Influence of sensory feedback on arm reaching movements

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1 Introduction

We frequently perform arm reaching movements to a specific position, such as when picking up an object. Hand trajectories of such reaching movements are approximately straight and take bell-shaped speed profiles, regardless of the initial and final positions [1]. Many hypotheses have been proposed to explain why such trajectories are selected, one of which is that the trajectory is planned in the visual coordinate system [1, 2]. In this study, to examine this hypothesis we verified whether the hand trajectory is deformed so that its apparent trajectory becomes straight when a distorted hand trajectory is presented subjects as visual information and whether the hand trajectory loses its straightness when no visual information is given.

2 Methods

Ten male and ten female subjects wearing a head-mounted display (HTC Co, VIVE Pro) participated in two types of reaching tasks. Reflective markers were attached to the head, shoulders, elbows, wrists, and index fingers of their right arms and the trajectories were measured at 60 fps using three motion capture cameras (NaturalPoint Inc, OptiTrack, Prime). Experiment 1 was the reaching task between spherical targets. The subjects were instructed to move their hand as quickly and accurately as possible to the target when it appeared and to remain still there. Two seconds after the hand reached the target, a new target appeared 15 or 20 cm away on the sagittal axis and this process was repeated 16 times. This process was performed twice for each of the following conditions. First, a control condition (C1) was imposed in which the actual hand trajectory was displayed in the VR space. Second, a spatial distortion condition (D1) was imposed in which the actual hand trajectory was displayed in the VR space as a slightly curved trajectory to the left, even if the actual one was straight. After that, practice time was taken to become accustomed to the distortion condition, and the spatial distortion condition (D2) and the control condition (C2) were imposed again. In Experiment 2, the participants were instructed to move their hands back and forth as quickly and accurately as possible between planar targets parallel to the frontal plane for 40 seconds. In the auditory condition, the hand position was indicated by a sound with a frequency corresponding to the distance from the target and the contact with the target was notified by a sound with a constant frequency. In the visual condition, the hand position was indicated by a cursor and the contact with the target was notified by the same sound as in the auditory condition.

3 Results and Discussion

3.1 Hand trajectories when visual information is distorted

Figures 1 and 2 are the hand trajectories in the spatial distortion conditions (D1 and D2) in Experiment 1, respectively. The horizontal (x) and vertical (z) axes represent the frontal and sagittal axes, respectively. In each figure, (a) and (b) denote the trajectory when extending and flexing the arm, respectively. The number of each curve shown in the legend is the order of reaching. In the case of the reaching with arm extension (Fig. 1(a)) the hand trajectory appeared to be distorted to the left in the first half of reaching which is in the same direction as the visual distortion, and once pulled back to the right, and then the trajectory was adjusted near the target. After practice, the trajectory became almost straight as shown in Figure 2(a). This result suggests that the trajectory is selected so that the actual hand trajectory not the apparent trajectory is straight. In the case of the reaching with arm flexion (Fig. 1(b), 2(b)), the trajectory was slightly distorted to the right but did not change much after practice and the difference from the control condition was small. This suggests that the effect of visual information on hand trajectory is small in this case. Around the target, the trajectory tended to be distorted to the right, the opposite direction of visual distortion, regardless of the direction of reaching.

Figure 3 shows the mean values of the variation from the sagittal axis on the plane $z = 5$ cm. Each point represents the mean value of each subject, and the blue and red boxplots correspond to arm extension and flexion, respectively. The trajectory was significantly distorted to the left (CI: [0.966, 0.131]) in the spatial distortion condition 1.

3.2 Hand trajectories when no visual information is given

Figure 4 shows the reaching trajectories when extending the arm in Experiment 2: (a) the auditory condition and (b) the visual condition. The trajectories of arm extension in the auditory condition (Figure 4(a)) were distorted to the

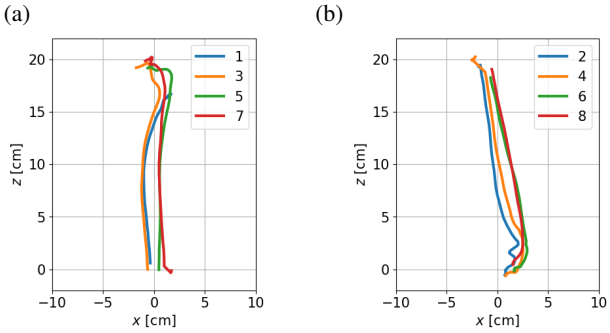

Figure 1: Hand trajectory in the 1st spatial distortion condition

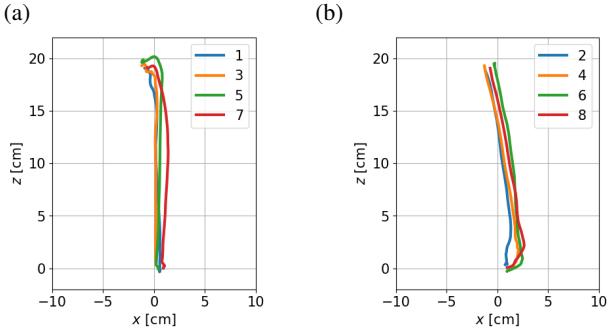

Figure 2: Hand trajectory in the 2nd spatial distortion condition

left. On the other hand, the trajectories in the visual condition (Figure 4(b)) and those of arm flexion in the auditory condition were almost straight.

Figure 5 shows the distortion of the hand trajectories. The distortion was evaluated by the area between the straight line connecting the start and the endpoints and the actual trajectory, with the area to the right of the straight line being positive and the area to the left being negative. Each point represents the mean values of each subject, and the blue and red boxplots correspond to the arm extension and flexion, respectively. The hand trajectories of arm extension were

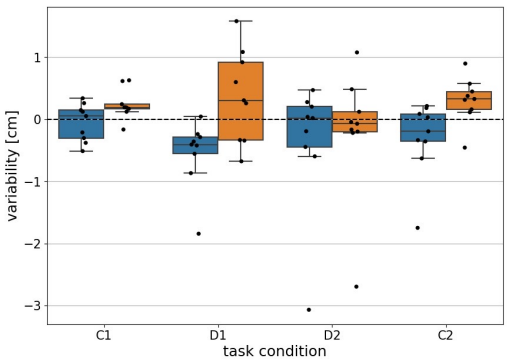

Figure 3: Positional variability at $z = 5$ cm (see Fig.1) of each subject's reaching trajectory in Experiment 1

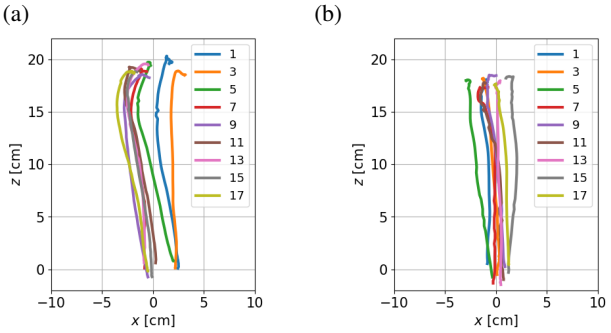

Figure 4: Hand trajectories in the auditory and visual conditions of Experiment 2

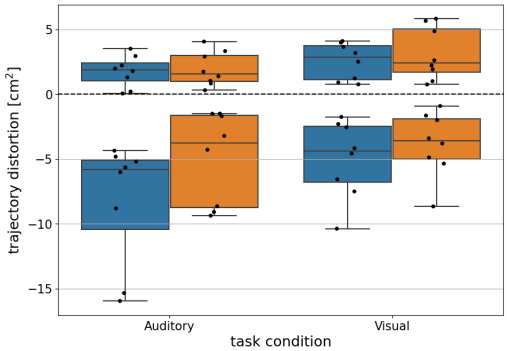

Figure 5: Distortion of the reaching trajectories in Experiment 2

significantly distorted to the left (t-test, $p < 0.05$) in the auditory condition.

4 Conclusions

The results of Experiment 1 showed that when distorted visual information was given, the trajectory initially amplified the distortion of the apparent trajectory but gradually changed so that the actual trajectory became straight. The results of Experiment 2 suggest a slight loss of linearity in the trajectory when no visual information is given.

These results suggest that visual information sometimes works in the direction of loss of linearity of reaching trajectories and that not only visual information but also somatosensory or other sensory information may significantly influence trajectory selection.

Acknowledged

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References

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