Seen in a flash: spatial and temporal aspects in movement related (mis)localization

Maij, F.

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Chapter 5

Misjudging where you felt a light switch in a dark room

Previous research has shown that subjects systematically misperceive the location of visual and haptic stimuli presented briefly around the time of a movement of the sensory organ (eye or hand movements). In all these studies the stimuli (a flash or a tap on the finger) are quite different from what one encounters in daily life. In this study we tested whether subjects also mislocalize real (static) objects that are felt briefly while moving ones hand across them, like when searching for a light switch in the dark. We found that subjects systematically mislocalized a real bar in a similar manner as has been shown with artificial haptic stimuli. This demonstrates that movement related mislocalization is a real world property of human perception.

Introduction

When you come home late at night and need to find the light switch in a totally dark room, you sweep your hand across the wall to feel where the switch is. During these sweeping movements you need to know where your hand is in space (information provided by proprioception and motor commands), and you need to know whether and when your hand feels the switch (tactile information). This information needs to be combined in order to know that the light switch is located at the position where the hand was at the time it touched the switch. Once you have moved over the switch you need to move your hand back to the place at which you felt it to turn on the light. Surprisingly, it is hard to find the switch although you just touched it while moving your arm. In this paper we study this localization problem, especially whether these localization errors are systematic.

In vision it is known that people make systematic errors when localizing objects flashed around the time of saccades (Bischof & Kramer, 1968; Dassonville et al., 1992; Lappe et al., 2000; Maij et al., 2009; Mateeff, 1978; Matin & Pearce, 1965; Ross et al., 1997) or during smooth pursuit (Brenner, Smeets, & van den Berg, 2001; Kerzel, Aivar, Ziegler, & Brenner, 2006; Rotman, Brenner, & Smeets, 2004). These systematic localization errors are primarily in the direction parallel to the movement (Honda, 1993). Similar mislocalization patterns have been reported in haptics (Dassonville, 1995; Watanabe et al., 2009). In those studies a small vibrator, attached to the index finger, delivered a tap on the finger around the time of an arm movement.

All the above-mentioned studies used artificial stimuli that differ in many ways from what we normally encounter in our everyday environment. In vision flashes that were very shortly presented were used and in haptics taps on the finger with no displacement on the skin were used. Dassonville (1995) raised the question in the discussion of his paper as to why these large haptic mislocalizations are not more obvious in daily life. In the present study, we tested whether the same pattern of mislocalization occurs under more natural conditions. Subjects were instructed to localize a thin bar that was placed on top of a table. They felt this bar while moving their arm from one location to another across the table. We will show that this task, that is comparable to the light-switch example mentioned above, yields similar systematic errors to those found with artificial stimuli.

Methods

Six subjects volunteered to participate in the experiment (including two of the authors). The study is part of a research program that was approved by the ethics committee of the Faculty of Human Movement Sciences.

Setup

We instructed the subjects to sit on a chair and blindfolded them. We asked the subjects to move their right index finger either to the left or to the right across a tabletop (the two most distal phalanges of the index finger were placed on the tabletop) from the side of one cube (sides: 2.5 cm) to the side of another cube

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(see figure 1A). The space between the cubes was 40 cm. We placed a thin aluminum bar (0.5 cm wide; 0.1 cm high) on the table at a random position on the movement path. The bar was oriented orthogonally to the path and was long enough for its far end never to be felt. The right index finger's trajectory was recorded by attaching an infrared light-emitting diode (IRED) to the nail and recording the IRED's position with an Optotrak system (Northern Digital Incorporation, Waterloo, Ontario, Canada; sampling rate = 500 Hz). Three additional IRED's were attached to the aluminum bar and the two cubes.

Procedure
Each trial started by the experimenter instructing the subject at which cube to start. This was determined at random. The subject placed the index finger so that it touched either the left side of the cube on the right or the right side of the cube on the left. The bar was then placed at a random position between the cubes and the subject was instructed to start. He or she moved his or her fingertip across the surface of the table at whatever speed he or she found convenient until the finger reached the other cube. After this movement the subject had to indicate the perceived location of the bar by lifting the finger and placing it at that location, see figure 1B. When the subject started moving to the perceived location of the bar the researcher moved the bar to another location along the path so that the subjects received no feedback (subjects were aware of this). In total there were 160 trials for each subject (80 trials starting at each side).

Data analysis
We used the recorded positions of the index finger and bar to determine the localization error and the timing error (as explained below and in figure 1B). The beginning and end of the movement were determined with a velocity threshold of 5 cm/s. We discarded trials in which the arm movement was not smooth (for instance because the subject stopped moving the finger after he or she crossed the bar) and trials in which the subject started moving before the instruction to start.

Positive values of the localization error indicate an error in the direction of the arm movement (nearer to the end position of the movement; e.g. indicating a position that is too far to the right for a rightward movement). We plotted the localization error as a function of the different locations and times of contact with the bar (relative to movement onset). The timing error was defined as the difference in time between when the finger reached the actual location and when it reached the perceived location of the bar (see figure 1B). We fit a regression line through the data points of the timing error to compare the results with those of Dassonville (1995).

The duration of the contact between the finger and the bar was determined by dividing the sum of the width of the finger (approximately 1.5 cm) and the width of the static bar (0.5 cm) by the velocity of the finger's movement at the time of contact. The average duration of contact was determined for each subject.
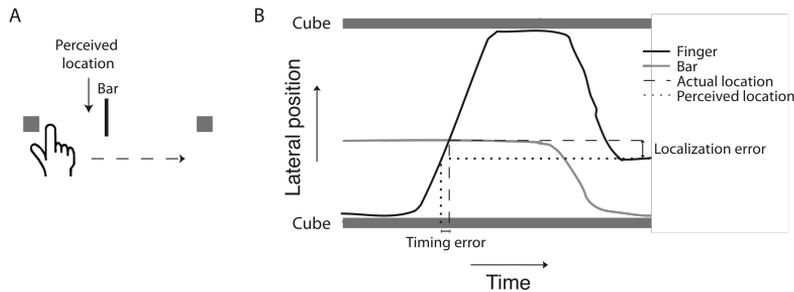
Figure 1. The haptic localization task. *A.* Top view. *B.* Time course of an example trial, the subject moved the fingertip (black line) from the left cube to the right one. During the movement the finger crossed the aluminum bar (gray line). After reaching the other cube the finger moved back to the perceived location of the bar (that had been moved away in the meantime). The movement to the perceived location of the bar was performed with the finger lifted off the table (not shown). The difference between the perceived location and the actual (original) location of the bar is the localization error. The timing error is the difference in time between when the finger reached the actual location of the bar and when it reached the perceived location of the bar during the initial movement.

Results

We discarded on average 3% of the trials. The average duration of contact between the finger and the bar was 28 ± 7 ms (mean ± standard deviation across subjects). For each subject we display the perceived distance of the bar from the start position as a function of the actual distance (figure 2A). Three of the six subjects (EB, AH and WS) have a tendency to underestimate the distance. All subjects have considerable variability in the localization of the bar; standard deviations of several cm. This is considerably larger than the precision of proprioceptive localization at a similar position (van Beers, Sittig, & Denier van der Gon, 1998).

In figure 2B we show the localization errors as a function of the time from movement onset. The negative slope of the smooth curve through the data points indicates that the longer the finger moved, the more the bar was perceived at a position that was crossed earlier than was the actual bar location. This is even more evident from the timing error (the time between when the finger was at the actual location and when the finger was at the perceived location; figure 2C). One subject shows a different result (ND). This subject moved very fast and the bar was usually perceived to be near either the start position or the end position of the movement. Regression coefficients for the timing error as a function of the time of contact relative to movement onset are shown in table 1.
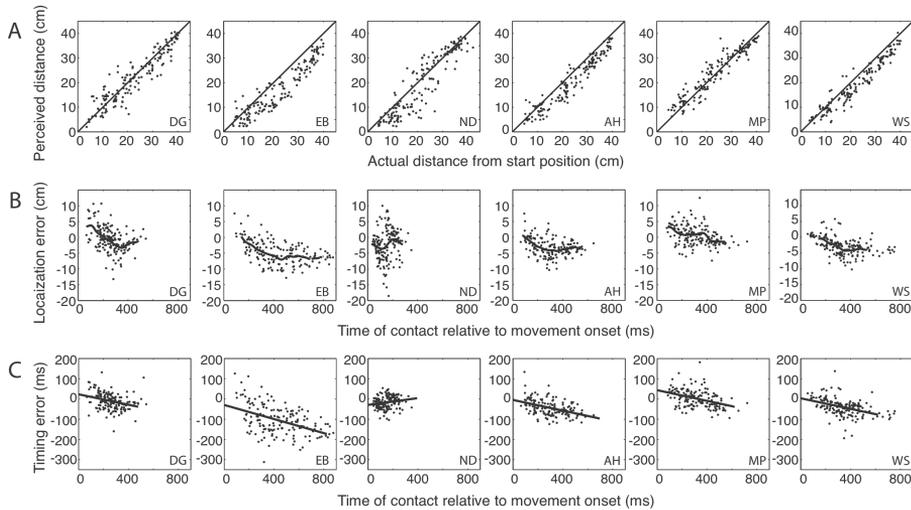
Figure 2. *Each subject's performance.* **A.** *The perceived position of the bar as a function of the actual position of the bar.* **B.** *The localization error as a function of how long after movement onset the finger touched the bar. The smooth curves through the dots are averages based on a moving Gaussian window (σ = 25 ms).* **C.** *Timing error as a function of how long after movement onset the finger touched the bar. The lines represent linear regressions to the data points.*

Table 1. *Regression coefficients of linear fits of the timing error as a function of the time of contact with the bar relative to movement onset. We also give the ranges of the intercept, slope and R^2 values of the four subjects (in the lower row) from table 3 of Dassonville (1995).*

Subject	Regression coefficient of the timing error		
	Intercept (ms)	Slope	R^2
DG	23	-0.13[**]	0.10
EB	-29	-0.17[**]	0.22
ND	-29	0.09[*]	0.04
AH	-5	-0.13[**]	0.19
MP	44	-0.13[**]	0.17
WS	4	-0.13[**]	0.19
Mean	**1**	**-0.10**	
Dassonville	**72 to 162**	**-0.12 to -0.49**	**0.11 to 0.73**

[*] Slope is significantly greater than zero (t-test, p<0.05)
[**] Slope is significantly less than zero (t-test, p<0.0001)

Discussion and conclusion

Dassonville (1995) raised the question in the discussion of his paper as to why the large systematic haptic mislocalizations that he found in his experiment are not more obvious in daily life. We performed an experiment in which we tested whether the localization errors are also systematic in a task that is more similar to daily life tasks. Our results showed that subjects make similar systematic

errors when localizing a bar during an arm movement under more or less natural conditions. Thus we probably make similar errors in daily life but our variability is so large that we are not bothered by the systematic localization errors that we make around the time of movements.

Subjects were instructed to localize a static thin bar that they felt while moving their finger from one location to another. The systematic mislocalization pattern that we found was similar to the pattern found in previous research in which subjects localized an artificial stimulus: a tap on a moving finger (Dassonville, 1995; Watanabe et al., 2009), a flash presented near the time of a saccade (Bischof & Kramer, 1968; Dassonville et al., 1992; Lappe et al., 2000; Maij et al., 2009; Mateeff, 1978; Matin & Pearce, 1965; Ross et al., 1997) or a flash presented during smooth pursuit (Brenner et al., 2001; Kerzel et al., 2006; Rotman et al., 2004).

We found a smaller average slope of the regression lines of the timing error relative to movement onset than the slope of the regression lines in the experiment of Dassonville (1995). The differences in slope could arise from the fact that the average duration of the tactile stimulus was clearly longer in our experiment (28 ms) than the 6 ms in the study of Dassonville (1995). Experiments in vision often present extremely short flashes (e.g. Lappe et al., 2000; Ross et al., 1997; Schlag & Schlag-Rey, 1995). Rotman and colleagues (2005) showed that systematic localization errors decrease with increasing (static) stimulus presentation for visual stimuli during smooth eye movements. If this is also true for tactile stimuli then the difference in stimulus duration can explain the slopes.

The intercepts of the regression lines of the timing error are smaller than the intercepts found by Dassonville (1995). This could be explained by one or more of the other differences between the studies. In the haptic localization study of Dassonville (1995) the stimulus could be presented before, during and after the start of the eye or hand movement. In our experiment we were only able to test the perceived location of the bar during the hand movement, because the subjects had to move their finger to touch the bar, this resulted in a smaller range of positions at which the bar could be presented. Moreover, Dassonville (1995) instructed his subjects to move their hand in the air (obtaining only proprioceptive information about the location of the finger), whereas in our study the subjects were instructed to move the finger across a surface (obtaining both proprioceptive and cutaneous information about the location of the finger). Considering these differences between the studies it not surprising that we find some quantitative differences between them. Importantly, qualitatively we find very similar mislocalization patterns.

In summary, we can conclude that errors when touching a real object are not fundamentally different from ones when the stimulus is delivered by a vibrator attached to the finger. This demonstrates that movement related mislocalization is not limited to artificial stimuli. We show that these errors are present in a task that is reminiscent of finding a light switch in the dark.