed that 1PP provided superior user experience compared to 3PP and M3PP across multiple metrics. Participants reported lower oculomotor and better comfort with 1PP due to three possible factors: reduced camera movement speed, better alignment between virtual and actual movements, and absence of potentially disorienting mirror reflections. User satisfaction was also higher for 1PP, supported by significantly better SUS scores. The NASA-TLX results indicated lower mental and temporal demands and reduced frustration under 1PP. Interestingly, M3PP showed mixed results with high variance in mental demand (SD = 2.26 compared to 1PP's 1.87 and 3PP's 1.89), reflected in contrasting user feedback - some found the mirrors helpful while others found them distracting. Subjective rankings strongly favoured 1PP for comfort and sketching accuracy, suggesting that VR applications should prioritize this perspective for tasks requiring precision and focus. These findings indicate that while 1PP provides the best overall user experience, future research could explore optimizing 3PP and M3PP for specific use cases.

7 Conclusion and Future Work

Our study examined how different POVs affect user performance and experience in VR sketching tasks. The results demonstrated that 1PP significantly outperformed both 3PP and M3PP POVs regarding shape likeness and stroke quality. Users also reported better experience with 1PP, showing higher system usability scores and lower mental demand and frustration.

Building on the user study findings, our next step will investigate underlying causes of performance differences across POVs based on participants' spatial ability scores and body movement data. Future work should also identify novel ways to analyze movement patterns under different POVs to better identify the advantages and disadvantages of using specific POVs.

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