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Evaluation of Surround-View and Self-Rotation in the OCTAVIS VR-System

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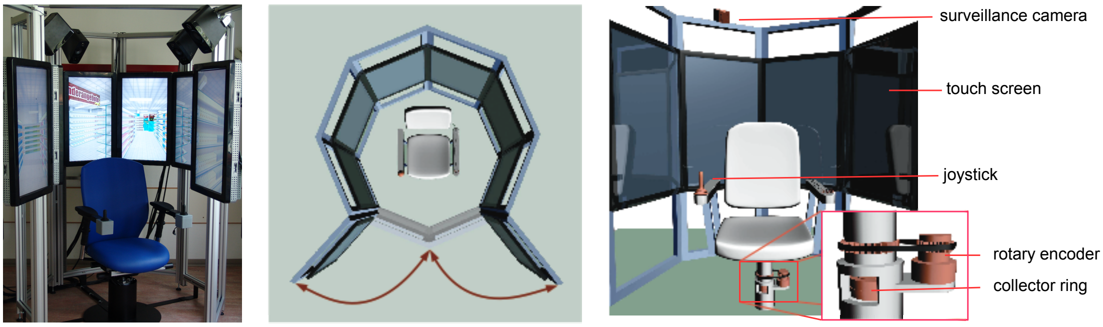

Figure 1: *In the* OCTAVIS *system (left) eight screens are arranged in an octagon to provide a* 360° *surround-visualization of the virtual environment. Two door segments can be opened (center). Navigation in the VR is performed through an office chair, whose orientation determines the movement direction, and a "throttle joystick" in the armrest (right).*

Abstract

In this paper we evaluate spatial presence and orientation in the OCTAVIS *system, a novel virtual reality platform aimed at training and rehabilitation of visual-spatial cognitive abilities. It consists of eight touch-screen displays surrounding the user, thereby providing a 360° horizontal panorama view. A rotating office chair and a joystick in the armrest serve as input devices to easily navigate through the virtual environment.*

We conducted a two-step experiment to investigate spatial orientation capabilities with our device. First, we examined whether the extension of the horizontal field of view from 135° (three displays) to 360° (eight displays) has an effect on spatial presence and on the accuracy in a pointing task. Second, driving the full eight screens, we explored the effect of embodied self-rotation using the same measures. In particular we compare navigation by rotating the world while the user is sitting stable to a stable world and a self-rotating user.

Categories and Subject Descriptors (according to ACM CCS): I.3.6 [COMPUTER GRAPHICS]: Methodology and Techniques—Interaction techniques

1. Introduction

Visual-spatial abilities are a key attribute for managing everyday life. No matter whether we travel by plane to a conference, by train to visit a relative, or by car to see the ocean, we need to locate ourselves in space to decide which direction to go to arrive at a fixed destination. Also to find our way around in a building we rely on our spatial understanding. We do so even when other people describe specific locations to us, when we interpret pictographic signs, or when we read any kind of spatial map.

Since spatial thinking is one of the seven primary mental abilities in the theory of intelligence, and also since sports, design, mechanical construction, and even perception of music strongly depend on a functioning spatial cognition, we are very limited when the corresponding brain areas get injured (e.g., through stroke, neuro-degenerative disease, or an accident). Luckily, visual-spatial abilities can be improved or recovered through specific training.

Recent developments in virtual reality (VR) research have shown that simulated environments in appropriate devices can be used for therapy, such that training effects can successfully be transferred to real life. In a highly interdisciplinary research effort we developed an immersive VR device for clinical studies focused on visual-spatial training and rehabilitation. Our VR system is called OCTAVIS and is illustrated in Figure 1.

To mimic visual perception of reality as closely as possible the OCTAVIS presents the virtual environment in a 360° panorama view on eight touch-screen displays surrounding the user. HMDs disqualified for our project because of their low acceptance by patients. A well suited interaction metaphor for VR navigation is real walking or walking in place. However, many stroke patients are not able to walk or even stand. Hence, we employ a rotating chair as input device for navigation, where the walking direction is determined by the chair orientation and forward/backward movement is controlled by a joystick in the armrest. A detailed description of the OCTAVIS system is given in [DZK*12].

While this system has already proven its effectiveness in clinical studies [ZDK*13], in this paper we evaluate two of its particular properties: We analyze which effect on spatial presence and spatial orientation skill (i) the eight-screen surround-view and (ii) the user's physical self-rotation have, using the MEC SPQ and a custom pointing task.

2. Related work

It has been shown that spatial knowledge does not transfer easily from virtual reality to the real world [Pso95, GM98]. We want to test the effect of the OCTAVIS on the ability to orient oneself and to navigate through the virtual environment, the so-called *way-finding*. In the initial definition of way-finding by Kevin Lynch [Lyn60] the four components of way-finding are: orientation, route decisions, mental mapping and closure. See Raubal and Egenhofer [RE98] for an overview. Mental maps, also called cognitive maps, are the concepts agents create in their minds to enable them to plan their activities. They are an abstraction of the environment based on the sensory input of the agents. Mental maps are (sometimes) helpful in way-finding, but way-finding does not necessarily have to rely on mental maps.

In their work on child development, Piaget and Inhelder [PI67] differentiate between perceptual space and conceptual space. The perceptual space is created and inherently tied to sensori-motor activities that lead to corresponding perceptions. Its development precedes that of the conceptual space in early childhood. The orientation aspect of way-finding can be linked to the concept of perceptual space, whereas mental mapping is clearly linked to conceptual space. So there are two different cognitive mechanisms that are at work in way-finding. At least the first in development, the perceptual space, is strongly grounded in sensori-motor activities and thus some effort has to be taken to provide sufficient sensori-motor cues. A VR interface for navigation has thus to provide sufficient cues for both levels to fully support natural way-finding, e.g., by providing appropriate visual cues and a suitable locomotion technique [DP02]. In the OCTAVIS, we implemented techniques to address both levels: a 360° surround-view to maximize visual cues and a chair allowing physical self-rotation for the locomotion part (Figure 1).

2.1. Related work on locomotion

There are effects of the choice of the locomotion technique on way-finding and in particular on orientation. It has been shown that locomotion interfaces that provide proprioceptive and vestibular feedback have a positive effect on the user's navigation capabilities [DS93, CGBL98, RL09]. According to expectation, interfaces that come close to the real walking experience provide an excellent feedback and support navigation performance of humans (see e.g. [RVB11]).

Interfaces that come close to natural walking are redirected walking [Raz05], motion compression [NHS04], seven-league-boots [IRA07], and scaled-translational-gain [WNM*06]. However, all of these interfaces have been designed to allow for navigation in larger-than-real spaces (i.e., the size of the virtual world is larger than the real estate) and thus feature some kind of compression or scaling [WNR*07]. Some of these techniques require a method for re-orienting the user in the virtual world whenever she approaches a barrier in the real world, which might reduce presence [Raz05, PFW09]. On the other side, interfaces that only allow for a partial approximation of natural walking, such as walking-in-place or treadmills [Hol02, DCC97], are difficult to handle [SGF*10] and might thus yield only suboptimal performance.

Currently, there is a disagreement about whether real walking simulation is the key factor [RL09] or if it is sufficient to make the users do physical rotations to alter their orientation [RSPA*06]. Motivated by recent work of Riecke et al. [RBM*10] who found excellent orientation performances when pairing physical rotation with continuous joystick-based translation, we test whether this also applies for the situation in the OCTAVIS, where the user remains seated.

There is not much work on navigation through virtual reality in a seated position. A recent exception is the work on redirected driving by Bruder et al. [BIPS12]. They use electric wheelchairs that drive in the real world to provide sufficient proprioceptive feedback to the driving user. However, they are using HMDs to provide a full visual immersion into virtual reality. They find that people are a little

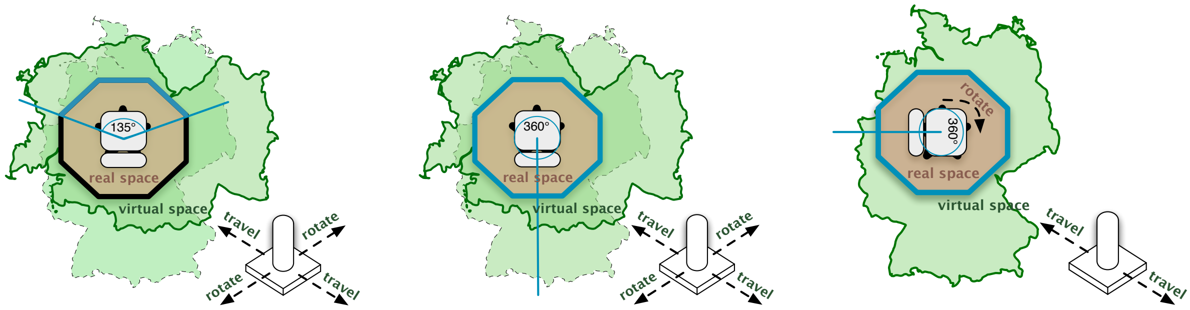

Figure 2: *We designed three conditions for our study. Left: The Frontal-View condition (FV) has a 135° field of view (3 displays) and rotates/travels the virtual space through a joystick. Center: The Surround-View condition (SV) employs a 360° field of view and again navigates the VR by joystick. Right: The Rotating-User condition (RU) has a 360° field of view, but the user rotates in real space to control walking direction in the virtual space; the joystick is used to navigate forward/backward only.*

less sensitive to a redirection of their orientation when driving the wheelchair than when walking. This could imply that users are less sensitive to rotations of the wheelchair. In our system, however, the users have full control of their rotation, while in the study of Bruder and colleagues a joystick was used to guide the motor-driven wheelchair. A promising insight of their study is that they found no significant difference in presence, thus driving through the virtual world while being seated was sufficient to establish a similar presence as natural locomotion. However, comparing locomotion using several strategies Nybakke et al. [NRI12] found that task performance was better using a motorized wheelchair than traveling in a seated position with translation controlled by a joystick and rotation controlled by swiveling. Their results also suggest that distributing translation and rotation movements over two modalities could lead to more sequential locomotion patterns.

2.2. Related work on field of view

In early work on the effect of the field of view on presence, Hendrix and Barfield [HB95] already showed that increasing the field of view increases presence. However, their restricted technical setup only allowed a comparison in a range of 10° to 90°. Interestingly, they did not find a significant improvement between 50° and 90°.

A decrease of the field of view was observed to come along with a decrease in cognitive map building performance [AM90]. McCreary and Williges [MW98] reported that the field of view did not have an effect on landmark knowledge, but had a significant effect in a pointing task, where participants had to point to occluded objects. They also found a correlation between computer experience and performance in the pointing task.

In a desktop-based setup with up to 180°, Seay et al. [SKHR01] showed that an increase of the field of view to 180° increases the feel of presence, but also increases nausea, especially for passengers not actively navigating in the virtual world. Lin et al. [LDP*02] tested displays with fields of view of 60°, 100°, 140°, and 180°. They report an increase of presence with an increase of field of view, albeit the increase seemed to approximate a plateau between 140° and 180°. In their memory test, the results also correlated positively with the perceived presence.

There is a general effect of underestimating traveled distance in virtual reality [WK98], which might affect wayfinding. Knapp and Loomis [KL04], however, could not find a significant effect of a limited field of view on distance estimation. Steinicke et al. [SBJ*10] showed for HMD-based projections that participants underestimated rotation in virtual reality. However, in the OCTAVIS the frames of the projection screens provide fixed anchors for orientation and thus the estimation of rotation should be rather congruent.

Under the assumption that an increased field of view facilitates orientation and thus supports cognitive map building, the OCTAVIS was designed to support the maximum field of view independent of the viewing direction of the user. This does not hold for most desktop- or projection-based studies mentioned above and the effects remain to be evaluated.

3. Method

To investigate spatial presence and orientation in the OCTAVIS we designed a two-step experiment. In the first step we modified the real field of view and in the second step we changed the rotation aspect of our navigation metaphor. We did so comparing three experiment conditions:

Frontal View (FV): In the first condition (Figure 2, left) we used three displays to render the virtual maze. This resulted in a wide, but still limited, frontal view of 135°. To navigate the world the user operated a joystick with two axes: one to move forward/backward and the other to rotate the virtual scene in order to change the travel-

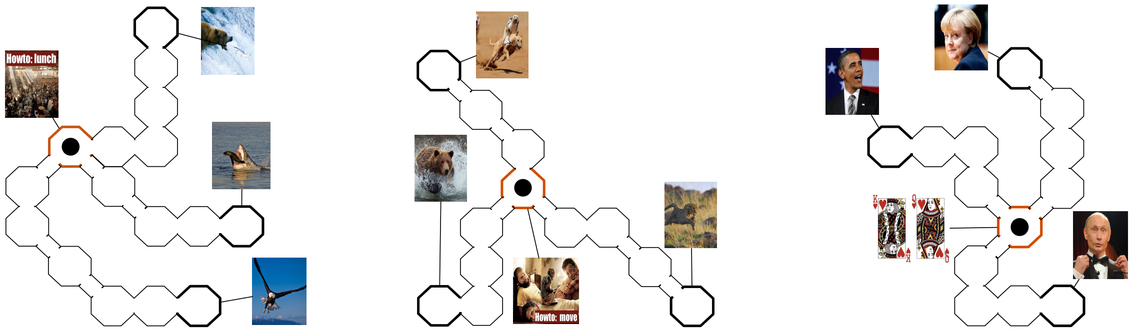

Figure 3: *Maps of the three museum-like mazes each participant saw during consecutive runs. Participants always started at the central room (black dot). Here and in the rooms at the end of each corridor an image was displayed. These four images were to be remembered in their spatial relationship to each other and pointed to during the pointing task.*

ing direction. This rotating world principle is a common metaphor used in most first person desktop games.

Surround View (SV): For the second condition (Figure 2, center) we kept the rotating world metaphor, but extended the field of view to a 360° horizontal surround view employing all eight displays for rendering the maze. To prevent confusion about the front-direction we explicitly marked one monitor as front-monitor.

Rotating User (RU): The third condition (Figure 2, right) used the 360° surround-view rendering, but instead of a rotating virtual world with the user sitting stable, now the user physically rotated herself to control the traveling direction. This way, "front" was where the user turned the chair to, which was measured by a rotary encoder in the office chair (Figure 1, [DZK*12]). The joystick had just one axis enabled used to move forward/backward.

To enable a comparison of the three conditions in a within-subject manner, three mazes have been designed. According to the findings in the field of space syntax and research about dementia-friendly architecture [MS09, DE00, BWÖ04], orientation in a building benefits from straight circular corridor systems, right-angled turns, architectural symmetry, direct sight, large rooms, and different textures and geometries per room.

Since in our study we aimed at challenging orientation, we designed our mazes to be hard with respect to the above criteria: We developed a modular system of 30 equally textured small octagonal cells with different entrance-exit-combinations. These cells can be configured on a rectangular grid to create a maze, a corridor arrangement, or an architectural room-assembly. We conducted a pre-study with different cell combinations to ensure both a sufficient and comparable complexity between mazes. Based on the experience from the pre-study, we decided for the three corridor-arrangements shown in Figure 3. Each arrangement consists of three asymmetrically coiled corridors, some of which feature unusual turns of 45°.

Semantically, each maze acted as a museum hosting four images of the same topic. The first one showed how different creatures lunch (humans, bears, sharks, eagles), the second one how they move (humans, dogs, cheetahs, bears) and the last one was about styles of government (monarchy, Obama, Putin, Merkel). The images were displayed in the central room joining the three wings and also in the last room at the end of each corridor (Figure 3). An impression of an inside view is given by Figure 4.

Figure 4: *Screenshot of the maze as participants saw it.*

In the actual experiment every participant had to perform three consecutive sub-experiments, each in a different maze. All participants started in Maze 1 and finished with Maze 3, but we randomized the three conditions (FV, SV, RU) to be used for the mazes, such that 16 participants (8♀, 8♂, age=23.2, sd=4.6) performed the experiment in the order FV-SV-RU, 16 (8♀, 8♂, age=24.5, sd=10.0) in the order SV-RU-FV, and further 17 (8♀, 9♂, age=23.7, sd=6.1) in the order RU-FV-SV. In total we tested 49 healthy participants (24♀, 25♂, age=23.8, sd=7.1) with different education backgrounds (pupils, university students, craftspeople, office employees).

After the personal data acquisition including a self-rating on VR-experience (VR-skill), a short training in a circular corridor with two pictures was performed before each sub-experiment. Here participants learned the respective navigation metaphor, the viewing setup, and about their pointing accuracy. The following sequence describes the actions per sub-experiment.

1. Be spawned in the central room and memorize its picture.
2. Walk to the end of each corridor, memorize the picture in the last room, and walk back to the central room.
3. Point from the central room to each of the pictures in the corridors in the order visited.
4. Again, walk each corridor to its end, point back to image in the central room and to the images in the other corridors, and travel back to the central room.
5. Point from the central room to each of the pictures in the corridors in the visited order.

In case they forgot, participants were allowed to ask in which corridor a specific picture was displayed. After completing the set of three experiments the participants had to fill out a questionnaire. Finally we tested the participants' mental rotation capabilities with the paper-and-pencil *Mental-Rotation-Test* by Vandenberg [VK78] in its A-version (MRTA).

To measure the spatial presence and spatial orientation skill for each condition we employed two measurement instruments:

Pointing Task: First, a pointing task was performed within the virtual maze [CGBL98]. Pointing to an object was done by touching a touch-screen, which issued a ray from the viewer's position in VR through the touched pixel of the respective screen/view. The horizontal angular difference between this ray and the exact direction to the object in question was used as the angular error.

Questionnaire: Second, a combined questionnaire was filled out. The Measurement-Effects-Conditions Spatial Presence Questionnaire (MEC SPQ) [VWG*04] measures not only the feeling of presence in general, but focuses on *spatial presence*. We used the four-items per sub-scale version with a 1–5 rating scale (1="not at all", 5="very much"). We extended the questionnaire such that for each question the participants had to give three answers, one for each condition. We also added five questions rating general aspects of the system, again for the different conditions: fun, tiredness, cyber-sickness, intuitiveness of control metaphor, and realism of control metaphor.

4. Results for Frontal-View vs. Surround-View

First we compare the questionnaire results and pointing task accuracies of the frontal view (FV) condition to the surround-view (SV) condition.

Since the data from the MEC SPQ was not normally distributed and a log-normal transformation did not solve the problem, we calculated the results with the non-parametric Mann-Whitney-U test. These computations discovered no significant effects on the sub-scales *Attention*, *Involvement*, and *Suspension-of-Disbelief*, but very clear ones on the following sub-scales:

- *Spatial Situation Model* ($W = 26011$, $p = 0.00$)
- *Spatial Presence Self Location* ($W = 8217$, $p = 0.00$)
- *Spatial Presence Possible Actions* ($W = 25031$, $p = 0.00$)

Figure 5, left, shows the mean values of all sub-scales. Note that all significant sub-scales directly reflect spatial presence. In contrast, attention, involvement, and suspension-of-disbelief are more related to general presence, not spatial presence in particular. This suggests a distinguished impact of the additional five screens on the participants' subjectively experienced location.

Analyzing the general system ratings (Figure 5, center) with the Mann-Whitney-U test we found the following two effects to be significant:

- *Realism* ($W = 923.5$, $p = 0.02$)
- *Fun* ($W = 807.5$, $p = 0.00$)

The differences between the ratings for *Cyber-sickness*, *Intuitiveness of control*, and *Tiredness* were not significant. On the one hand, this is somewhat contrary to the literature claiming a wider field of view causing more cyber-sickness [LaV00, SKHR01]. On the other hand, 135° is already a wide field of view to begin with. Since the control metaphor stayed the same for both conditions it is no surprise that we found no significances for the questions related to control.

Since our pointing tasks differed in complexity, we analyzed the following groups of tasks individually:

- from every picture to every other,
- from a specific corridor-picture to every other picture,
- from a specific corridor-picture to another specific one,
- from a specific corridor-picture to the center-picture,
- from the center (1st time) to a specific corridor-picture,
- from the center (2nd time) to a specific corridor-picture.

To avoid distortions due to the different order of sub-experiments per participant, we considered only the data from the first sub-experiment for this analysis (Maze 1, respectively first condition). Since all three groups were similar in gender-ratio, age, VR-skill (FV=2.5, SV=2.1, RU=2.1), and even MRTA-scores (FV=6.3, SV=6.3, RU=6.5), we consider this between-subject comparison of pointing-errors the most robust approach. Since this data was not normally distributed, we again employed the Mann-Whitney-U test. Contrary to our expectations we found no significant differences between any groups of pointing tasks in the FV condition compared to the SV condition. Figure 5, right, compares the pointing errors between conditions. Although the spatial presence was found to be significantly higher with a surround view, it seems to have no effect on the actual orientation in the same virtual environment.

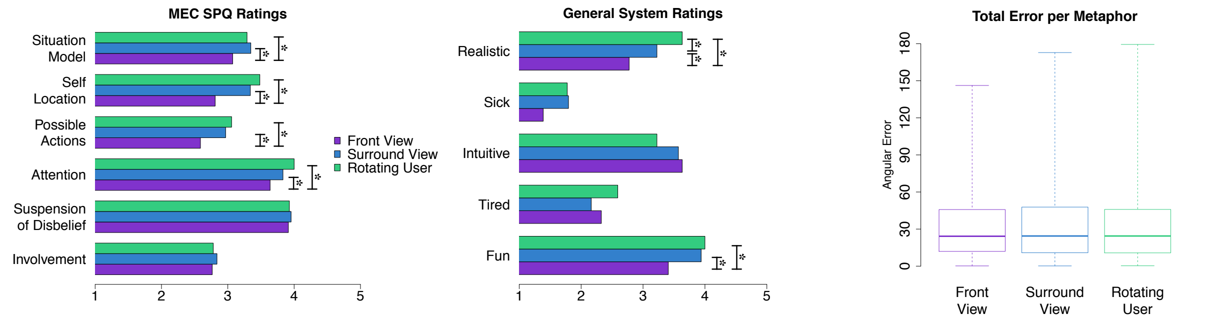

Figure 5: *Left: Ratings of MEC SPQ comparing its sub-scales for all three conditions (∗ = significant). Center: Ratings for the general system aspects (∗ = significant). Right: Angular error considering each of the 15 pointing actions per participant in the first maze, showing very similar medians and distributions for all three conditions.*

5. Results of Rotating World vs. Rotating User

After showing the effects of an extended field of view, we now describe our results on the effects of user embodiment. Therefore we compare the results of the surround-view (SV) condition (stable user, rotating virtual space) to the rotating-user (RU) condition (stable virtual world, self-rotating user).

The MEC SPQ ratings (Figure 5, left) revealed no significant differences except for the *Attention* sub-scale ($W = 17398$, $p = 0.05$). Since many participants reported a strong focus on the control mechanism in the RU condition, the questions regarding the *Attention* sub-scale may have been misunderstood in the sense that they were answered with respect to the attention on the hardware controls and not on the task in the virtual maze. According to our MEC SPQ results, disabling virtual world rotation and instead performing direction changes by embodied self-rotations does not have a significant effect on spatial presence.

For the general system questions the participants significantly ($W = 904.5$, $p = 0.01$) distinguished their ratings only on the *Realism* scale in favor of the RU condition (Figure 5, center). This is an important result suggesting the removal of the abstraction layer introduced by common control metaphors, such as joysticks or other devices used to rotate the world, instead of having an embodied rotation like we are used to from the real world. However, the results for *Intuition of control* are not significant. We argue that this is due to the fact that most participants are young, and even when they stated a low VR-experience they are already somewhat familiar with the rotating world paradigm (e.g., through computer games), but are not familiar with self-rotation. The attention to the unknown control metaphor may have had a negative influence on the *Intuition* ratings.

Similar to the step from FV to SV, the step from SV to RU yields no significant differences in pointing errors between the conditions for the first maze. In fact, Figure 5, right, shows that the error distributions are nearly the same for all three conditions, when looked at *in total*. This even holds for the second and third sub-experiment.

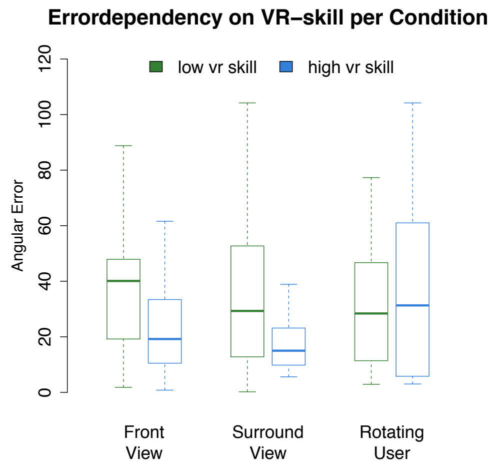

Figure 6: *The angular error of pointing tasks for corridors just traveled decreases with higher VR-skill for the FV and SV conditions, but is independent from it in the RU condition. The lines in the box-plots represent median values.*

Like in Section 4 we examined specific pointing tasks in closer detail, but this time observed a difference in correlations between pointing error and VR-skill between the two conditions. Namely, pointing from the end of a corridor back to the central room we found a Spearman correlation factor of $\rho \approx -0.35$ both for the FV and the SV condition. On the contrary, in the RU condition the correlation factor was nearly zero. Figure 6 shows the dependency of pointing error on VR-skill for all three conditions. Since self-ratings of VR-skill are error prone and no participant stated himself a VR-skill of 5, we classified participants into low VR-skill (1–2) and high VR-skill (3–4). Though statistically not significant, the chart clearly shows that in the conditions where the world was virtually rotated (FV and SV) the error decreases with increased VR-skill, meaning the user benefited from former VR-experience. In the RU condition, however, VR-skill had no influence on the pointing accuracy. Here participants with low VR-skill had nearly the same error as participants with high VR-skill. We did not find such correlations with the MRTA-scores, but people with good mental rotation scores in a paper-and-pencil test are not necessarily good in orientation in an immersive virtual environment.

Since the average VR-skill per group and also the means of the MRTA did not differ much, this observation truly seems to depend on the navigation metaphor only.

Because this effect was not true for arbitrary pointing tasks, user rotation appears not to be beneficial for virtual map learning in global (conceptual) space. However, since it was true for the specific pointing task at the end of a corridor just traveled, we suspect it to contribute to orientation and the ability of locating oneself in the immediate (perceptual) space.

6. Discussion

Our questionnaire results clearly indicate that expanding the user's view to a full 360° surround-view enhances the feeling of spatial presence. It also improves realism and apparently is more fun. In addition to the recorded statements we observed that many participants in the Surround-View condition looked behind themselves before a pointing action, although they could also have rotated the virtual world in front of them. This furthermore supports the actual use of the displays behind the user. However, the quantitative measures of angular error in the pointing task do not show any improvement of accuracy. But this is due to the fact that the involved senses and their stimuli are nearly the same for both the FV and SV conditions. The difference in the *peripheral* sight of 22.5° (=(180°-135°)/2) for each side may be neglected.

Changing the rotation metaphor from a stable user and a rotating virtual world to a stable virtual world and a self-rotating user further improves significantly on realism. Though otherwise the questionnaire results for the Rotating-User condition do not significantly vary from the Surround-View condition, they do so compared to the Frontal-View condition for spatial presence *(Situation Model, Self Location, Possible Actions)* and *Fun*. This means that the new control metaphor in RU does not undo the enhancements gained by the transition from FV to SV. For pointing actions along corridors just visited the independence of the pointing error from the VR-skill in the RU condition suggests an advantage over the FV and the SV condition for immediate self-location, not for map learning in general.

Since our participants were rather young and all somewhat accustomed to virtual environments and computer controls, we may encounter different results for an elderly group without any such knowledge. Only a single participant of our study fulfills this criteria. At the age of 56 his median angular errors for the pointing task were 113.3° (FV), 83.4° (SV) and 49.4° (RU). Within-subject differences between conditions this big were not observed for any younger participants.

7. Conclusion

In this paper we evaluated the effect of the full horizontal surround view and the embodied self-rotation of the OCTAVIS system on spatial presence and orientation. Our results clearly indicate that both features are indeed beneficial in the context the OCTAVIS was designed for: training and rehabilitation of spatial cognition for patients with brain functions disorders. This target group typically consists of elderly people with no prior experience in virtual reality. As a consequence, they benefit from the surround view as well as from the rotating-user control metaphor.

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