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Influence of Path Complexity on Spatial Overlap Perception in Virtual Environments

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Abstract

Real walking in large virtual indoor environments within a limited real world workspace requires effective spatial compression methods. These methods should be unnoticed by the user. Scene manipulation that creates overlapping spaces has been suggested in recent work. However, there is little research focusing on users' perception of overlapping spaces depending on the layout of the environment. In this paper we investigate how the complexity of the path influences the perception of the overlapping spaces it connects. We compare three spatial virtual layouts with paths that differ in complexity (length and number of turns). Our results suggest that an increase of the path's length is less efficient in decreasing overlap detection than a combination of length and additional turns. Furthermore, combination of paths that differ in complexity influences the distance perception within overlapping spaces.

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1. Introduction

One of the fundamental interaction tasks within virtual environments (VE) is navigation [BKLP05]. In the real world, navigation is most commonly achieved through the natural body motions associated with walking. While walking is simple and intuitive from a user's perspective, supporting this natural method of locomotion in VEs remains a significant challenge due to space and cost limitations. Furthermore, the virtual space that is required for a number of use cases, e.g. large indoor environments like museums, greatly exceeds the real world workspace and needs to be compressed.

To counter these issues, various prototypes of interface devices have been developed to support walking in VEs. They enable remaining in a relatively small space or even prevent the change of the position in the real world [Iwa13]. An alternative to them is the walking-in-place approach that allows walk-like gestures to travel through VEs, while the physical location does not change [FWW08]. However, in practice simulated walking cannot replace natural walking [SVCL13]. Unlike the artificial locomotion techniques, real walking has a positive impact on user experience, including sense of presence [UAW*99], spatial updating [CGBL98], search task performance [RL09], attention [SFC*10], and higher mental processes [ZLB*05].

To address the limitations of natural locomotion in large-scale virtual environments within limited physical space, researchers have developed a class of techniques known as redirected walking [Raz05]. It utilizes the fact that during locomotion visual cues are dominating over other senses and compensate for inconsistencies. By applying gains to the user's real movements, redirected walking makes it possible to steer the user along a more compact path in the physical environment. However, human sensitivity to these manipulations is rather high and to perform the unperceivable redirection this approach still demands a large tracking space [SBJ*10], [SBRH08].

Virtual scene manipulation has a large potential to increase the compression factor for indoor VEs. Its main feature is to enable different virtual spaces to share the same real world space by moving parts of the VE. A number of interesting approaches for spatial manipulation have been suggested, such as change blindness effects [SCK*11], [SCFW10], overlapping architecture known as "impossible spaces" [SLF*12], and dynamic procedural generation of impossible layouts called "flexible spaces" [VKBS13]. They demonstrate that spatial overlap can be efficiently used in certain cases and promise high potential benefit for effective space compression.

In prior art, there are no findings about the minimum requirements for effective use of overlapping architecture and how to maximize the overlap without it being noticed. More importantly, there is still a lack of fundamental knowledge on how different virtual layouts impact the spatial overlap perception.

As a first attempt to fill this knowledge gap, we present a study that investigates the influence of layout properties on overlap perception. Our main contribution is the investigation on how the complexity of the walking path influences the overlap perception. We extend previous studies by exploring opportunities to further improve the efficiency of the spatial compression in “impossible spaces” [SLF*12] and contribute to the understanding of some properties of “flexible spaces” [VKBS13].

2. Related Work

Scene manipulation for space compression in VEs is a relatively new concept. Every technique aims at achieving the largest seamless overlap in different scenarios and uses various spatial layouts.

Suma et al. in [SCK*11] and [SCFW10] modified the direction of the user’s movement within multiple scenes in a systematic way by relying on a change blindness effect. According to [SR05] change blindness is a striking failure to see large changes that normally would be noticed easily. By changing the position of the door in a room, users were redirected to exit the room in a different direction, without them noticing. Moreover, after completing the task users were able to draw a consistent map of the environment. Unfortunately, this method can only be applied in strongly constrained scenarios and is hard to generalize.

VEs using “impossible spaces” employ very simple architecture [SLF*12]. Two layouts were evaluated. In the “fixed room” layout the positions of the rooms with constant sizes were manipulated, causing a change in length of the connecting corridor. The maximum unnoticeable overlap for two rooms in this layout was approximately 50%. The “expanding room” layout (see Figure 1 a, b) kept the occupied area fixed for the two rooms and the rooms were expanding in size by the movement of the wall between them – creating spatial overlap and keeping the corridor size constant. The paper showed that in this condition users were likely to notice an overlap of over 30%. It has been shown in [SLF*12] that scene manipulations produce distance overestimation in VE. However, the other researchers have demonstrated that distances in general [LK03], [IRA07], [IRA06] and the distances one has travelled [FLKB07] are underestimated in VEs in comparison to the real world. While not directly comparable to previous research this effect might provide important insights on spatial perception of impossible architecture. For the distance estimation task the authors used a blind walking egocentric distance estimation method [RATY90]. It requires participants to walk to the previously seen target without visual feedback. This approach has been shown to be the most accurate, reliable, and a commonly accepted metric for distance estimation task [RATY90].

The concept of “flexible spaces” [VKBS13] utilizes the inability of humans to remember their path accurately to manipulate spatial perception. The authors indicated that putting a distance between a pair of rooms by the means of a long twisty corridor might allow an overlap of up to 100% to stay unnoticed. This assumption can be supported by the fact that cognitive maps that represent the obtained knowledge about an environment are often distorted. This distortion is explained by the hierarchical structure of the map and the mental strategies that have been employed by the user to remember the environmental details [Vin99]. Moreover, some of the maps even cannot be represented by images [MB83]. Spatial memory tests showed that even in 2D tasks, path characteristics like self-overlapping of the path, lengths of the path‘s segments and angles between them have significant effect on the success of the path recall [PEM05]. However, to our best knowledge there are no studies that investigated, if the latter holds for VEs, in particular, for VEs that use virtual scene manipulations.

The concept of “flexible spaces” VE also includes dynamic randomized regeneration of the VE’s layout. The constant change of the layout of the VE is preventing users from building the habitual cognitive map. This random nature of the generated corridors makes the systematic evaluation of the path properties difficult. Nonetheless, the pilot study of “flexible spaces” suggested that this concept might be a valid approach towards the generalized application of spatial overlap. Therefore, it is necessary to fully understand the effect the paths have on overlap perception for an optimal use of “flexible spaces” and to verify the properties of this VE.

Consequently, there is a strong need to explore layouts with complex paths in VEs and their influence on overlap perception. This knowledge will help to achieve generalized optimal space compression with adequate space representation, interaction and task performance capabilities.

3. User Study Design

The techniques “impossible spaces’ and “change blindness” suggest that the path between several spaces influences the perception of the environment itself. “Flexible spaces” suggests that the complexity of the corridor is the key towards an unperceivable spatial optimization of VEs. In this study we investigate how the corridor that connects two spatially overlapping virtual rooms influences the overlap detection and distance estimation.

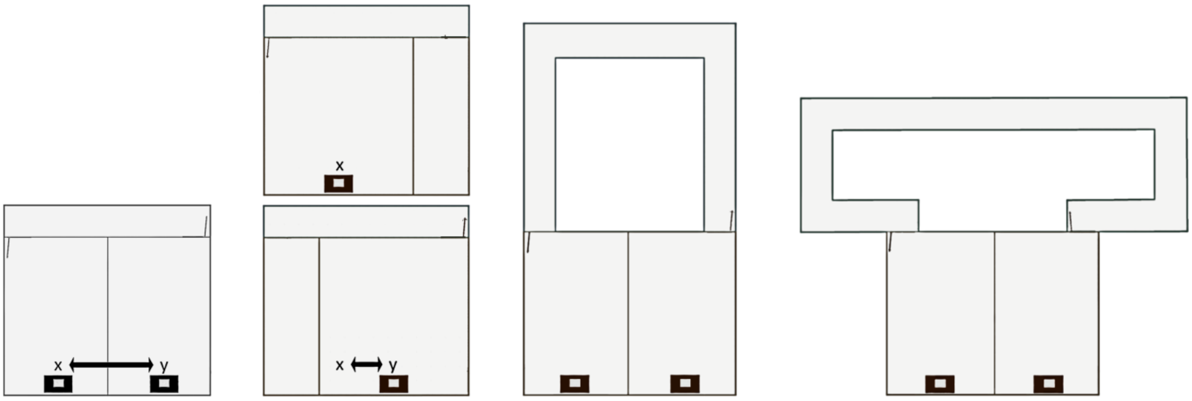
As the complexity is a composite concept in case of the corridors, there are two ways to increase it: 1) a simple way is by adding extra length to the shortest realistic path, and 2) a more intricate way would mean an increase of both length and number of turns in the corridor. Therefore, in this study we examine both stages of complexity. That leads us to the following hypothesizes:

H1 – A corridor longer than the shortest realistic path between two rooms decreases the overlap detection.

H2 – An even longer corridor with more turns than the shortest realistic path or its extended version has stronger influence on the overlap detection.

H3 – The amount of distance overestimation within overlapping rooms depends on the complexity of the corridor that connects them.

For the experiment, we used a repeated measures within-subjects design with two independent variables that repre-



(a) (b) (c) (d)

Figure 1: V*irtual layouts with different corridors: (a) – short corridor with 0% of overlap, (b) – short corridor with 60% overlap, (c) – U-shaped corridor with 0% overlap, (d) – C-shaped corridor with 0% overlap. Arrows show the distances between the tables depending on the overlap percentage.*

sented the type of the corridor and the amount of the overlap.

To keep the room arrangement uniform and corridors' architecture intact throughout the experiment, we fixed the positions of the outer walls of the rooms and formed the overlap by moving the wall between the rooms (see Figure 1 a, b). This room arrangement corresponds to the "expanding room" condition from the "impossible spaces" study.

The first independent variable - the type of the corridor - has three levels. Accordingly we designed the following three layouts:

- the shortest realistic path between two rooms that are sharing a wall was 7 m long. It was used as a baseline condition (see Figure 1 a, b);
- the U-shaped corridor (see Figure 1 c) decoupled the path from the rooms and increased in length up to 17m, while the number of the turns stayed the same;
- the C-shaped corridor increased the length up to 27m and added 4 additional turns (Figure 1 d).

The second independent variable is the amount of overlap. This variable defines the changes in the size of each room. As the maximum unnoticeable reported overlap for the chosen rooms' arrangement is approximately 30% [SLF*12], we tested 0% (no overlap), 20%, 40%, and 60% overlap. Overlap is measured in the percentage of the shared space relative to the area of the whole room. The room size varied from 5.45x3.53m in case of 0% overlap to 5.45x 4.59m for the 60% overlap.

Considering that the experiment is conducted with fully informed participants, which makes it hard to extrapolate the result to uninformed users, we decided to perform the experiment in a single session and without repeats of conditions to minimize the learning effect.

All three corridor types and four overlap conditions resulted into 12 combinations that were tested during a single session. For each corridor type the four overlap levels were presented in pseudorandom order. The order of the layouts presentation was limited in a way that there were no corridor repetition and no repetition of the same overlap condition in sequence. The order of the presentation was counterbalanced across the experiment.

4. Procedure and Environment

The total time of the study was approximately 45 minutes. At the beginning of the study participants signed the informed consent and filled in the Kennedy simulator sickness pre-questionnaire (SSQ) [KLBL93] and a general questionnaire indicating their age, gender, game and 3D game or virtual reality experience

4.1 Test Preparations

The objective of the study requires full awareness and understanding of the overlapping spaces concept by the participants. To keep the explanation procedure as uniform as possible, participants were provided with illustrated material that explained possible/not overlapping and overlapping spaces together with a detailed explanation of the experiment's procedure. Upon reading the information material, they were interviewed to confirm their understanding of the overlap concept and to clarify any possible questions. Participants were encouraged to share their observations and impressions with the experimenter during the experiment by talking aloud. Finally, participants were reminded that they were allowed to take a break or discontinue the experiment at any time. During the instruction process the participants were able to see the workspace before the exposure to the VE; thereby, they were aware of the dimensions of the physical space.

Next, participants were fitted with the head mounted display (HMD) and a backpack with equipment, they practiced to walk in a simple scene with no architecture similar to the experimental conditions. Participants also practiced walking without any visual feedback. Figure 2a shows the participant walking in the workspace.


(a) (b)

Figure 2: *(a) – The user walks in the large workspace with additionally occluded peripheral vision. (b) – User's view in the virtual world in a room with 0% overlap.*

During the entire experiment, the experimenter was walking next to the participants to ensure their safety and to prevent the participants from using the experimenter's or direction of her voice as a spatial reference point.

4.2 Test Tasks

As soon as users completed the preparation phase, they were instructed to locate a red platform in the environment and to step on it to start the experiment. After that the experience started within a virtual room. Figure 2b shows a screenshot of the participants view in the VE. As instructed before, they had to carefully explore the room and approach the virtual table with a laptop to switch it on by getting close to it. This action opened the door to the corridor. As soon as participants were ready to continue, they went to the corridor to get to the other room. The participants were allowed to look back into the room if they did not walk more than 2 meters (2-3 steps) away from the door. Observation of the corridor and the room at the door was also allowed.

Overlap Identification Task: The participants were instructed to explore a pair of rooms connected by a corridor. In the second room they performed a two-alternative forced-choice (2AFC) task by identifying the two rooms as possible/not overlapping or impossible/overlapping. Like in the previous research, the participants were asked to express their certainty about the decision they made. However, we wanted to avoid obtaining nominal data about certainty, but rather interval values. Therefore, we substituted the nominal values that were used in previous research (not confident, somewhat confident, and confident) to a more self-explanatory scale from 0 (not confident) to 10 (very confident). The responses were recorded by the experimenter, while the participant stayed immersed in the VE.

Distance Estimation Task: Having completed the first task, participants were asked to, approach an identical table with a laptop in the current (second) room, and then look in the direction of the first room. When she confirmed that she was ready, the rendering of the virtual building was disabled, the HMD's display became black, and participants performed blind walking to the place where they thought the table in the first room was located. When the estimated distance was walked, participants stopped and the distance was recorded by the experimenter.

Upon completion of the Distance Estimation Task, they were asked to locate another red platform and the experience started with different corridor and overlap parameters.

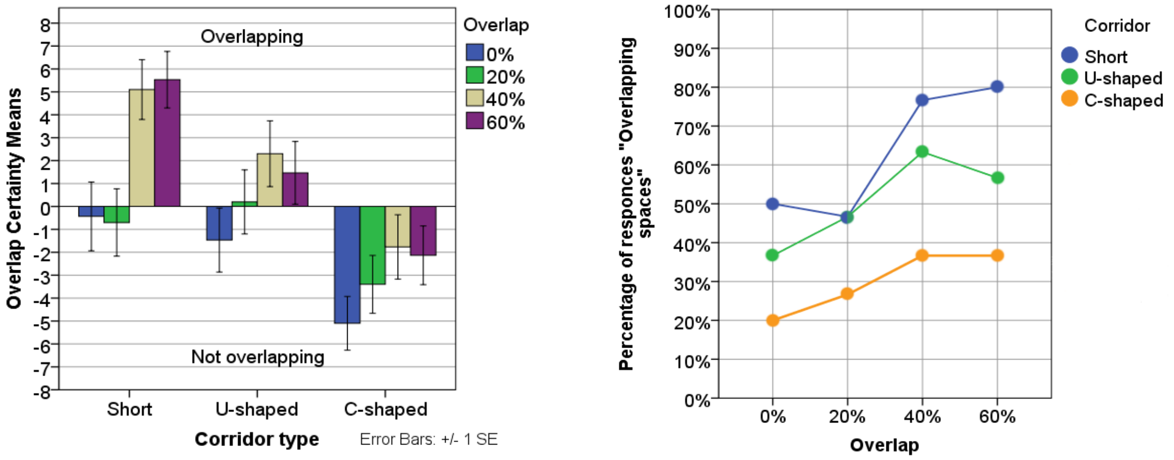
To make sure that no specifics of the real world environment were used as additional cues, the virtual rooms' locations in the physical workspace differed. In addition, the starting platform's position within a pair of rooms was alternated between the left and right room, forcing the participants to walk in clockwise and counter clockwise directions to avoid a learning effect when walking along the same path.

After completion of the walk-through, the participants filled-in the SSQ post-test and a short final questionnaire. The final questionnaire included questions about the strategy used to identify the overlapping spaces, and a difficulty rating of the corridors from 0 (easy) to 10 (difficult) for the main task. We also asked if the participants would want to experience a larger building that uses overlapping spaces, why and whether the participants would expect to notice the overlapping spaces without our explanation and if anything had a positive or negative impact on their experience.

5. Setup

The experiment was performed in a 14x14 meters workspace with two columns in the center, which were three meters apart. Participants were equipped with an Oculus Rift DK2 HMD (FOV 100°) and a backpack with a laptop PC featuring a NVIDIA GeForce GTX 880M and an Intel Core i7 CPU.

The entire weight of the backpack was 3.5 kg making the entire setup fully wearable. The environment was rendered by the Unity 3D game engine. For test application development, we used our own VR framework prototype comprising hard- and software components for pose tracking,



(a)

(b)

Figure 3: *(a) Means of the combined overlap answers and confidence scores (vertical axis) for different overlap percentages in the ascending order for each of the corridor types (horizontal axis). Positive scores indicate confidence the rooms are overlapping. Error bars represent standard errors. (b) The percentage of the response "overlapping spaces" (vertical axis) for different levels of overlap (horizontal axis) and different corridors (see the legend).*

stereoscopic scene viewing and high quality rendering. This framework is unpublished yet with a publication currently in preparation. The wide area tracking system provided 3DOF positional tracking updates with approximately 30Hz. For the three degree of freedom orientation tracking, we used the Oculus built-in inertial measurement unit comprising accelerometer, gyroscope and magnetometer.

6. Participants

In total, 13 female and 17 male subjects (age 20-48, M = 29.07) participated in the study. Participants were recruited at Facebook's local English-speaking groups on a volunteer basis. They were required to be over 18 years old, with normal or corrected-to-normal vision, to not suffer from severe motion sickness, epilepsy, contact transmitted diseases and be able to walk normally with a backpack. Subjects were of different background ranging from students to professionals with expertise in sports, sales, economics, biology, architecture, computer science and physics. Ten participants indicated that they never played in computer games and 12 had an extensive game experience. Only six people stated they played video games more than six hours per week. 16 had no experience with 3D games or VR environments, six had stated to be slightly experienced, four were experienced and four stated to be experts.

7. Results

We use the effect size as a quantitative measure of the strength of a phenomenon. We used Pearson's correlation coefficient (r) for estimation and Cohen's benchmark for interpretation of the size of the effect that does not depend on measurements scales. If not stated otherwise, all tests in this paper use the significance value $\alpha = 0.05$.

7.1 Overlap Detection

Figure 3 shows the change of the overlap confidence scores depending on the corridor type as well as percentage of the participants that identified space as "overlapping" for different corridors and overlap percentages.

The statements about the rooms' spaces were coded as -1 – for "not overlapping rooms" and 1 – for "overlapping rooms". To achieve a better understanding of human perception, we combined the overlap and certainty scores, resulting in overlap certainty scores from -10 to +10 (where the negative values signify that the spaces were identified as not overlapping). Their means are shown in Figure 3a. The scores were analyzed using 3x4 factorial repeated measures analysis of variance (ANOVA) for the within-subjects effects of the corridor type. There was a significant main effect of the corridor type on the combined impossibility scores, F (2, 58) = 10.913, as well as overlap, F (2, 58) = 9.969. Contrasts revealed that for rooms with C-shaped corridors scores significantly differed from scores with the U-shaped corridor F (1, 29) = 9.009, r = 0.49. C-shaped corridors produced a large sized effect indicating that layouts with it were perceived as not overlapping spaces, much stronger then layouts with U-shaped corridors. The scores between the short and U-shaped corridors turned out to be not significant, regardless the obtained medium sized effect (F (1, 29) = 2.7, r = 0.29), that indicates a trend.

To determine if the U-shaped corridors had any effect compared to the short corridors, we performed a Wilcoxon signed-rank test for scores for each overlap percentage. Given that we tested a specific hypothesis (H1) that longer corridors lower the impossibility-confidence scores, we report the exact significance of one-tailed tests.

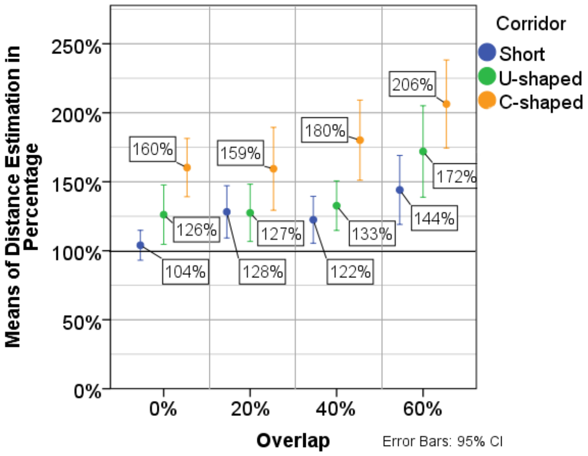


Figure 4: *The distance walked in the distance estimation task, as a ratio between the physical distances walked to the actual distance between virtual tables.*

Only for 60% of overlap the impossibility-confidence scores were significantly lower for the U-shaped corridor (Md = 4.5) then for the short one (Md = 8.5), producing a medium sized effect (z = -2.519, r = -0.33). For the 40% overlap the scores' difference was not significant (Md_S= 9.0, Md_U = 6.5, p = 0.063), although also produced a small effect r = -0.198.

To gain further insights in the influence of the layout we performed similar analysis for the U-shaped and C-shaped corridors. The results were significant for overlaps of 0% (Md_U = -5, Md_C = -8, z = -1.92, r = -0.25), 20% (Md_U = -3, Md_C = -7, z = -1.845, r = -0.24), and 60% (Md_U = 4.5, Md_C = -5.5, z = -1.995, r = -0.26). The results for the overlap of 40% were not significant, but also produced a medium sized effect (Md_U = 6.5, Md_C = -6, z = -1.623, r = -0.21).

7.2 Distance Estimation

In Figure 4, the distance walked in the distance estimation task is illustrated as a ratio between the mean of the physical distances walked to the actual distance between virtual tables.

The distance estimation task data were analyzed using the 3x4 factorial ANOVA. Maulchly's test indicated that the assumption of sphericity had been violated for the main effect of the overlap, $\chi^2(2)$ = 16.451, p < 0.05. Therefore, we corrected the degrees of freedom using the Greenhouse-Geisser estimates of sphericity, ε = 0.9. Subsequently, the effect of the overlap on the distance walked was significant, F (2.145, 62.207) = 13.962.

We also found a significant effect of the corridor type on the distance overestimation (F(2,58) = 24.824). The contrasts revealed that the distances walked after the U-shaped corridor layout were significantly more overestimated compared to the short corridor (F(1, 29) = 5.538, r = 0.4), resulting in a medium-sized effect. The distance walked after the C-shaped corridor was also significantly more overestimated than after the U-shaped corridor (F(1, 29) = 22.104, r = 0.66). The C-shaped corridor resulted in a large effect.

We used Pearson's correlation coefficient to estimate the correlation between the distance overestimation and overlap certainty scores. The correlation was significant (r = -0.405, 95% BCa CI [-0.481, -0.320], p <0.001; R^2=0.164).

7.3 Simulator Sickness

To complete the experiment, the participants had to walk in a large environment for about 25 minutes equipped with the wearable VR setup. Only two participants requested to take a break during the experiment. No participants had withdrawn from the study.

The participants experienced an increase in self-reported simulator sickness after the experiment (M = 6.33, SD = 8.07) compared to before the experiment (M = 3.26 SD = 4.88). The difference, 3.07, BCa 95% CI [1, 5.12], was significant t (29) = 3.046, p = 0.005 and presented a medium-sized effect, r = 0.49.

7.4 Further Findings:

Difficulty scores. The scores of how difficult it was to identify overlapping spaces for different types of corridors are as follows: short corridor M = 4.55, SD = 3.32; U-shaped corridor M = 5.96, SD = 2.44; C-shaped corridor M = 6.86, SD = 3.35. For the C-shaped corridor three participants gave the difficulty score of 0 and two gave a score of 2, in both cases the reasoning was that with these corridors rooms cannot be overlapping. 17 participants indicated that they could have noticed the overlapping spaces without our explanations. 11 of them would have expected to notice the overlap in layouts with short corridors.

Acceptance. The scores of the acceptance related question inquiring if the participants will be open for the exploration of a more complex building that uses overlapping spaces on a scale from 0 (not at all) to 10 (absolutely yes) produced a mean M = 8.73, SD = 2.36, indicating the majority vote for the answer "yes".

Strategies. Only 10 out of 30 participants tried to count steps, 18 - relied on perception and visualization, and two used virtual objects for size estimation in the VE.

"Same room" illusion. Eight participants reported that they returned to the same room after walking through the corridors. Within this group of participants seven in total referred to one of the U-shaped corridor layouts with various overlaps. One of them additionally referred to a C-shaped layout with 20% overlap. Another participant who mentioned the U-shaped corridor also identified two short corridor layouts with 40% and 60% overlap as the same room experience. Finally, one participant commented similarly a C-shaped corridor layout with 0% overlap.

"Room displacement" illusion. Two participants reported that the rooms were not aligned with each other and therefore could not be overlapping. Two cases featured the C-shaped corridor layouts and two - the U-shaped corridor

layout. The explanations were also supported by the hand positioned in a way that made it clear that the rooms are apart and not aligned. Similar behavior (performing distance estimation intentionally on a diagonal instead of straight path) was exhibited by three more participants without any comments for U-shaped and C-shaped corridors.

8. Discussion

To analyze the participants' perception of overlapping spaces with different architectural layouts, we used self-reported measures together with an egocentric distance estimation task and talking aloud.

Our results show that the increase in complexity of the corridor decreases the percentage of the participants who classified the space to be overlapping (see Figure 3b). While the effect of the U-shaped corridor relative to the short corridor was not significant, the means of confidence scores showed a declining trend. That partially supports our hypothesis H1. It is also possible that the length of the corridor was insufficient to produce a significant difference.

The significant difference of the scores between the U-shaped and C-shaped corridors as well as between short corridor and C-shaped ones supports our H2 hypothesis. The additional turns added extra length and changed the shape of the corridor. As a result, the U-shaped corridors were rated as more difficult for the task performance than the short corridors, but less difficult then C-shaped ones. There was also a reflection in the participants' comments, such as "Oh, this one is longer" or "Different one" for U-shaped corridors and "Things get complicated" or "I'm not sure if they are overlapping, it was far away" or "The corridor was so long, they can't be overlapping" for the C-shaped corridors.

It is also important to take into the consideration that all the layouts in our experiment had symmetric shapes. The asymmetric corridors might help to reduce the length of the path in general and mask the overlap.

In case of the C-shaped corridors, a noticeably higher percentage of participants identified the connected rooms as not overlapping in comparison to the U-shaped and especially short corridors. That also supports our H2 hypothesis.

However, the percentage of answers "overlapping" in case of a short corridor, which also can be interpreted as probabilities, differs from the reported probabilities of the previous research [SLF*12]. The "impossible spaces" research reported probability for the response "overlapping" as low as 10% for the short corridor layout with 0% overlap, while in our case 50% of the participants gave that answer. Therefore we speculate that long corridors might have a priming effect on the overlap perception in the layouts with shorter corridors. Our subsample of 10 users, who started the experiment with the short corridor layout and different amounts of overlap, gave scores for the first layout that matches the observed answer ratio from previous research. However, the sample is not large enough to draw a final conclusion. Those, who observed U-shaped or C-shaped corridors layouts first, were more likely to rate the following short corridors layouts as overlapping.

The significant difference between the distance estimation results supports our hypothesis H3 that the corridor complexity has an influence on the distance perception. Our results also show the consistent overestimation that maintains a similar overestimation trend for all the corridor types. There is also an inverse correlation between the overlap confidence scores and overestimation. The increase of confidence that the spaces are overlapping decreases the distance overestimation. The 16.4% of the variance of the overestimation is shared with overlap confidence scores.

At the same time, in the distance estimation for our baseline condition the distance overestimation did not reach the levels of the previous research as reported in [SLF*12]. If we compare the results for short corridors of prior research, the overestimation for the 0% overlap was approximately 120% and for the 60% overlap it reached as high as a bit over 300%. In contrast, our results show 104% and 144% of overestimation for 0% and 60% overlap, respectively. The increase of accuracy in this task might be explained in a number of ways. Among them would be the difference in room sizes 5.45 by 3.53m in our study for 0% overlap in comparison to 3.66 by 7.32m in previous research. There is also a difference in the sizes of areas used for walking in different layouts, as the more complex corridors required more space. Also the previous research compared two different ways of creating overlap and used only the short corridors. Therefore, there might be a connection to the details of the VEs, but further research is needed in this case.

Another unexpected outcome of our study is the reported "same room" and "room displacement" illusions that seem to be connected to the corridor shape. The groups of participants, who reported these phenomena, were completely different. While the "same room" illusion could be possibly caused by the overlap identification task, we find it difficult to explain the "room displacement" as our VE is strictly symmetrical. Therefore, future investigation is required if these observations are connected to the distance asymmetry in cognitive maps as described in [MB83] or if there were other reasons.

Finally, our results and the consistency of the effects clearly suggest that the relation between the overlap perception and corridor complexity is much stronger than it was assumed in prior art.

9. Conclusion and Future Work

In this paper, we presented research that is the first attempt to study in detail the influence of virtual corridor complexity on overlap perception, while navigating through a VE by real walking. We hope it will become a foundation for efficient space compression of large indoor VEs in limited physical workspace. Our results showed that the complexity of the corridors lowers the probability for the space to be identified as overlapping. At the same time, the probability for less complex layouts to be perceived as overlapping might be increased when combined with more complex layouts. Additionally, there is an inverse correlation between the distance overestimation and confidence that the spaces are overlapping. Our results suggest that combination of corridors with different complexity might increase the users' awareness of the distances within the explored VE.

From the practical point of view, there is a need to vary the corridors' layouts to avoid exposing the actual size of the walking area. The observed distortions of the paths in our symmetrical VE suggest that the asymmetrical layouts might be more efficient in creating unperceived overlapping spaces. Therefore, we plan to explore the effect of asymmetrical corridors on the overlap perception in our future work.

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