Investigating Portal Scale Selection in Virtual Reality Docking Tasks

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Abstract

Precise object manipulation in virtual reality (VR) often requires operating across different spatial scales, or placing portals—a view and interaction window into another part of the virtual environment—to interact with distant objects. Despite their potential, research on scalable portals remains limited. We investigate how users select portal scales when performing a controlled six-degree-of-freedom docking task through a single adjustable portal. In the task, two objects appear inside the portal; users must grasp one and dock it into the other. We hypothesize that users adjust the portal scale to align the task's required workspace with their own body-referenced comfort range. To test this hypothesis, we alternated two initial portal scales (5x vs 1/5x) with jitter and measured the final chosen scale, manipulation time, and docking accuracy. Results show that (i) final portal scales were biased by the initial state – consistent with anchoring effects – and (ii) participants with longer dominant-hand spans tended to prefer larger final scales, supporting the embodied scaling hypothesis. These findings suggest that portal-mediated interaction is guided by body-referenced workspace normalization and inform the design of VR interfaces that support comfortable switching between micro- and macro-scale manipulation.

Keywords

Portal-based interaction, Multi-scale manipulation, 6-DOF docking, Embodied scaling

1. Introduction

Imagine standing in VR with a beam extending from your controller like a laser pointer. You sweep the beam across the scene, touch a distant object with its tip, squeeze the trigger, and the object is acquired. Small motions of your wrist let you steer the target in space; a nudge on the controller rotates or translates it until it snaps neatly into place. This ray-casting metaphor lets you act on faraway content without walking, bringing remote selection and placement into a compact hand gesture. It is fast, direct, and requires little physical effort: the beam provides precise pointing for acquisition and a continuous tug for manipulation, enabling delicate alignment at a distance while you remain anchored where you stand.

Object selection and manipulation in virtual reality (VR) must accommodate targets that vary widely in virtual size, distance, and required precision—and are often beyond arm's reach. Remote techniques such as ray-casting, reach extension, and Worlds-in-Miniature (WIM) provide access but typically rely on high gains or long lever arms, making fine alignment highly sensitive to hand jitter and small tremors, especially near the last centimeters of a dock [1, 2, 3]. These trade-offs motivate interaction styles that retain spatial context while reducing gain-induced noise at the end-effector [4, 5].

Against this backdrop, portal-based interaction has gained attention. A portal is a bounded opening that connects two regions of the virtual scene via a fixed spatial mapping. Visually, the target region is rendered into the aperture with correct clipping and occlusion; interactively, hand poses that cross the rim are transformed into the portal's target region, where grasp, collision, and docking are resolved and mirrored back. By letting users act through the aperture, portals support remote, precise manipulation without locomotion and without the instability that often accompanies high-gain control [6, 7, 8, 9].

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Despite growing interest, the design space for how a portal should be instantiated for manipulation remains under-specified. Prior work offers limited guidance on (i) where to place the aperture relative to the user and targets, (ii) how large the opening should be (aperture size/aspect) and how its view frustum and clipping should be configured, and (iii) how the portal's spatial mapping should be chosen to carry hand poses and interactions across the rim. More critically, when a portal is used to manipulate objects, most systems do not articulate how these choices ought to co-vary in multi-scale scenarios. For example, the portal setting appropriate for a fine peg–in–hole dock should not be the same as that for placing a crate-sized target; the former calls for a different portal scale (and likely a tighter aperture/frustum) than the latter. Without a principled treatment, portal configuration inadvertently couples changes in visual framing (angular size, perspective, occlusion) with changes in motor gain and control stability, making it difficult to attribute performance differences to either perception or mechanics [10, 11].

To address this gap, we systematically investigate portal instantiation for multi-scale object manipulation in a controlled 6-DoF docking task. We use a single portal placed in front of the user, allow pre-task adjustment of its internal setting via a linear controller mapping, and lock the setting at grasp onset to separate portal choice from motor execution. Accordingly, we pose the following research questions:

RQ1: How do users decide the portal scale in VR?

1. **RQ1-1**: How does the chosen portal scale relate to the user's body metrics (e.g., dominant-hand length)?
2. **RQ1-2**: How does the initial portal state ($5\times$ vs. $1/5\times$, with jitter) bias the final chosen scale?

Here, portal scale refers to the relative scaling of the virtual workspace visible through the portal aperture. For example, a setting of $1/5\times$ magnifies the portal's internal workspace fivefold, making distant objects appear closer and larger, while $5\times$ reduces it to one-fifth, making the workspace appear smaller and farther.

To investigate these questions, participants complete 30 trials in which the portal is initialized to either $5\times$ or $1/5\times$ (15 each), presented in randomized order with small jitter. Before grasp, participants adjust the portal via a linear mapping (e.g., button/joystick up/down); at grasp onset the portal setting is locked, and the user docks object A to object B through the aperture. For each trial we log time to dock, portal-manipulation time, and the initial and final portal settings, enabling quantitative analysis of scale choice, anchoring effects, and performance relations. Our findings motivate design guidelines for portal-mediated manipulation. This yields more predictable multi-scale docking performance for future studies.

2. Preliminary Study

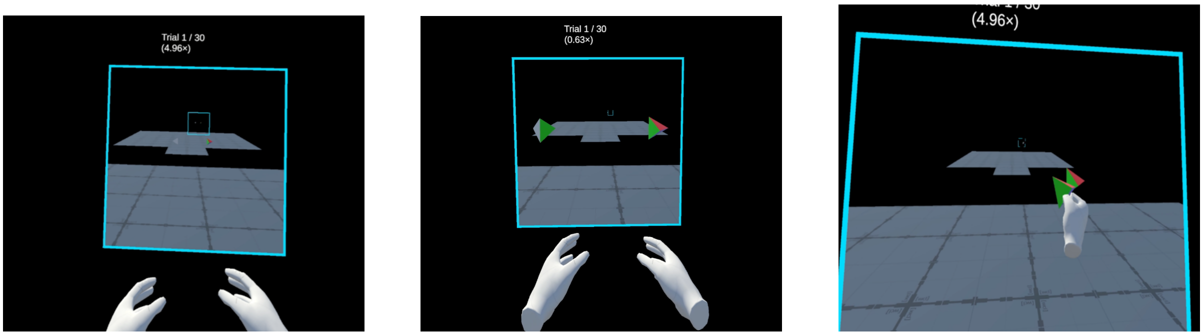
2.1. Participants

A pilot test was conducted with six participants who had substantial experience with VR(5 male, 1 female; mean age = 26.8). Before the main task, each participant reported handedness and we measured the length of the dominant arm used for the task. Arm length was measured along the dorsal surface from the acromion to the tip of the middle finger while fully extended.

2.2. Materials

2.2.1. Hardware and Setup

In this experiment, the participants wore Meta Quest 3 VR HMD, which has a resolution of 2064 × 2208 pixels per eye and a field of view of 110° horizontally and 96° vertically. The virtual environment was developed using Unity 3D Engine 2020.3.42f1 LTS, and the VRPortalToolkit[12]. Participants stood within a clear area ($\approx 2 \times 2$ m) during the experiment.



(a) 5x scaled Portal (b) 1/5 scaled Portal (c) Docking Task Interaction

Figure 1: Illustration of the portal scaling conditions and the docking task.

2.2.2. Virtual Environment

A single rectangular portal was rendered at a comfortable arm's length in front of the user (see Fig. 1). The portal mapped a target subspace of the scene into the aperture with correct clipping/occlusion against the host scene. Inside the portal two rigid objects were present: a movable object A and a stationary target B. The task was a six-degree-of-freedom select–move–align (dock) from $A \to B$. Docking success required (i) anchor-to-anchor Euclidean distance ≤ 1 cm and (ii) relative orientation error $\leq 5^\circ$, both satisfied for ≥ 1 s (dwell). On success, an audio cue was played and the next trial started.

2.3. Portal Control, View Coupling, and Locking

Participants could adjust the portal's internal setting (the scale of the enclosed space) before grasp via a linear controller mapping (e.g., button/joystick up/down; constant-rate increase/decrease). To control visual confounds, we adopted a scene-centric constant angular-size coupling: when the portal scale s changes, the camera-to-portal distance is set to

$$d(s) \;=\; s\,d_0 \qquad (d_0 = 40\,\mathrm{cm}),$$

so that the apparent angular size of scene content remains approximately invariant across scales. The choice of $d_0 = 40\,\mathrm{cm}$ is grounded in ergonomics literature, which identifies the comfortable or optimum reach zone in front of the torso to be roughly 30–40 cm from the body [13, 14]. Practically, $d(s)$ is applied along the camera's forward axis, and the physical aperture pose (orientation) is fixed across trials.

At the moment of the first successful grasp of A (grab onset), both the portal scale s and the induced distance $d(s)$ are locked for the remainder of the trial, keeping visual framing and motor gain stable during placement. Docking is then completed through the aperture without any mid-task change of scale or portal placement.

2.4. Study Design

We adopted a within-subjects design with one experimental factor:

$$\textbf{Initial portal state} \in \{5\times,\ 1/5\times\}.$$

Each participant completed **30** trials (15 per initial state), presented in randomized order. To avoid trivial anchoring on exact values, the initialized state included a small additive jitter (e.g., 5 ± 0.3 and 0.2 ± 0.03). Participants freely adjusted the portal setting prior to grasp, after which the setting was locked and the dock was completed through the aperture.

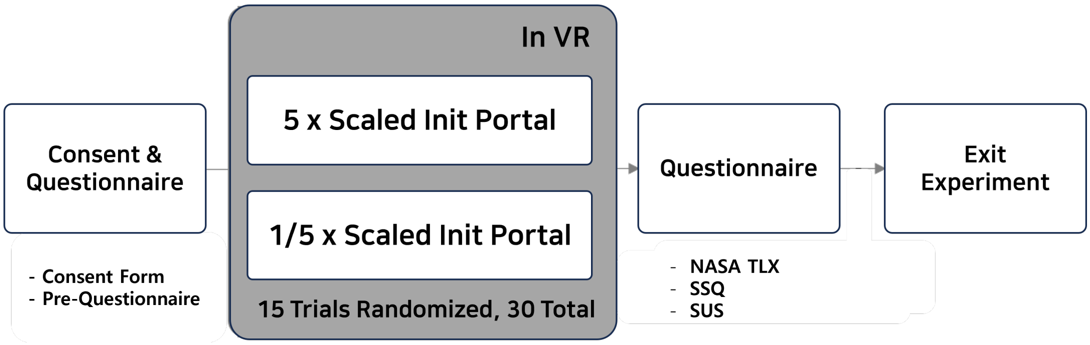


Figure 2: Study protocol. After consent and a pre-questionnaire, participants completed 30 trials in randomized order: 15 initialized at $5\times$ and 15 at $1/5\times$ (with small jitter). Before grasp, the portal scale could be adjusted; at grasp onset it was locked. After the main block, participants completed the SSQ, SUS, and NASA–TLX.

2.5. Procedure

The overall experimental procedure is illustrated in Fig. 2. Upon arrival, participants provided demographic and handedness information, after which the length of the dominant arm was measured. Participants were instructed that the object–portal layout, including object–portal distances, would remain fixed across scales and that only the portal's internal scale could be adjusted prior to grasp. They were asked to tune the portal so that the effective work volume felt comfortable relative to their own body. After a baseline Simulator Sickness Questionnaire (SSQ), the main experiment commenced. The main block comprised 30 consecutive trials with no scheduled breaks. At the end of the session, participants completed the SSQ, NASA–TLX, and System Usability Scale (SUS) questionnaires.

2.6. Measures

For each trial we logged:

- **Time to dock** (s): elapsed time from trial start to docking success.
- **Portal-manipulation time** (s): cumulative time during which the portal setting actually changed prior to grasp.
- **Initial portal state**: the randomized starting value ($5\times$ or $1/5\times$ with jitter).
- **Final portal choice**: the last portal value just before grab onset (locked thereafter).

SSQ, NASA-TLX, SUS were additionally recorded after the experiment ended.

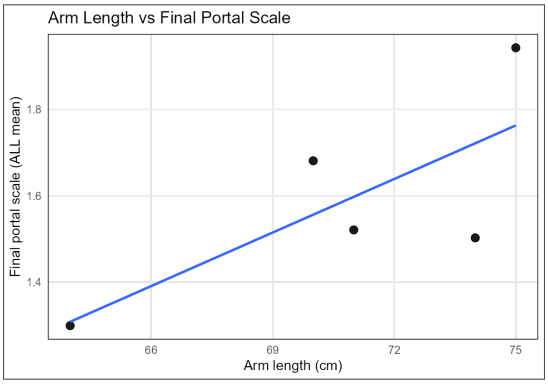
2.7. Hypotheses

Building on the idea that users choose portal settings to normalize task extent to a comfortable, body-referenced work volume, and that initial states can anchor subsequent choices, we pre-registered the following hypotheses:

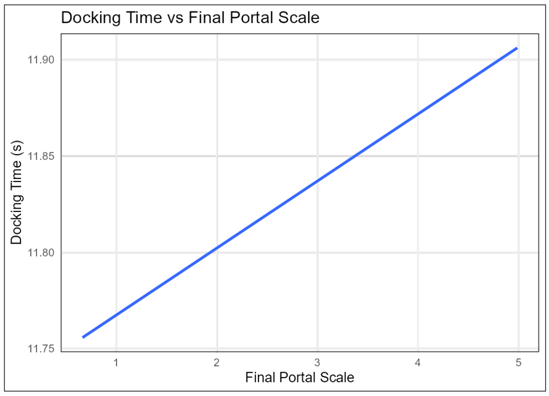
- **H1** Participants will choose a portal scale that brings the task's required work volume into a comfortable hand-referenced range (relative to dominant-hand length).
- **H2** The initial portal state ($5\times$ vs. $1/5\times$, with jitter) will bias the final portal choice.

3. Results and Discussion

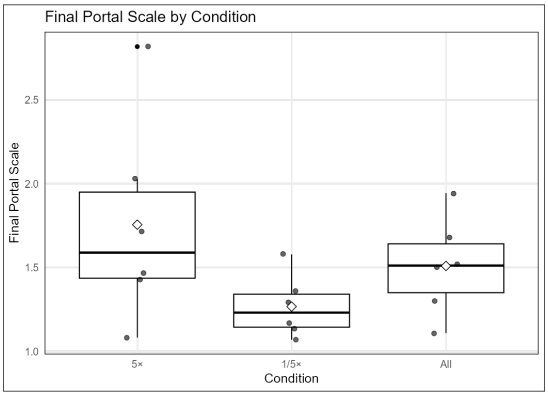
Data analysis was conducted on six participants.



(a) Arm length vs. final portal scale



(b) Docking time vs. final portal scale



(c) Final portal scale by condition: initialized at $5\times$, at $1/5\times$

Figure 3: Summary of key relationships in the portal docking study. (a) Relation between dominant-arm length and the final portal scale. (b) Relation between final portal scale and docking time. (c) Distribution of final portal scales by initial state ($5\times$ vs. $1/5\times$).

3.1. Init Scale and Final Scale

To test whether the initial portal scale influenced the final scale chosen by participants, we compared the two initialization conditions (5× vs. 1/5×) using a Wilcoxon signed-rank test. The test did not reveal a significant difference, $V = 18$, $p = .142$,

3.2. Arm Length and Final Scale

Pearson correlation analysis indicated a positive association between arm length and final portal scale, $r = .80$, $p = .058$. A linear regression confirmed this trend, $F(1, 4) = 6.92$, $p = .058$, $R^2 = .63$.

3.3. Docking Time and Final Scale

A linear regression of docking time on final portal scale was not significant, $F(1, 175) = 1.64$, $p = .202$, $R^2 = .009$.

3.4. Subjective Measures

For NASA–TLX, mean ratings across six dimensions were as follows: Mental Demand = 2.83, Physical Demand = 4.67, Temporal Demand = 1.33, Performance = 8.17, Effort = 7.67, and Frustration = 2.67 (0–10 scale). The SUS yielded a mean usability score of 81.2 (SD = 6.1), with scores ranging from 72.5 to 87.5. For SSQ, weighted scores showed low levels overall. The mean pre-exposure scores were Nausea = 0, Oculomotor = 10.1, Disorientation = 2.3, and Total = 5.6, while the post-exposure scores were Nausea = 1.6, Oculomotor = 11.4, Disorientation = 11.6, and Total = 9.4. This indicates that there was little effect on sickness throughout the experiment.

3.5. Discussion

Although the Wilcoxon signed-rank test found no significant differences across initial conditions and final portal scales, the descriptive pattern indicated that portals initialized at $5\times$ generally yielded larger final portal scales than those initialized at $1/5\times$. We interpret this as cautious support for H2: the initial portal state biased subsequent scale choices in the predicted direction, consistent with anchoring and comfort-range adaptation. However, given the small effect size and the non-significant pairwise tests after correction, this evidence should be regarded as provisional rather than conclusive.

The correlation analysis between arm length and final portal scales suggested that participants with longer arm spans tended to select larger final portal scales, a trend further supported by linear regression. Although this relationship did not reach conventional statistical significance, the effect size was substantial. A plausible interpretation is that participants with longer arms perceived larger workspaces as more comfortable and aligned with their natural reach. In other words, individual embodiment may have shaped portal scaling behavior, such that a longer arm span provided a broader comfort zone, leading to higher final scale selections. This interpretation offers tentative support for H1.

Although the regression analysis did not reveal a statistically significant relationship between final portal scale and docking time, a slight trend suggested longer docking times at larger scales. One possible explanation is the increased impact of hand jitter at higher portal scales. When the portal is magnified (e.g., $5\times$), even small involuntary hand movements are amplified within the workspace, making precise alignment more difficult and prolonging the docking process. Conversely, smaller scales attenuate jitter effects, facilitating smoother control. Thus, while the effect was not statistically reliable, the observed tendency indicates that excessive scaling may introduce instability in manual interactions during docking tasks.

4. Conclusion

In this study, we investigated how users adapt portal scale during a single-portal docking task in VR, focusing on the anchoring effect of initial portal size. Our results demonstrated a asymmetry: when the portal began at an enlarged scale (5×), participants tended to leave the final portal scale larger compared to when the initial scale was reduced (1/5×). This pattern suggests that initial scaling conditions biased users' perception of an appropriate or comfortable scale, consistent with anchoring effects observed in decision-making research.

Analyses of completion time and portal manipulation behavior further indicated that scale adjustments were not merely transient corrections but influenced users' docking strategies throughout the task. Correlation analyses also suggested a relationship between participants' interaction time and the magnitude of scale adjustments, reinforcing the interpretation that portal scale is not just a neutral parameter but a determinant of task performance. However, we acknowledge that given the small sample size (six participants), these results should be regarded as exploratory and descriptive rather than conclusive.

Taken together, the study provides preliminary evidence that scale anchoring plays a decisive role in multi-scale portal interaction. For future design of portal-based VR systems, careful consideration should be given to the initial scale presentation, as it may shape users' expectations and operational strategies. More broadly, our work highlights the importance of controlling visual-motor coupling during scale transitions to isolate motor performance effects from perceptual confounds, paving the way for more principled design of multi-scale interaction techniques in immersive environments.

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Declaration on Generative AI

During the preparation of this work, the author(s) used X-GPT-5 in order to: Grammar and spelling check.

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