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Effect of the size of the field of view on the perceived amplitude of rotations of the visual scene

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Abstract

Efficient navigation requires a good representation of body position/orientation in the environment and an accurate updating of this representation when the body-environment relationship changes. We tested here whether the visual flow alone - i.e., no landmark - can be used to update this representation when the visual scene is rotated, and whether having a limited horizontal field of view (30 or 60 degrees), as it is the case in most virtual reality applications, degrades the performance as compared to a full field of view. Our results show that (i) the visual flow alone does not allow for accurately estimating the amplitude of rotations of the visual scene, notably giving rise to a systematic underestimation of rotations larger than 30 degrees, and (ii) having more than 30 degrees of horizontal field of view does not really improve the performance. Taken together, these results suggest that a 30 degree field of view is enough to (under)estimate the amplitude of visual rotations when only visual flow information is available, and that landmarks should probably be provided if the amplitude of the rotations has to be accurately perceived.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Line and Curve Generation

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1. Introduction

When moving around an environment, different sensory channels - i.e., vision, proprioception or the vestibular system - provide us with congruent information about the amplitude, speed and acceleration of our displacements [ISK95, BGV97, CGBL98, YH98, BWP99, WCRP04, JB06, RCB07]. This information is used to permanently update the representation of visual space in order to navigate efficiently in the surrounding world. When navigating in virtual worlds, however, vision often constitutes the only available sensory input. In line with this, understanding how visual information is used to estimate the amplitude of the relative displacements between the body and its surroundings has potential applications in the design of virtual environments.

As opposed to the real world, most of the displays used in virtual reality have a restricted field of view (FOV). This is for instance the case with head-mounted displays (HMDs), where the field of view lies mostly within the range of 30-60 degrees. Yet, several studies suggested that peripheral vision is critical for motion perception, showing that the size of the FOV affects navigation abilities [AM90, TYHH05], postural control [DL67, AC80, KKMW00], speed perception [Osa88, PVC08], and the sensation of self-motion induced by a moving visual stimulus [BDK73, HDB75, BPY75, AHZ99, MRTB05]. For instance, Turano and collaborators have shown that peripheral visual information is important for establishing and updating an accurate representation of the spatial structure of the environment [TYHH05]. Similarly, Alfano and Michel [AM90] have shown that the quality of the cognitive representation of the visual space decreases when the FOV decreases. Concerning postural control, spontaneous standing sway increases without peripheral vision but remains unaffected by the occlusion of central vision [DL67, AC80]. Finally, a large literature devoted to the study of vection, i.e., the illusion of self-motion induced by a moving visual stimulus, suggests that peripheral vision plays a dominant role in evoking such illusion [BDK73, HDB75, BPY75]. In the present experiment, we tested whether the size of the horizontal FOV affects the perceived amplitude of rotations

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Figure 1: *Panoramic screen, 230x125 degrees of field of view.*

of the visual scene about the body's vertical axis.
Within the visual modality, two different kinds of cues can be used to estimate the relative displacements between the body and the environment. First, the fixed structure of the visual scene provides static cues, or landmarks. Motion amplitude can be estimated by computing the changes in the relative position/orientation of the body with respect to these landmarks [BW95, WCRP04]. Second, the relative motion between the observer and the visual scene generates a visual flow on the retina, which visual flow can be used to update body position/orientation in the environment [CGBL98, JB06, RCB07]. Our work specifically focused on the contribution of the visual flow to the perceived amplitude of rotations of the visual scene. Therefore, we used a visual scene devoid of any landmark, and the participants were required to maintain central fixation during the rotation of the scene so that they could not use eye movements to code the amplitude of the rotation.

2. Methods

2.1. Participants

Ten participants (aged 21-35, mean = 24.5) took part to the experiment. None of them had a history of sensorimotor disorder, and all had normal or corrected-to-normal vision. All participants gave their informed consent before taking part in the experiment, which was performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki.

2.2. Experimental setup

The subjects were seated in a darkened room, centrally located within a quarter sphere screen (Figure 1).

The height of the chair was adjusted for each subject so that the head was at the 'origin' of the screen, i.e., the point from which the geometry of the virtual scene is correct. A wheel-controlled potentiometer with a pointer and two buttons was fixed 25 cm in front of the subject and used to launch the trials and give the responses. The visual scene consisted of white dots with limited life-time randomly generated in a 3D hollow cylinder centered on the eyes' position. In the full FOV condition, this random dots pattern covered the whole screen. In the 30 and 60 degrees FOV conditions, software-implemented blinders (background-colored) were used to limit the horizontal field of view symmetrically on both sides of the central fixation cross. When rotated, this random dots pattern induced a visual flow corresponding to a self-rotation around the vertical axis of the subject. The central fixation consisted of a red cross sustaining 1.5 de-

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grees of visual angle and the target was a red dot of 1 degree of visual angle.

2.3. Procedure

The subjects initiated each trial by pressing the right button. At the beginning of each trial, the fixation cross was presented directly in front of the participants at eye level. Subjects were instructed to maintain fixation for as long as the cross was displayed. One second later, the dots pattern was also presented and remained stationary. After one second, the target was presented for two seconds, 5 degrees left from the central fixation cross. 125 ms after target extinction, the dots pattern could be rotated and the subjects had to update the memorized position of the target according to the perceived rotation (i.e., direction and amplitude) of the pattern. The fixation cross forced the subjects to rely exclusively on the visual flow to update the position of the target. In particular, it prevented the subjects from tracking the dots during the rotation of the pattern, which would have enabled them to use eye movements to code the amplitude of the rotation. The rotations had a raised-cosine velocity profile and lasted between 800 and 2750 ms, depending on the amplitude and peak acceleration. The fixation cross and the dots pattern were switched off three seconds after target extinction. The subjects could then give their response, using the pointer to indicate the position at which the target would be if it moved with the dots pattern. More specifically, they had first to orient the pointer towards the estimated position of the target, then press the left button to get visual feedback about the pointed position and fine-tune the pointing, and finally validate the response by pressing the right button. This pointing procedure was used to limit the response bias that was likely to occur if using an adjustment procedure. During this pointing stage, the subjects were free to move their eyes and head.

2.4. Conditions, blocks and duration

The experiment used three independent variables: (i) the horizontal field of view (FOV), or visual angle sustained horizontally by the dots pattern (three levels: 30, 60 and 230 degrees, all horizontally centered on the central fixation cross); (ii) the rotation amplitude of the dots pattern (nine levels: clockwise and counterclockwise rotations with four different amplitudes in each direction (15, 30, 45 and 60 degrees) plus a control condition in which the pattern remained stationary); and (iii) the peak acceleration of the rotations (two levels: 50 and 150 $^{\circ}/s^2$). The experiment therefore consisted of 54 different conditions. Each subject performed five repetitions of each condition for a total of 270 randomly ordered trials, which were split into three blocks of 90 trials each.

Before running the experimental blocks, each subject first conducted two training blocks of 20 trials each. In the first training block, the target remained on the screen for the whole duration of the trials, rotating with the pattern. This block notably allowed the subjects to have a better representation of the rotations of the target, and to familiarize themselves with the pointing device. The second training block was identical to the experimental blocks, i.e., the target was extinguished before the rotations of the pattern.

Each experimental block lasted about 30 minutes with a five-minute break between two successive blocks. In total, the experiment lasted about 2 hours, which included the 20 minutes devoted to instructing and training the subjects at the beginning.

2.5. Data analysis and statistics

Pointing errors were computed by comparing the pointing responses with the actual target position after rotation. For each subject and each level of FOV, the actual target position was determined using the mean pointing response for control trials as reference for the initial target position. This is because the trials without rotation of the pattern (control) provided a measure of the constant error of the subject when pointing towards the memorized target. Underestimations of the amplitude of the target (dots pattern) rotation were assigned negative values and overestimations positive values.

The size and the variability of the signed pointing errors were entered in two separate 3*9*2 [FOV(30, 60, 230)*rotation amplitude(ccw60, ccw45, ccw30, ccw15, 0, cw15, cw30, cw45, cw60)*peak acceleration(50, 150)] repeated measures analyses of variance (ANOVA). Post hoc comparisons using Newman Keuls tests ($p < .05$) were conducted when necessary.

3. Results

For the control trials, the pointing responses were very accurate and little variable, the average pointing error being 0.1 $\pm$ 1.7°. Concerning the trials with rotation, the subjects were able to perform the task and estimate the rotation amplitude of the dots pattern. As shown in Figure 2, the average perceived amplitude of the rotations correlates pretty well with the actual amplitude. However, a closer look at the pointing errors indicates that if the amplitude of the small rotations (15 and 30 degrees) was on average relatively accurately perceived, the amplitude of larger rotations was systematically underestimated, the underestimation increasing with the amplitude of the rotations (Figure 3).

In line with this, the ANOVA on the size of the signed pointing errors revealed a main effect of the rotation amplitude ($F8, 72 = 12.01$; $p < .001$). The post-hoc tests, however, failed to indicate any significant difference between the different levels, probably because of the large variability of the pointing responses (Figures 3, 4, 5). Neither the size of the field of view nor the peak acceleration of the rotations had a significant influence on the size of the signed pointing errors.

As the size of the errors, the variability of the responses increased with the amplitude of the rotations (Figure 4).

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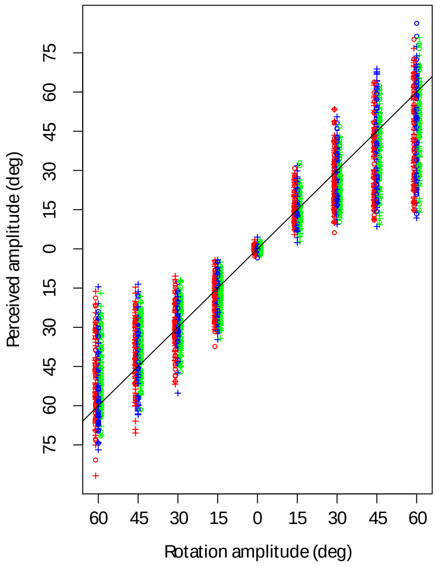

Figure 2: *Perceived rotation of the visual scene as a function of the actual rotation. All single responses are plotted. The three FOV conditions are color-coded (red = 30°, blue = 60°, green = full FOV) and the velocity profiles of the rotations are shape-coded (cross = peak acceleration of 150°/s^2 and circle = peak acceleration of 50°/s^2). The black line corresponds to Y=X.*

This was confirmed by the ANOVA (F8, 72 = 56.64; p < .001). Notably, the post-hoc tests indicated that the variability of the responses was significantly smaller when no rotation occurred (control) than for all rotation amplitudes but 15 degrees clockwise. Also, the variability of the responses for the 15 degree rotations (clockwise and counterclockwise) was significantly smaller than for the largest two rotation amplitudes (45 and 60 degrees in either direction). The size of the field of view also had a significant effect on the variability of the responses (F2, 18 = 4.36; p < .05), the variability tending to decrease as the field of view augmented (post-hoc tests non significant, though).

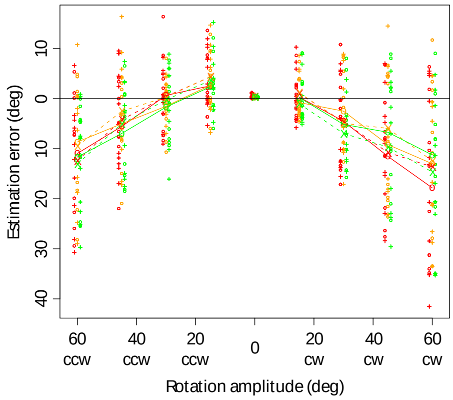

Figure 3: *Estimation error as a function of the rotation amplitude. Each data point corresponds to the average error of one participant in one condition. The three FOV conditions are color-coded (red = 30°, orange = 60°, green = full FOV) and the velocity profiles of the rotations are shape-coded (cross = peak acceleration of 150°/s^2 and circle = peak acceleration of 50°/s^2). Data points located below and above the black line correspond to an underestimation and an overestimation of the rotation amplitude, respectively.*

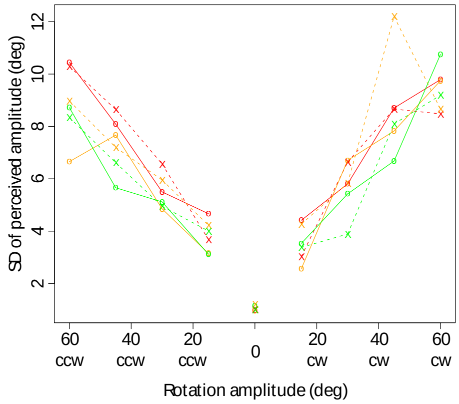

Figure 4: *Average standard deviation of the estimates as a function of the rotation amplitude. Color and shape code is identical as for Figure 3.*

4. Conclusions

The results of the present experiment show that (i) visual flow alone can be used to estimate the amplitude of rotations of the environment relative to the body, (ii) these estimates are quite variable and this variability augments with the amplitude of the rotations, (iii) beyond 30 degrees of visual scene rotation, the amplitude is systematically underestimated, scaling with increased visual scene rotation, (iv) increasing the size of the horizontal FOV (30 degrees being the baseline) does not affect the average performance but slightly reduces the variability of the responses, and (v) in the range 50-150 degrees/s^2 of peak acceleration, the perceived amplitude of the rotations is unaffected by the velocity profile of the rotations.

Previous studies have investigated a human's ability to use visual information to update the representation of the visual space when the orientation of the body changes with respect to the environment [CGBL98,BWP99,JB06,RCB07]. These studies report that that the visual flow alone does not al-

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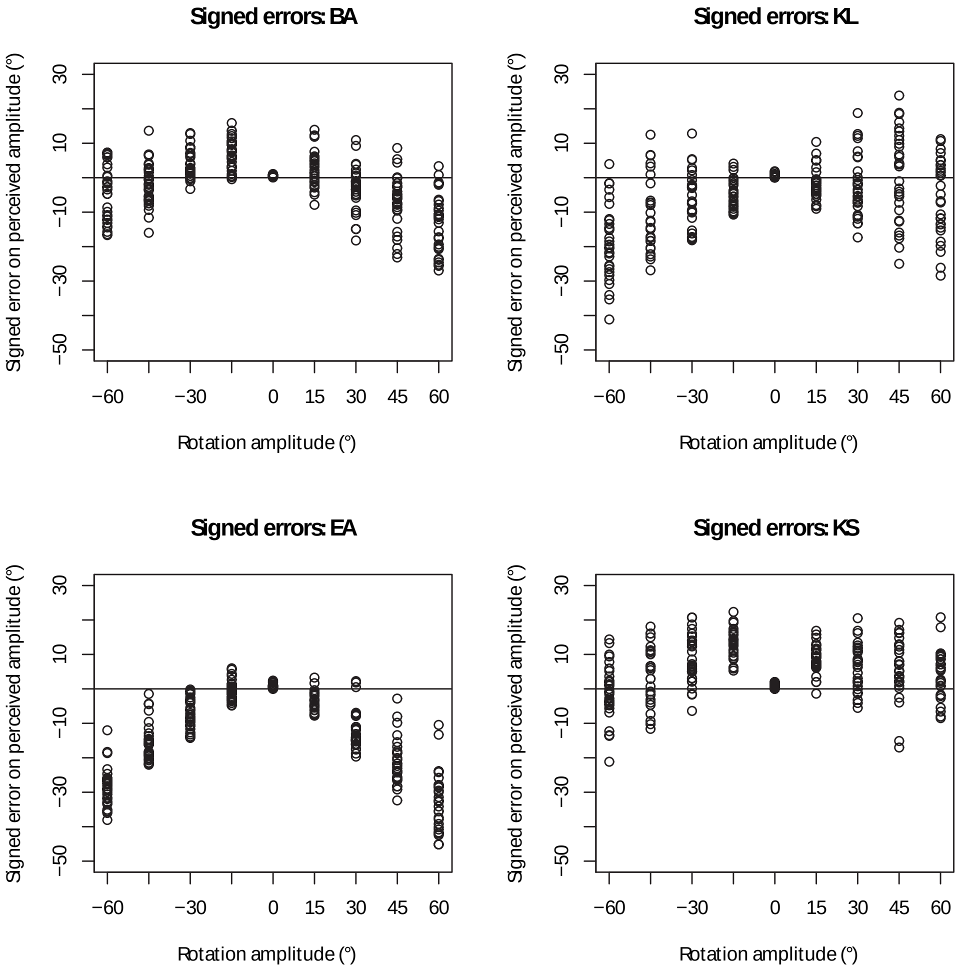

Figure 5: *Signed errors for four participants showing different patterns of response.*

low for an accurate updating of the representation of visual space. Although the paradigm and stimuli used in the present experiment differ from those on which these previous studies were based, our results confirm these findings. Therefore, when only visual information is available for navigating in virtual worlds, landmarks should probably be provided.

For the large rotations of the visual scene, the subjects systematically underestimated the amplitude of the rotation. Similar underestimations of the amplitude of the stimulation have already been reported for visual [BWP99] as well as vestibular [BGV97] rotations about the body vertical axis. Bakker and collaborators suggested that such a tendency to stop before a target is reached might have been brought about by evolution to stop us early from dangerous collisions with objects or from falling into pits [BWP99]. They interpret the increasingly larger undershoot errors as a way to maintain an adequate safety margin when the confidence in the accuracy of the path integration decreases. An alternative explanation is that these underestimations merely reflect a range effect [Pou75], i.e., a response bias towards the middle of the range of the possible responses that is commonly observed in subjective assessments.

In contrast to other studies that have reported an effect of horizontal FOV size on motion perception [BDK73,HDB75, BPY75, Osa88, AHZ99, MRTB05, PVC08], we found only a slight reduction of response variability when the size of the FOV was increased, and absolutely no effect on average performance. Our results therefore suggest that when only visual flow information is available, having more than 30 degrees of horizontal field of view may not provide enough useful information to update the internal representation of space. We are currently employing additional experiments to determine the influence of the vertical field of view.

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