Relative Room Size Judgments in Impossible Spaces

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ABSTRACT

In VR, "impossible spaces" allow virtual rooms to occupy overlapping portions of physical space. We investigated how size judgments of impossible spaces are influenced by the ratio of the sizes of overlapping rooms. Participants (n=36) were randomly assigned to one of three conditions and completed 13 trials. Participants' reports accurately reflected the true ratio of the rooms in all conditions; however, participants reported less extreme ratios as the ratio increased. The results suggest that important spatial relationships are preserved in impossible spaces, namely 1) judged sizes of individual rooms, and 2) judgments concerning the relative sizes of different rooms.

Index Terms: Human-centered computing—Visualization—Visualization techniques—Treemaps; Human-centered computing—Visualization—Visualization design and evaluation methods

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1 BACKGROUND

Impossible space enables nature walking in virtual environments (VEs). In impossible space, the VE consists of adjourning rooms connected by hallways and corridors. In order for impossible space to work, the VE need to switch between the two rooms without detection from the user as both rooms cannot fit within the physical space. A trigger is usually set at the halfway point of the environment to restructure the architecture of the rooms. Previous studies looking at impossible spaces have focused on distance perception and detection thresholds. Prior work on impossible space has found that participants detection thresholds for overlap at around 31% for an expanding room layout and 56% for a small room layout. Suma et al found that participants are perceiving distances between objects similarly to that of a non-impossible space [3]. These results show that people are able to perceive overlap quicker in smaller spaces however, when it comes to distance estimation, people base their judgements on Euclidean geometry. In addition to the overlapping architecture, Imura et al found that the added complexity of corridors and hallways of the VEs has an effect on user's perception of overlap in impossible spaces [1]. Results also showed that less complex environment is more readily detectable as impossible compare to one that is not. Robb et al. expanded on these findings and explored how impossible space can altered users' perceptions of reference locations within a virtual environment [2]. They found that users judgements of the impossible spaces were based off visible constraints within the VE.

2 METHODS AND APPARATUS

We designed a between-subjects repeated-measured study to understand how judgements concerning the size of impossible spaces is influenced by the ratio of overlapping rooms and by the means through which size judgments are made. Participants completed 13 trials in one of three conditions, where the ratio of the sizes of rooms A and B was varied between trials. All three conditions used the same ratio of rooms across all 13 trials. Two different layouts were used across the three conditions. The first condition, which served as our baseline condition, presented the two rooms as existing on two separate "split" levels, with an elevator connecting them. This served as our baseline as it would be physically possible for these rooms to ocupy the same XZ coordinate, as they existed on different Y planes. The second and third condition presented both rooms on a "flat" level, which resulted in an impossible space. In addition to varying the layout, we also varied how participants reported their size judgments. In all three cases, participants reported their judgment by moving a slider on a map of the space to indicate where they believed the far wall of the room to be (see Figure **??**). For our baseline condition, participants made their judgments for both rooms on separate maps and we call that the Split-TwoMaps condition. For our second (Flat-OneMap) and third (Flat-TwoMaps) condition, participants made their judgements for each room on the same map.

Participants used a wireless HTC Vive Pro HMD to conduct the experiment. The Lighthouse 2.0 tracking system was used to track a 4m x 6m space. The experiment was run using a computer capable of maintaining a frame rate of 90 FPS for the duration of the experiment. The virtual environment was created using the Unity game engine.

3 RESULTS

We calculated the judged position of the central wall for both rooms for each trial. From this data, we also calculated the judged ratio between rooms (the width of room A divided by the width of room B), and the total judged width of both rooms (the width of room A plus the width of room B). Each of these judgments was analyzed using a one-way repeated measures ANOVA, where the condition served as a between-subjects factor. The room label (A or B) was also included as a covariate.

Reported Individual Room Sizes. A main effect was observed for condition ($F(2,31) = 6.955, p = 0.0027, \eta^2 = 0.06$). Pairwise comparisons revealed that participants reported the room size as significantly smaller in the FlatRoom-SingleMap condition than in either other condition ($p = 0.0013$), and that no differences were observed between the other two conditions ($p = 0.526$). The relationship between actual room size and judged room size can be seen in Figure 1. Overall, participants tended to judge rooms as smaller than they actually were. This effect grew more pronounced as rooms got larger, and when in the Flat-OneMap condition.

Total Reported Width of Both Rooms. A main effect was observed for condition ($F(2,31) = 6.955, p = 0.0032, \eta^2 = 0.118$). Pairwise comparisons revealed that participants reported the total width of both rooms as significantly smaller in the Flat-OneMap condition than in either other condition ($p = 0.0013$), and that no differences were observed between the other two conditions ($p = 0.525$). The relationship between actual total width and judged total width can be seen in Figure 2. It can be observed that if the judged value exceeds a value of 1.0, then the total size of the space would be impossible to accommodate on a single floor in the real world.

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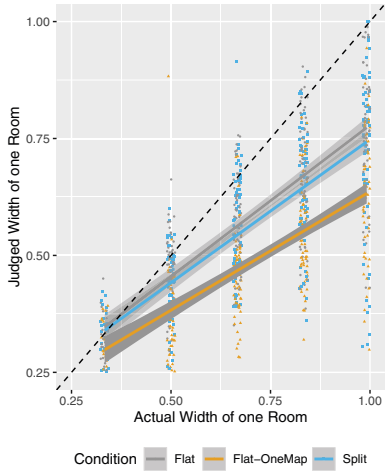

Figure 1: The relationship between the actual size of a room and the judged size of a room is shown above. No difference was seen between participants judgments in the Split and Flat conditions, however the judged width decreased significantly in the Flat-OneMap condition.

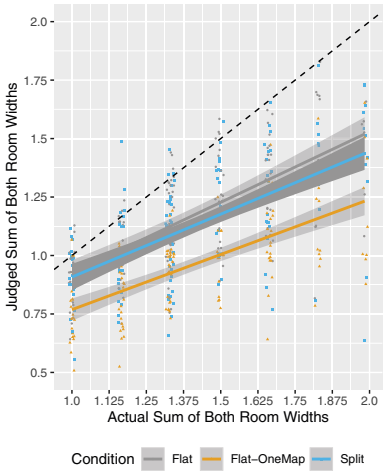

Figure 2: The relationship between the sum of the actual width of rooms A and B (actual sum) and the sizes participants judged rooms A and B to be (judged sum) is shown above. On average, participants judged the total width of both rooms to exceed 1.0 at roughly 1.15 in the Split and Flat conditions, and exceeded 1.0 at roughly 1.5 in the Flat-OneMap condition.

Participants began reporting impossible values in the Flat condition when the actual width of both rooms equaled roughly 1.125, but only began reporting impossible values in the Flat-OneMap condition when the actual width of both rooms equaled roughly 1.5.

Ratio Between Reported Room Sizes. No main effect was observed for condition ($F(2,31) = 0.176, p = 0.84$). The relationship between actual ratio and judged ratio can be seen in Figure 3. The judged ratio closely approximated the actual ratio of all conditions. However, reported ratios were higher on average in more extreme conditions (e.g. when one room was much smaller than the other). This can be seen by noting how the judged ratio is higher than expected when the actual ratio is low.

3.1 Discussion and Conclusion

This poster present the results of a study designed to understand how relative room sizes are interpreted in impossible spaces, and how the reporting method used impacts the sizes reported by users. We found that participants accurately judged room sizes when reporting the size of each room individually, but underestimated the size of rooms when considering them simultaneously. However, even when underestimating the size of individual rooms, participants preserved the accurate ratio between the size of each reported room. Taken together, these results suggest that participants preserved the most important information concerning sizes of rooms within the environment they explored: they accurately judged the size of rooms when considered individually (ignoring the size of other overlapping rooms), and they accurately preserved the relative relationship of the sizes of all rooms in the environment.

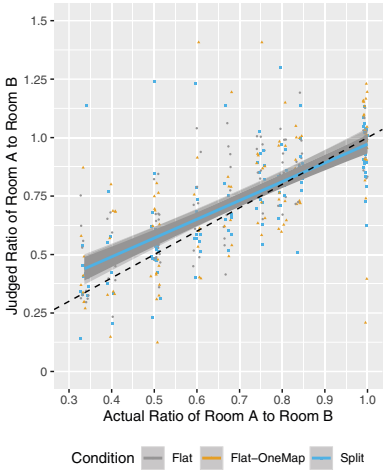

Figure 3: The relationship of the actual and judged ratio between the sizes of rooms A and B is shown above. The judged ratio was similar to the actual ratio in all conditions, as can be seen by the similarity between the true ratio (shown by the dashed line) and the best-fit line modeling the judged ratios.

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