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RESEARCH NOTE

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Moving one's finger to a visually specified position: target orientation influences the finger's path

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Abstract It has previously been shown that, when subjects are instructed to move their finger slowly from one point to another the finger follows a path that deviates systematically from a straight line connecting the two points. The deviation depends on the angle between this fictive line and a line connecting the subject's finger with his body. In the present study, we examined whether the deviation also depends on the target's orientation. In two experiments, subjects were instructed to move a finger slowly towards five targets. We recorded the finger's movements. In one experiment, the targets were aligned. In the other, they were oriented radially around the starting point. Otherwise, conditions were the same. The difference in target orientation influenced the finger's path. Most importantly, when the targets were oriented radially around the starting point, the finger's path was straight. We conclude that pointing is more than moving the finger to a specified position.

Key words Spatial localisation · Motor control · Movement · Pointing · Human

Introduction

We constantly move our hands to visually specified positions in space. It is a crucial aspect of picking, moving or pushing objects. Considering the limitations of spatial vision, in particular judgements of distance (Sedgwick 1986; Todd and Norman 1994), it is not too remarkable that subjects should misjudge the direction from one point to another. Moreover, small errors can easily be compensated for during the movement (Brenner and Smeets 1994; Carlton 1981; Pélisson et al. 1986). What is remarkable is that the misjudgements are systematic (de Graaf et al. 1991).

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The systematic misjudgements persist when subjects are blindfolded (moving their hand to tactile targets), and are even present in the congenitally blind (de Graaf et al. 1994). Thus, they cannot be purely visual. They also cannot be due to mechanical properties of the arm, because they are also present when subjects are asked to set a pointer in the direction they would move their finger, rather than to actually move their finger towards the target (de Graaf et al. 1991).

The deviation from a straight path towards the target depends on the direction in which the finger has to move with respect to its position relative to the body. The path is straight when the finger starts between the body and the target (de Graaf et al. 1993). Such deviations could arise during the transition from a body-centred representation of the target's position in space (as found in "higher" sensory areas, e.g. Duhamel et al. 1992; Gentilucci et al. 1983), to a representation of the displacement that is required to get the finger to that position (as found in motor and premotor cortex, e.g. Caminiti et al. 1991). However, it is not clear why the deviations should be so systematic, and so similar in all subjects.

When asked to move their finger in a certain direction rather than towards a target, subjects movements did not deviate systematically from a straight path (de Graaf et al. 1994). This suggested to us that the deviations do not originate in a misperception of space, but that they are caused by properties inherent in the targets themselves. We therefore set out to examine whether the orientation of the target influences the hand's path towards it. We found that it does.

Materials and methods

Subjects were seated at the cut-off edge of an incomplete, 39-cm-diameter circular surface. The cut edge was 4 cm nearer than the centre of the circle. The subject's eyes were about 25 cm behind and 45 cm above the surface centre. A screw at the surface centre served as the starting point for all the movements. The targets were five (2×2×4 cm) wooden blocks. They were 30 cm away from the starting point, in five directions (from 45° left to 45°

right of straight ahead; see Fig. 1). The head was not restrained, but subjects were instructed to move it as little as possible. There was no restriction on (or instruction concerning) eye movements. The position of the subject's index finger was determined at a rate of 250 Hz and a better than 0.1 mm resolution (in all directions) using a movement analysis system with an active infrared marker attached to the tip of the finger (Optotrak 3010, Northern Digital). The last few centimetres before the finger reached the targets was not recorded, because the marker disappeared behind the target.

Seven right-handed subjects (including the authors) served as subjects. They were instructed to choose a position on the target in advance, and to move straight towards this position as soon as we indicated that they could start. They were instructed to move slowly, with no limitation on the movement or reaction times (the overall average movement time was 1.4 s; the intra-individual average ranged from 0.8 s to 2.1 s).

We conducted two experiments, alternating the order in which they were run with each consecutive subject. The only difference between the two experiments was the orientation of the targets: frontal (Fig. 1a) or radial (Fig. 1b). Subjects moved their finger eight times to each target. The order was systematic: they first moved once to each target, starting with the leftmost target and ending with the rightmost one, then they repeated the sequence from right to left, then again from left to right, and so on.

We isolated the relevant part of the finger position data (which we will refer to as the finger's trajectory) by finding a section during which the finger moved at least 22 cm, while the component of the finger's velocity in the average direction of motion was larger than 5 mm/s between each pair of consecutive samples (one trial of one subject was discarded, because we failed to find such a section before the marker disappeared from view; on average the isolated trajectories were about 26 cm long). The maximal deviation of the finger from the straight line connecting the first and last point of each trajectory was determined and used for statistical analysis.

We also computed average trajectories. To do so, a line connecting the first and last point of each trajectory was divided into 99 equal steps. For each of the 100 resulting locations along the line, we determined the finger's position when crossing a line orthogonal to the original line (positions between measured values were determined by linear interpolation). These finger positions were then averaged across trials.

Results

Figure 1 shows the overall average of all trajectories towards each target (seven subjects; eight trials each). The only difference between the two experiments was whether the targets were aligned or oriented radially around the starting point. Figure 2 shows the magnitudes and directions of the maximal deviations of the finger in each experiment. With frontal targets (Fig. 1a; open symbols in Fig. 2), subjects' fingers clearly deviated systematically from straight paths. There was a significant deviation to the left for the target situated 45° to the left of the starting point, and a significant deviation to the right for the target situated 22.5° to the right of the starting point (as predicted by the work of de Graaf et al. 1991; one-tailed t-test across subjects, $P<0.05$). With radial targets (Fig. 1b; filled symbols in Fig. 2), there were no system-

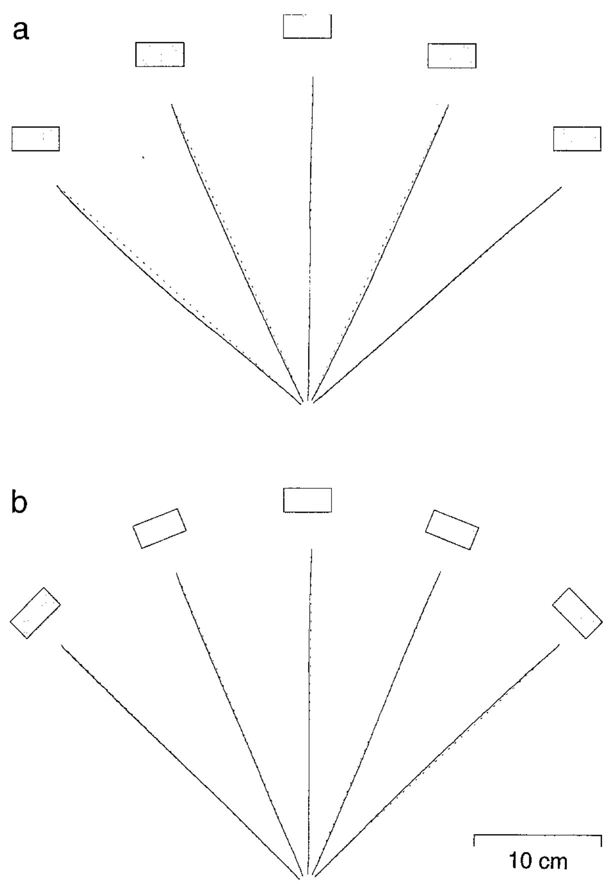

Fig. 1a, b Top view of seven subjects' average trajectories towards five targets. The only difference between the two experiments was whether the targets (*shaded rectangles*) were aligned (**a**) or oriented radially around the starting point (**b**). In the former case, subjects' fingers moved along a path (*solid curves*) that deviated systematically from a straight line (*dotted lines*). In the latter case, they moved straight towards the target

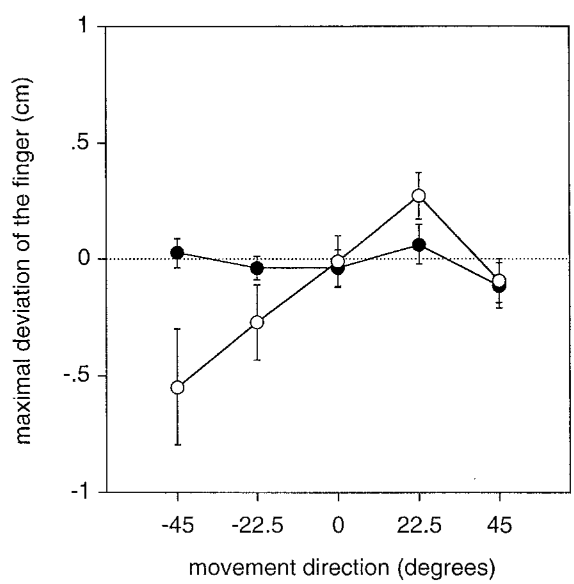

Fig. 2 The magnitude and direction of the maximal deviation from a straight line was determined for each movement. Average values for each of the five targets (with standard errors between subjects) are depicted by *open symbols* for the experiment in which the targets were aligned, and by *filled symbols* for the experiment in which the targets were oriented radially around the starting point. *Negative values* indicate leftward movements and deviations

atic deviations from a straight line ($P>0.1$). A three-way analysis of variance (seven subjects, five targets, two experiments) confirmed that the arrangement of the targets influenced the subjects' performance (significant experiment by target interaction, $P<0.0001$). There were also significant ($P<0.05$) main effects of target, subject and experiment; and significant interactions between subject and experiment, and between subject, experiment and target.

Discussion

Our most important finding is that we could eliminate the systematic deviations reported by de Graaf et al. (1991, 1994) by orienting the targets radially around the starting point. Thus, movements to a given position do not only depend on the required displacement, but also on the structure at that position.

Surprisingly, even with frontal targets (Fig. 1a), the deviations in the present study were smaller than those reported by de Graaf et al. (1991, 1994). This is unlikely to be due to differences in layout or in overall distance, because we used a similar layout, and distance has been shown not to be very important (de Graaf et al. 1993). It is also unlikely to be due to our subjects having moved somewhat faster, because that should only give rise to additional systematic deviations related to the biomechanics of the arm. It may be due to the circular surface in our experiments. This would imply that not only the structure of the target, but that of the whole surrounding can influence the finger's trajectory. Whatever the reason for our modest deviations with frontal targets, the fact remains that orienting the targets radially eliminates the well-established systematic deviations altogether.

Target orientation influences the finger's path towards the target. Could target orientation have been an important factor in the previously reported misjudgements of direction? As the previous studies used unoriented targets (circular light-emitting diodes), it is unlikely that the orientation itself is a critical factor. We speculate that the systematic deviations could have something to do with an anticipation of the "purpose" of the action.

When moving one's hand towards an object in order to pick it up, the grasp and transport components appear to be regulated independently (e.g. Chieffi et al. 1992). However, it is obvious that the way one approaches the object must suit the way one wants to grasp the object, and will therefore depend on the object's shape and orientation (Iberall et al. 1986). Considering the limited precision of visual judgements of the object's size, shape and distance, a safe strategy would be to approach the object's surfaces perpendicular to their orientations. Our results are consistent with such a strategy, and suggest that it is also present when moving one's hand towards an object without the intention of picking it up, i.e. when pointing. If this is really the origin of the deviations, perception must be influenced by the way we would have moved our hand, because similar systematic errors were found in a pointer setting task (de Graaf et al. 1991). Although this may sound peculiar, it is consistent with recent evidence that voluntary action can indeed influence perception (Ishimura and Shimojo 1994).

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