Utilizing dodge maneuvers as a distractor for interaction based redirected walking in virtual reality

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Abstract: Redirected walking techniques distort the translation and rotation of virtual reality users, causing them to cover more distance in the virtual environment than in reality. When users reach the boundaries of their physical space, they need to be reoriented using reset methods. The study investigated how a dodge maneuver in virtual reality can be designed as a reset method. It is shown that the shape, speed, and especially the incidence angle of incoming objects offer potential to reorient users.

Keywords: Virtual Reality, Redirected Walking, Distractors, Movement Study

1 Introduction

Redirected Walking (RDW) is a technique used in virtual reality (VR) to allow users to navigate virtual environments (VEs) that are larger than the tracking space (TS) available to them. RDW works by distorting the visual translation and rotation of the user in the VR, allowing them to cover more distance in the VE than they would in real life and be redirected away from the boundaries of their TS. Ideally, these distortions are imperceptible to the user.

However, even with RDW, users still require a large TS to navigate an open VE without obstruction. For example, to follow a straight virtual path unnoticed, the radius of the actual physical path must be at least 22 meters [SBJ+10]. In most cases, users do not have access to such a large space.

Reorientation techniques are a subset of RDW techniques [SBS+12, PFW09, NPB+18]. They are used when users reach the edge of their TS and can no longer traverse the VE as intended without leaving the TS. Reorientation techniques ensure that users and the VE rotate in such a way that the user can continue following their virtual path in physical space. This can be done explicitly by asking users to turn in place or subtly through distractors that draw their attention and cause them to rotate their head [PFW09]. Distractor reorientation works by spawning a distraction and rotate it around the users, if a reset is needed. Users rotate when they follow the distractor, and rotation amplification with higher thresholds can be used, as the attention of users is focused on the distractor. Head rotations offer a lot of potential for imperceptible manipulation, as rotational distortions are the least noticed [RKW01].

This study aims to investigate whether a dodge maneuver can be designed in such a way

that users can predictably dodge. The dodge maneuver can only be indirectly designed by creating a virtual object and its collision course with the users. To avoid a collision with the incoming object, users need to position themselves while focusing it, thus naturally rotating their heads during this motion. It is explored how the widest possible head rotations can be generated to be able to use the dodge maneuver as an effective reorientation technique at the edge of a TS.

2 Related Work

Cools and Simeone have shown that interactions and tasks can also serve as distractors, which lowered the perceptibility of roatation manipulations further [CS19]. By using tasks and interactions as distractors, Chen and Fuchs [CF17] and Langbehn et al. [LS19] embedded resets immersively into the VR experience itself.

Schmelter et al. demonstrated that complex interactions such as shooting, throwing, or close combat, which can inject discreet rotations of up to $\pm 5°$, can also serve as distractors. Based on this, they developed a prototype in which RDW-methods were an integral part of the VR experience [SHS+21]. The close-combat fighting scenario examined in that study is the interaction that most closely resembles a dodge maneuver to the best of this study's knowledge of researched interactions. Both fighting and throwing interactions were voted as the top distractors in that study, followed by shooting, focus, and pick up. Participants perceived rotations the least during fighting, likely because close combat fighting obstructed their view the most, similar to the use of reduced field of view in previous studies [SXMM18]. This effect could also be exploited in dodge maneuvers by using collision objects to obstruct the users' vision.

The Schmelter et al. study found that the fighting task yielded excellent results for reorientation, as participants had difficulty detecting rotation directions accurately. Close-range fighting was particularly effective due to the immersive nature of combat scenarios, where participants were focused on enemies and less aware of changes in the VE.

3 Hypotheses

Dodge maneuvers can be performed in different ways for the same collision situation (for example, ducking or sidestepping). For the use of rotation amplification, only the rotation around the vertical axis is important [RKW01]. To investigate the benefits of dodge maneuvers for rotation amplification, the angle α was defined as the largest directionally continuous head rotation around the vertical axis in *virtual* space. If no RDW is present, α is the same in virtual space as in real space. If RDW is applied, α differs from the *real* largest directionally continuous head rotation around the vertical axis by the amount its rotation was amplified.

H1 α-values of users with RDW show significant differences compared to α-values of users

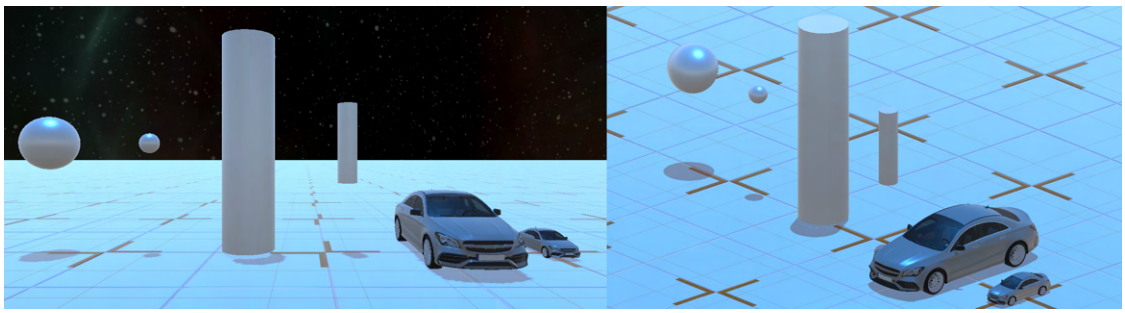


Figure 1: Perspective (left) and isometric (right) representation of all objects the test subjects had to avoid. The vertical position of the objects corresponds to their height position during the experiment. Presented in the virtual environment of the experimental application.

with no RDW

H2 Larger objects evoke larger α-values during dodge maneuvers than smaller objects

H3 Slower speeds evoke larger α-values during dodge maneuvers than faster speeds

H4 Objects approaching users from the central field of view ($\pm 30°$) evoke smaller α-values during dodge maneuvers

H5 The shape of the objects has a significant influence on α

H6 95% of the test participants manage to avoid 95% of the objects

4 Experiment Design and Test Session

The hypothesis were tested in a user study in which test subjects were divided into two groups. Group B did not use any RDW procedures, while Group A had the rotation of the test subjects distorted. The objects that the test subjects avoided varied in shape (Sphere, Cylinder, Car), size (small, big), speed (18 km/h, 24 km/h, 32 km/h), and incidence angle (40°, 27°, 13°, 0°, -13°, -27°, -40°). A total of 126 measurements were taken per test subject, with the order of the measurements being randomly generated by the application.The study included 30 participants with a mean age of 35.3 years with 15 participants in each group. Group A had 8 male and 7 female participants, while Group B had 7 male, 1 non-binary/genderqueer and 7 female participants.

Figure 1 illustrates the objects and their size ratios in the VE of the experimental application. The speed factor represents how quickly the objects moved towards the initial position of the test subjects. The incidence angle represents the angle between the gaze direction of the test subjects and the position of the object at the start of each measurement. Negative values indicate positions to the left of the test subjects, while positive values indicate positions to the right. The objects always started at a distance of 20 meters from the test subjects (Fig.2).



Figure 2: Setup of the virtual environment: In the bottom right corner, the starting position is marked by a spotlight and a white hologram of boots. The orange boots indicate the test subject's position in the virtual environment. Floating 2.5 meters ahead is the gray instruction text board. Seven collision objects (shape: car, size: large) are positioned at the starting positions of the incoming angles, 20 meters away. The target board is located 50 meters away. The objects shown here were never simultaneously visible during the experiment.

The experimenter described the task to the test subjects. Afterwards, the test subjects were fitted with the VR headset Meta Quest 2 and given the controllers. They were then shown the Guardian system of the Meta Quest 2 by bringing a controller close to the boundaries of their TS. The Guardian system prevents users from leaving their TS by displaying blue grid lines in the VE when they approach the boundaries. Once the test subjects had no further questions, the experiment was started. In the VE, the test subjects stood on a white plane in the middle of space. The application was completely silent. They could see their virtual hands that they could move with the controllers and on the floor, they saw two orange boots that always followed their movement. At the starting position of the measurement, they could see the same boots as white holograms as a indication of where to position themselves to start a measurement. When the test subjects were positioned and looked in the right direction the collision object appeared after a short countdown. The object flew towards the starting position, and the test subjects tried to avoid it. Approximately one meter behind the starting position, the collision object disappeared again. The test subjects repeated the positioning process before each individual measurement (Fig.3). Immediately after completing the experiment, the participants were given a questionnaire, that included the Virtual Reality Sickness Questionnaire (VRSQ) [KPCC18] followed by the iGroup Presence Questionnaire (IPQ) [SFR01]. The experiment was conducted at five different locations. Three of them were private spaces of the experimenter, and two test subjects were tested in their own homes. Figure 4 shows the boundaries of the TS at the different experiment locations. Each TS was large enough to encompass a circle with a radius of at least one

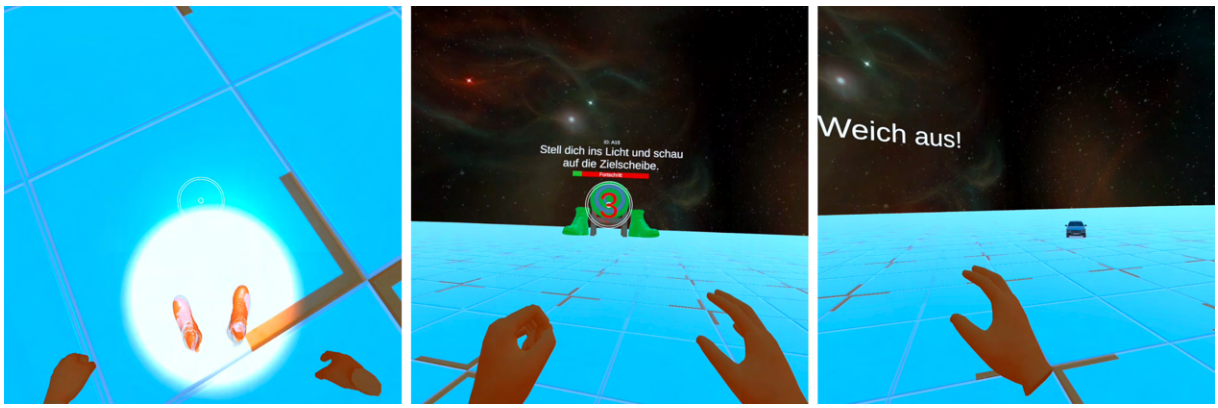


Figure 3: Test procedure of the application based on three screenshots of the experiment from test subject A15. Left: Positioning, Middle: Orientation, Right: The collision object approaching A15.

meter.

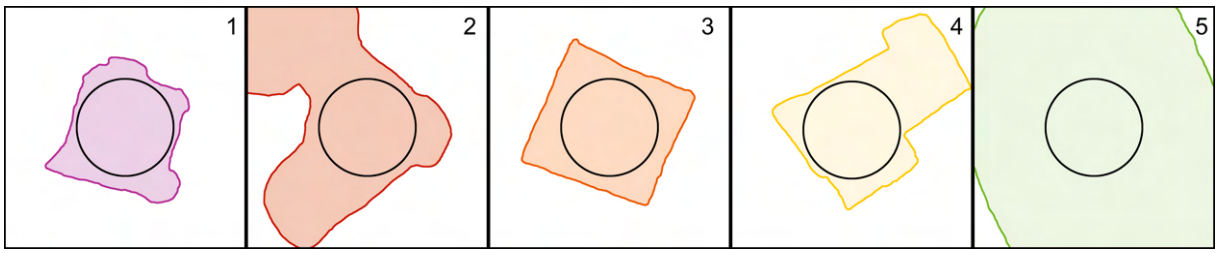


Figure 4: TS boundaries of all five experimental sites. The black circle has a radius of one meter. Its center represents the starting position of the test subjects. The TS boundaries of 2 and 5 are partially outside the image exported by OpenRDW.

5 Test Application and RDW Setup

The test application was deployed on a Meta Quest 2 headset and is built using the OpenRDW framework for Unity3D [LWSZ21]. OpenRDW provides the application with an implementation of the Steer-to-Center algorithm (S2C) [RKW01, HB13], as well as recording, exporting, and visualizing the motion and navigation data of test subjects. The S2C algorithm uses rotation gain to constantly steer users towards the center of the TS.

However, since the test subjects are already located in the center of the TS, but the dodge maneuvers are intended to be studied as a reset method occurring at the TS boundaries, the reference midpoint for the S2C algorithm was positioned one meter behind the initial position in the back of the test subjects. This allowed simulating reorientation towards the midpoint on a two-by-two-meter area without having to conduct measurements at the TS boundaries.

Williams and Peck [WP19] conducted an RDW study on rotation gain thresholds with distractors and Head-Mounted Displays with a 110° field of view. They found that positive gain was more noticeable to men than to women, while the opposite was observed for negative gain. Since the Quest 2 has a field of view of 104° [Mus23], and the collision objects can be interpreted as distractors according to Peck et al. [PFW09], the positive rotation gain was set to the value determined for men (1.4772) and the negative rotation gain to the value determined for women (0.7242) [WP19].

6 Recorded Data

The hypothesis *H1* to *H5* are answered using the α value. The application recorded the values by recording the head rotation angle that increased with each frame as long as the test person rotated their head in the same direction. Rotations to the right yielded positive values and rotations to the left negative values. The greatest absolute angle recorded (during the time the collision object was present) was saved as the α value for that dodge maneuver. For hypothesis *H2* to *H5*, the α values are related to the variables of shape, size, velocity, and incidence angle.

Finally the application recorded if the test subjects collided with the collision object. The data is used to answer research question *H6*.

7 Results

Two-sample independent t-tests for for the VRSQ scores and all subscores of the IPQ were conducted. None of the four IPQ subscores showed significant differences between groups A and B (Spatial Presence: t = 0.256, p = 0.7998; General sense of being there: t = -0.717, p = 0.479; Involvement: t = -0.212, p = 0.834; Realism: t = 0.241, p = 0.811). The analysis of the data from VRSQ shows that the test subjects in groups A and B do not exhibit significant differences in their VRSQ scores. The independent samples t-test yielded a t-value of 0.5872 and a p-value of 0.5618.

H1 cannot be rejected. For each measurement, the mean of all absolute α values was calculated and the means of one group were compared with those of the other. A two-sample independent t-test was performed, which revealed a significant difference and a strong effect between the two groups (t = -9.988; p = 7.184 x 10-20; d = 1.26, Fig. 5).

For the investigation of *H2* the mean values of all absolute α-values for each measurement were used too. However, the population was divided not between groups A and B, but between the levels small and large of the within-subject factor size. Therefore, the t-test for two dependent samples was employed. This test did not reveal any significant differences between large and small objects (t = 1.1468; p = 0.2536, Fig. 6 top left). Thus, the hypothesis must be rejected.

As for the analysis of *H3*, three dependent two-sample t-tests were conducted. All three tests revealed significant differences between the speed levels, and the effect is stronger

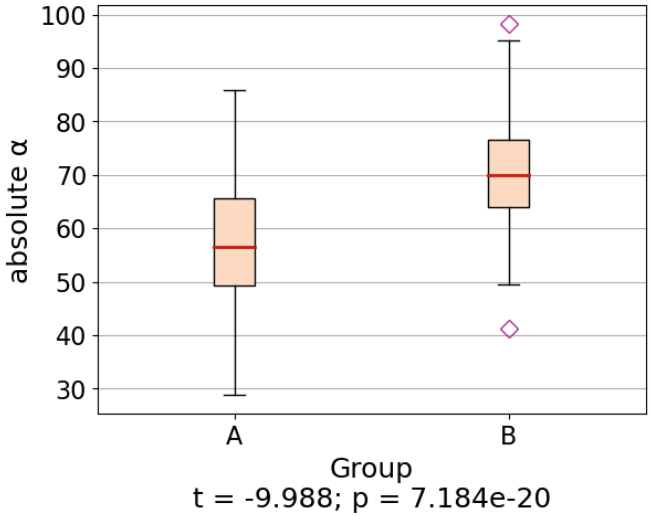


Figure 5: Mean values of absolute α-values

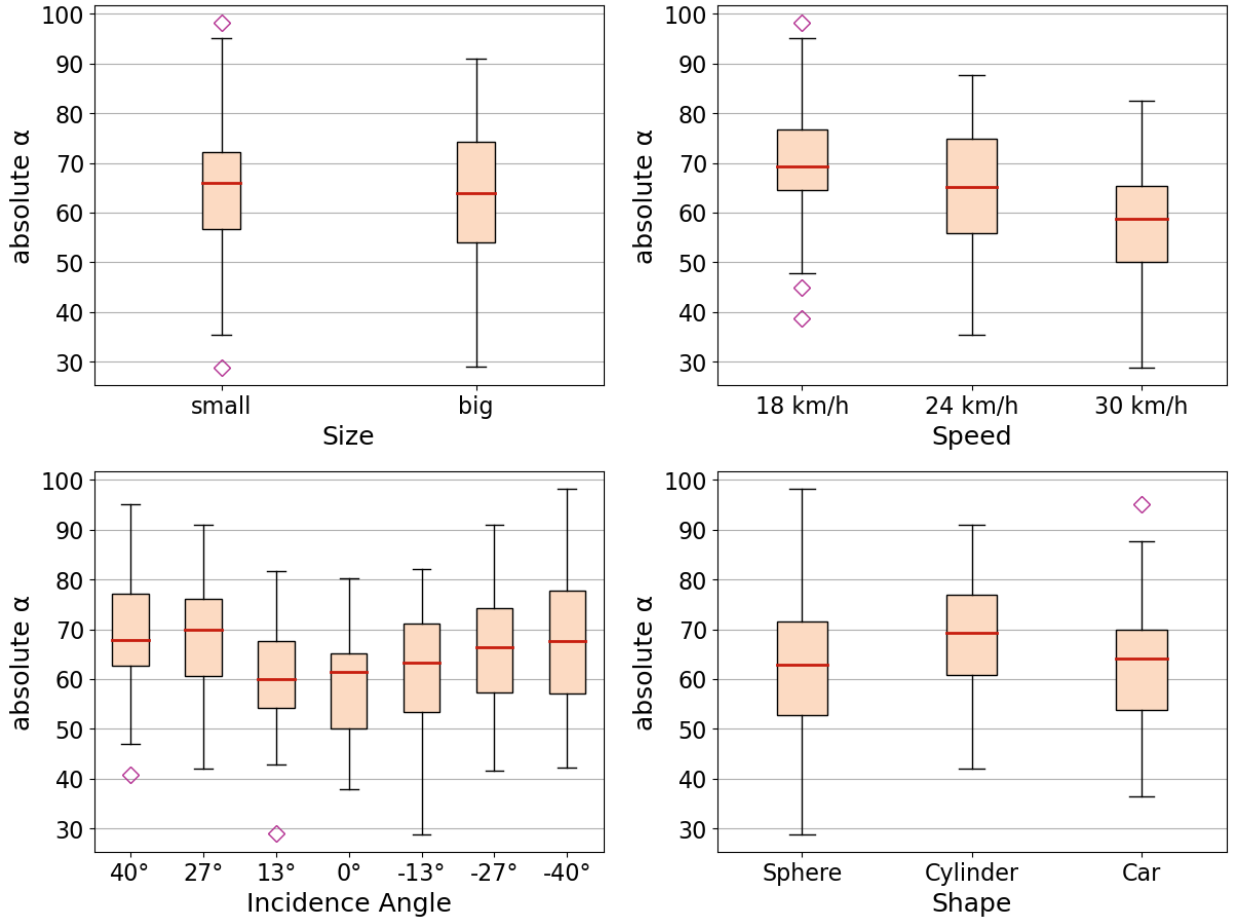


Figure 6: Mean values of absolute α-values for each factor within groups

between 18 km/h and 30 km/h compared to between 18 km/h and 24 km/h, or 24 km/h and 30 km/h. A clear trend can be observed in the box plot diagram (Fig. 6 top right).

Therefore, the hypothesis cannot be rejected.

The samples of the angle factor levels were examined using the paired two-sample t-test. No significant effects were found between the angles 40° and 27°, as well as -40° and -27°, thus *H4* must be rejected. However, there are significant effects as the absolute values of the incidence angles move further apart. In Fig. 6 bottom left, it can be observed that the absolute α-values decrease with smaller incidence angles. Larger incidence angles, therefore, lead to larger α-values.

The shape of the objects was also examined using the t-test for two dependent samples. It was found that the cylinder elicits significant differences in α values compared to the sphere and the car. The car shows a small effect (t = 4.535, p = 1.919 x 10-5, d = 0.483), while the sphere exhibits a moderate effect (t = -4.753, p = 8.309 x 10-6, d = 0.52). Therefore, *H5* cannot be rejected. However, there are no significant differences between the car and the sphere. (see 6 bottom right)

H6 was rejected. Only 47% of the test participants were able to avoid the objects with a success rate of 95%. Upon closer examination, it is further observed that only 3 participants from Group A achieved a 95% success rate, while in Group B there were 12. A Mann-Whitney U test was conducted, which showed a significant difference between Group A and B (U = 46.5; p = 0.0064) with a moderate effect (d = 0.53). Additionally, in the boxplot diagram in Figure 7, a clear outlier can be observed in Group B. Removing this participant normalizes the distribution, but the variances remain unequal. In this case, the t-test for two independent samples also shows a significant difference between the two groups (t = -3.7169; p = 0.0018), and the calculation for Cohen's d adjusted for unequal sample sizes indicates a very strong effect size of 1.5.

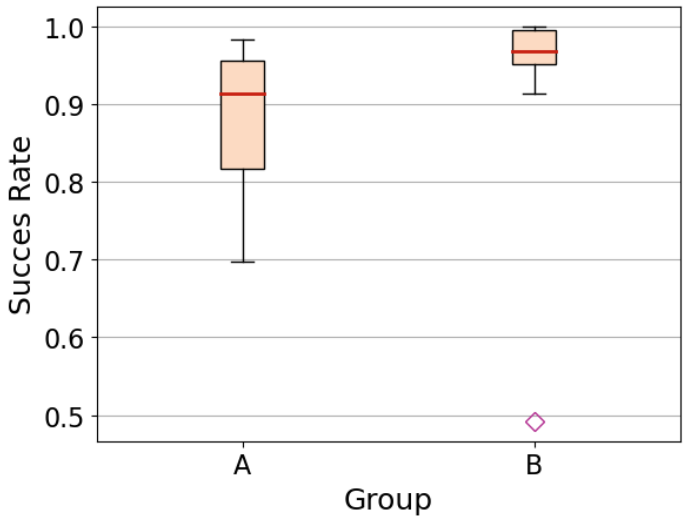


Figure 7: Success rates of dodge maneuvers

8 Exploration

Upon closer examination of the exported images of the real dodge paths, a tendency can be observed. The dodge paths cluster around a line that is orthogonal to the direction of approach. The heatmaps in Figure 8 show that there is a higher frequency of rightward dodging when the object approached from the left. When the objects approached from the right, the test participants seem to dodge in both directions with approximately equal frequency.

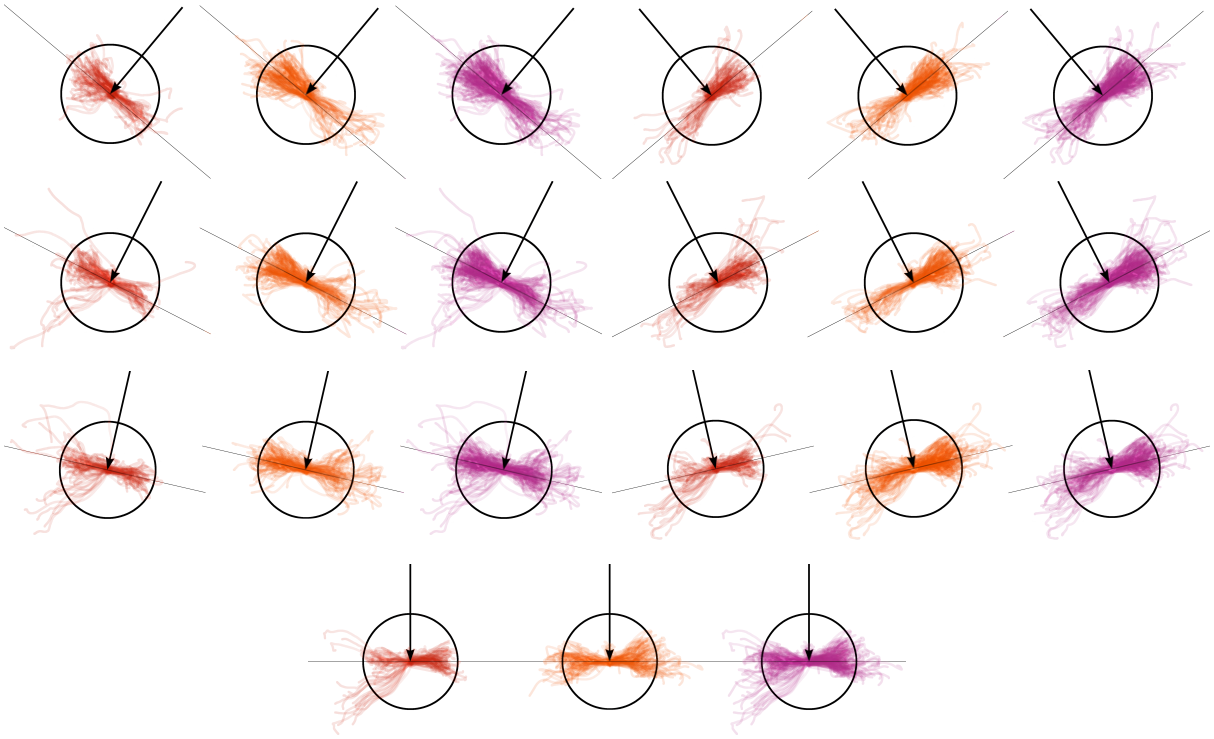


Figure 8: Heatmaps of the dodge paths for different incidence angles. Grouped to the left side are the positive incidence angles and to the right side the negative ones. First row are the angles ±40°, second row ±27° and third row ±13°. The bottom one is 0°. The dodge paths of group A are coloured red, the paths of group B are orange and the purple ones are the paths of both groups combined.

9 Discussion and conclusion

The study investigated how a dodge maneuver in VR can be designed to generate wide rotation angles, which can be used in combination with rotation gain as a reset method for RDW techniques. The participants avoided objects of different shapes and sizes at varying speeds and angles of incidence. One group used rotation gain, while it remained disabled for the control group.

The number of participants in this study was limited, resulting in statistically inconclusive results. However, the alternative methods chosen in this work revealed tendencies that can form the basis for further studies.

The hypotheses were based on the assumption that high α values lead to a large rotation of the VE. This assumption should have been initially confirmed in a separate experiment before analyzing the α values. In retrospect, the assumption can be verified using the rotation of the VE at the end of a dodge maneuver. However, this value is only available for half of the test participants (Group A). Ultimately, this value provides more meaningful information about the potential of dodge maneuvers compared as a reset method.

VRSQ and IPQ showed no significant differences between the application with rotation gain enabled and disabled. This suggests that dodge maneuvers can be frequently applied in VR without directly negatively affecting the cybersickness or immersion of the participants. They can potentially be used as an interaction-based reset method. However, further investigation is needed to determine the extent to which such an implementation affects the user experience.

The study demonstrated that participants with rotation gain enabled collided significantly more often with the objects. It is important to examine in detail why Group A performed worse in order to prevent the implementation of this reset method from becoming frustrating for users. The application used in the study did not provide any feedback to the participants on whether they successfully avoided the objects or not.

Furthermore, significant differences were found between the rotation values of the two groups. Since the real rotation of Group B cannot be compared to the virtual rotation of Group A, future experiments should examine the effects of each within-subject factor individually.

The speed of the collision objects resulted in significant differences in the participants' α values. The slower the objects approached the participants, the larger the rotation angles they achieved. Further steps should be investigated for more precise results. However, all collision objects started at the same distance from the participants, which left less reaction time for fast objects compared to slow ones. This effect should be considered in further examination of the speed factor.

In particular, the angles of incidence showed great potential for the design of dodge maneuvers. There was a tendency that objects approaching from the side generated higher rotation angles than objects approaching from the front. Further investigation, including angles of incidence outside the field of view, for example, in conjunction with approach sounds, could yield interesting results.

The exploration of the participants' motion paths revealed that they often avoided orthogonal to the angle of incidence. Further studies can investigate how to guide participants in a specific direction. The collected data from this study can also be further analyzed to examine how much space participants utilize for dodge maneuvers.

The potential of dodge maneuvers for RDW techniques is clearly present but should be

further investigated for concrete and safe implementations.

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