Is the Curvature in Hand Movements to Haptic Targets in the Mid Sagittal Plane Caused by a Misjudgment in Direction?

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Abstract. Goal-directed movements are generally slightly curved. The origin of this curvature has been related to a misjudgment of direction for movements towards visual targets. As it is known that there are large errors in haptic perception of direction, errors in the initial movement direction in movements towards haptic targets may also be related to errors in haptic perception of direction. To test whether this is indeed the case, we compared errors in the initial movement direction of goal directed movements towards haptically defined targets in a mid sagittal plane with the errors in setting a pointer towards the same targets. We found a good correlation between misjudgment in direction and errors in initial movement direction. We conclude that the curvature of movements towards haptic targets is also due to a misjudgment of direction.

Keywords: haptics, movement planning, perception of direction, initial movement direction, proprioception.

1 Introduction

When making a goal-directed movement, the movement trajectory is generally not straight but slightly curved. The origin of such curvature has been explained in many ways, for example by the biomechanics of the arm [1], a perceptual distortion of space [2,3,4], or a misjudgment in direction [5,6,7].

A relation between visual judgements of straightness and movement curvature was proposed by Wolpert et al [3]. They compared trajectories of hand movements with what was perceived as a straight line in the horizontal plane, and concluded that a visual perceptual distortion is responsible for the movement paths being curved. The same authors also showed that manipulating the visual feedback about hand positions made participants adjust their movements in so that the visual feedback was perceived to be straight [4].

In a study by de Graaf et al [5] participants made movements in a horizontal plane from a start position towards visually presented targets, and set the orientation of a pointer at the same start position to point towards the targets. These authors found that the initial direction of the movement deviated systematically from a straight line, and that a similar pattern of errors was made in setting

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the pointer. Smeets and Brenner [7] found a similar correspondence between the curvature in movements towards a target and the trajectory of a moving dot that was to be set to move to the same target in a straight line. From their results they concluded that a misjudgment of direction causes the curvature in goal-directed movements, rather than a deformation of visual space.

If the curvature of hand trajectories in goal directed movements is caused by a misjudgment in direction, errors in haptic perception of direction should also give rise to errors in the initial direction of movements towards haptic targets. Kappers and Koenderink [8] found large systematic deviations when blindfolded participants had to orient a pointer towards a haptic target in a horizontal plane. Even larger systematic deviations were found when participants felt a reference bar and had to orient a test bar so that it felt parallel to the reference bar. In another study by Kappers, participants had to set two bars to be parallel on a board in the mid sagittal plane [9]. Here too, participants made large systematic deviations. Blindfolded participants also systematically deviate initially from a straight line when making movements towards haptically defined targets in a horizontal plane. Their deviations are similar to those when moving to visually defined targets [6]. This suggests that in movements towards haptic targets, the curvature might also be caused by a perceptual misjudgment of direction.

To test whether this is indeed the case, we compared the initial movement direction of goal-directed movements towards haptically defined targets in the mid sagittal plane with the errors in setting a pointer towards the same targets in the same plane.

2 Methods

Participants and Experimental Setup. A group of 11 Right-handed participants gave their informed consent to participate in this study. The participants were blindfolded and were sitting in front of a table on which a board was placed in the participants mid sagittal plane (see figure 1). Three 3mm holes in the right side of the board served as start locations. Two small pin-heads on the left side served as target locations. This resulted in six possible paths. The start locations were situated at the near side of the board, and the target locations at the far side, so the participants made movements away from their body.

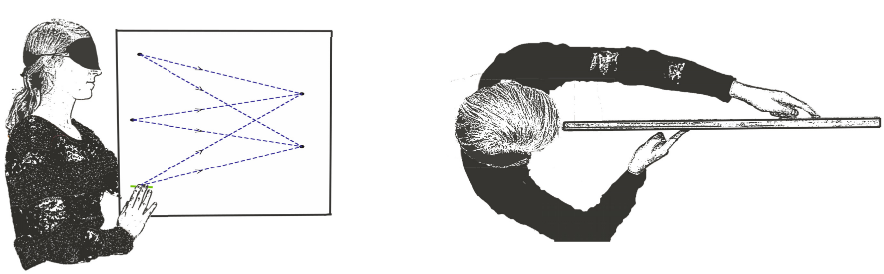

Fig. 1. Experimental setup. Left: side view. Right: top view.

Procedure. The study consisted of a movement task and a perception task, performed in separate blocks on the same day. The order of the two tasks was counterbalanced across the participants. Each task consisted of 60 trials: 10 for each combination of start and target location. The order of the trials was semi-random: subsequent trials always had a different start and target location. In the movement task, the participants placed their right index finger at one of the start locations and felt the target on the other side of the board with their left index finger. They were instructed to slide their right finger across the board in a straight line towards where they felt the left finger, and stop there.

In the perception task, a seven-centimeter long pointer with a diameter of three mm, that could rotate around its center, was placed with a random orientation at one of the three start locations. The participants were instructed to use their right hand to align the pointer towards where they felt the target with the left finger.

Data Analysis. Data recording was done with an Optotrak system with a sampling rate of 200 Hz. An infrared emitting diode (IRED) was placed on the tip of the index finger of the right hand in the movement task, and on the two ends of the pointer in the perception task.

The movement duration was defined as the interval in which the movement data differed from noise. The Optotrak data were considered to be noise when the direction of the line connecting two subsequent samples differed by more than 90 degrees from the line connecting the begin and endpoint of the movement. To find the start and endpoint of the movement, we searched from where the movement reached its peak velocity to the left and right for the first sample of noise.

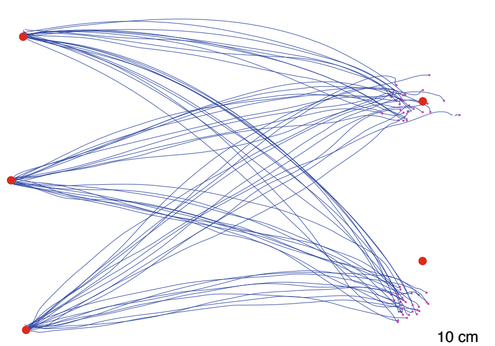

Fig. 2. Side view of the movements of one participant. The red dots are the start and target locations. The magenta dots are the participants endpoints.

To determine the initial movement direction the point on the movement path at which the radial distance from the start location was 3.5 centimeters was determined. The angle between the line connecting this point with the start location and the line connecting the target location with the start location was considered to be the error in initial movement direction. The angle between the line through the two tips of the pointer and the line connecting the start and target location was considered to be the error in the perception task. Counter clockwise errors, when seen from the right (i.e. upward trajectory deviation) were defined as positive.

Median errors were determined for each participant, for each combination of start and target location and task. The mean of the median errors for the six combinations of start and target location was then calculated for every participant and task. To examine whether the participant-specific error in perception is responsible for that participants error in initial movement direction, a regression analysis was performed. We took into account that there was uncertainty in on both measures by performing an orthogonal regression analysis.

3 Results

An example of the movements of one participant is shown in figure 2. This side view shows an upward error in the initial movement direction for all targets.

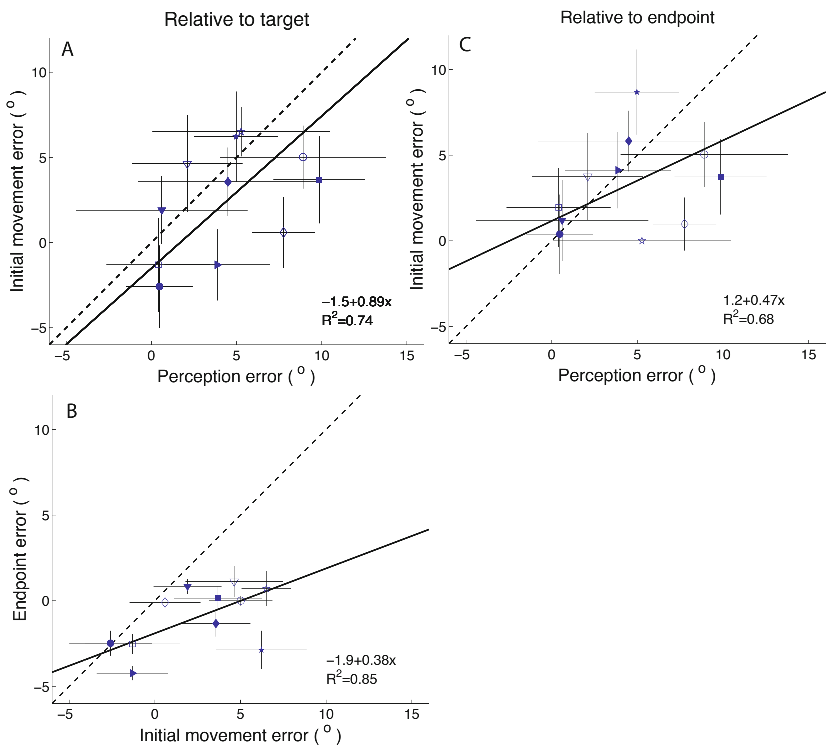

Fig. 3. Each symbol represents the mean errors of one participant, averaged over the six combinations between start and target location. The error bars represent the SEM across combinations of start and target location. A: relation between perception error and error in initial movement direction, whereby the latter error is defined relative to the target. B: relation between error in initial movement direction relative to the target and the endpoint error. C: relation between perception error and error in initial movement direction, whereby the latter error is defined relative to the movement endpoint.

On average participants took 3.09 (sd = 1.39) seconds to make the movements, irrespective of the combination of start and target location. On average, participants ended 10.8 mm (sd = 23.1) closer then the target and 31.8 mm (sd = 22.7 mm) below the target. The regression analysis is shown in figure 3a.

We found a good correlation, with a slope close to the expected 1.0 (see figure 3a). Some participants ended their movements much further from the actual target than others. This endpoint error was correlated with the directional error (see figure 3b). Do the variations in end position between subjects cause some of the correlation between the perception error and the error in the initial movement direction? To answer this question, we also calculated the error in the initial movement direction relative to the endpoint of the movement, and plotted this as a function of the perception error (figure 3c). A regression analysis revealed a clear correlation, although the slope was shallower than for the correlation between perception error and the initial movement error relative to the target.

4 Discussion

In this study the errors in the initial movement direction of goal-directed movements towards haptically defined targets in a mid-sagittal plane are compared with the errors in setting a pointer towards the same target in the same plane. If the curvature of hand trajectories in goal directed movements is caused by a misjudgment in direction, the errors in initial movement direction should be the same as the errors in the haptic perception of direction. This relation was clearly present in our data (figure 3a): all data points are close to the prediction (dashed line), and the slope of the best fit was 0.89.

On top of the positive correlation between errors in perception of direction and errors in initial movement direction, figure 3a and c also show that for most subjects, the errors are positive for both tasks. This means that the participants set the pointer and made their movements too far upwards. This may somehow be related to gravity. Note that despite generally starting to move too far upwards, subjects generally ended below the targets.

For most of the participants, the two fingers are at systematically different locations at the end of the movements (figure 3b). Moreover, the endpoint errors differ between participants: some have their right hand lower then their left hand, others higher. Such systematic participant-dependent errors in proprioceptive-proprioceptive matching resemble the participant-dependent errors in visual-proprioceptive matching [7]. This mismatch between the two hands might be due to errors in perceiving the location of either hand. Another explanation for this mismatch might be that participants did not want to deviate from a straight line. This implies that participants ended further from the target due to errors in initial movement direction, which explains the correlation seen in figure 3b.

Miall and Haggard [11] did not find a relation between haptic perception and the curvature in movements towards haptic targets. They asked the participants to trace along the edge of a ruler on a tabletop. The ruler was bent in different directions. There are two differences with our study. The first difference is that they did not give any instruction about the path to follow between the start and end location, whereas we asked our subjects to move as straight as possible. This lack of clear movement instruction might have added some variations to the curvature of the movements in their experiment. The second difference is more important: they measured haptic perception of *curvature* and we measured haptic perception of *direction*. The fact that Miall and Haggard did not find a correlation and we do supports our hypothesis that it is not the haptic feeling of what is a straight path, but a perceptive misjudgment of direction, that causes the movement paths to be curved. This distinction between errors in perception of direction and perception of curvature has also been made in the visual domain [7], and also there the experiments showed that direction, rather than curvature, is the variable that is misperceived.

We conclude that the error in initial movement direction is strongly related to the error in the perception of direction, when moving towards a haptic target in a mid sagittal plane.

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