

# Current Oculomotor Research

## Physiological and Psychological Aspects

Edited by

**Wolfgang Becker**

*University of Ulm  
Ulm, Germany*

**Heiner Deubel**

*Ludwig-Maximilians University  
Munich, Germany*

and

**Thomas Mergner**

*University of Freiburg  
Freiburg, Germany*

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# THE SUBJECTIVE DIRECTION OF GAZE SHIFTS LONG BEFORE THE SACCADE

Heiner Deubel,<sup>1</sup> David E. Irwin,<sup>2</sup> and Werner X. Schneider<sup>1</sup>

<sup>1</sup>Institute of Psychology  
Ludwig-Maximilians-University  
Munich, Germany

<sup>2</sup>University of Illinois  
Urbana-Champaign

## 1. ABSTRACT

Subjects in eye movement experiments sometimes report that they have moved their eyes to some location before their eyes have actually moved (Deubel and Schneider, 1996). We investigated this by presenting a brief test stimulus at various points in time after directing subjects to make a saccadic eye movement to a peripheral cue. The subjects had to report where they were looking when the test stimulus was presented. We found that visual stimuli presented at the saccade target location as early as 250 ms before saccade onset were reported as occurring after the saccade. In a second experiment subjects performed, intentionally, a saccade to a static cue. Also under this condition, subjects reported to look at the future saccade target location long before the saccade actually occurred. The data show that subjects are unaware of the time when they make even a large saccade, and that they have no explicit knowledge of the retinal position of stimuli. Rather, they mistake movements of visual attention for movements of the eyes.

## 2. INTRODUCTION

People are able to maintain an assigned gaze direction in total darkness for periods as long as two minutes, and they can return their eyes accurately to an assigned direction in the dark following a randomly-chosen pattern of large saccades (Skavenski and Steinman, 1970). Clearly this would not be possible if people had no (implicit or explicit) knowledge about where their eyes were pointed. In the light, knowing what one is looking at seems an even more trivial task; fixated objects appear clear and in the center of our

visual space. Despite this, in previous research we have observed that subjects sometimes report anecdotally that they have moved their eyes to a location when in fact their eyes are still fixating somewhere else (Deubel and Schneider, 1996). This finding suggests that people don't always know where their eyes are pointing, at least not while preparing a saccadic eye movement. We investigated this in two experiments reported here.

### 3. METHODS

The stimuli were presented under computer control on a color monitor (CONRAC 7550 C21) at a frame rate of 100 Hz (KONTRAST 8000 TIGA graphics board); eye movements were measured with an SRI Generation 5.5 dual-Purkinje eyetracker sampling at 400 Hz. Screen background luminance was set to 3 cd/m<sup>2</sup>; the luminance of the stimuli was 30 cd/m<sup>2</sup>.

Six paid subjects completed six sessions of 192 trials each during the experiment. Trials in which the subject saccaded in the wrong direction and those with saccade latencies shorter than 120 ms or longer than 600 ms were discarded; this eliminated less than 4% of all trials. Subjects were naive with respect to the object of the study, but they were experienced in eye movement tasks. Each subject showed the same pattern of results.

In Experiment 1 the subject began each trial by fixating a central cross (see Figure 1a). After a delay the central fixation disappeared and a saccade cue was presented, 6 deg in the periphery, to the left or to the right of fixation. A test stimulus consisting of an open circle appeared for 20 ms in the visual field with a temporal asynchrony that varied randomly between -50 ms and 450 ms. The circle could appear either in the screen center, at the position of the saccade cue or at a position opposite to the saccade cue (the example given in Figure 1a is for the "circle opposite" case). Depending on the timing of test appearance, the eyes would have moved or not when the circle was presented; the subject's task was to indicate by pressing one of two buttons whether his or her gaze had been on

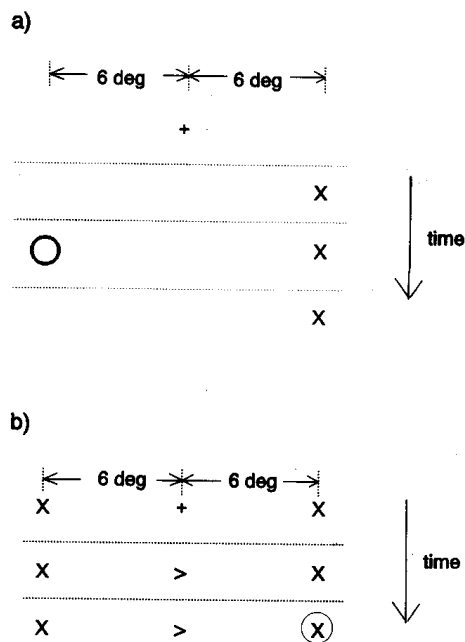


Figure 1. Schematic illustration of the procedure used in Experiment 1 (Figure a) and Experiment 2 (Figure b).

the central fixation point or on the saccade target at the time when the test stimulus occurred.

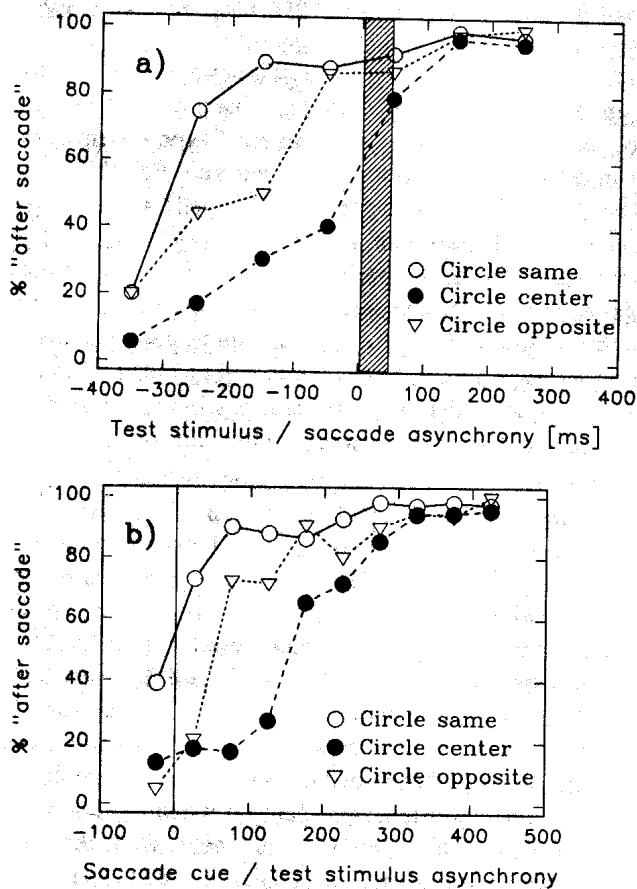
In Experiment 1, the saccade is triggered by the appearance of a peripheral cue. In order to evaluate whether possible effects were not simply due to the subject confusing saccade cue and test stimulus onsets, we performed a second experiment (Experiment 2) in which the saccade was made purely intentionally, without an external cue. For this purpose, the subjects were trained before the experiment to make a (delayed) saccade approximately 1 s after a central visual cue. In the experiment, a central fixation was initially displayed together with two static crosses, 6 deg in the periphery (see Figure 1b). After some delay, a central arrow was displayed indicating the saccade target. The subjects were now told that they should try to move their eyes to the indicated saccade target 1 sec after the arrow cue appeared. As in the previous experiment, the subjects had to judge whether a brief visual test stimulus appeared before or after their gaze shifted. Again the test stimulus consisted of a circle that could appear either on the screen center, on the indicated saccade target position, or opposite to that position.

#### 4. RESULTS

The results of Experiment 1 are shown in Figure 2. Mean saccade latency in Experiment 1 was  $231 \pm 71$  ms (SD) and was constant across conditions. Figure 2a plots test stimulus / saccade asynchrony on the abscissa; negative values mean that the test appeared before the saccade onset, and positive values mean the test appeared after the saccade onset. The hatched area indicates approximate saccade duration. The percentage of responses in which subjects said they were looking at the saccade target location when the test was presented is on the ordinate. The data are shown separately for the cases when the test stimulus was shown in the center (filled circles), on the side of the saccade cue (open circles), and on the opposite side (open triangles). Figure 2b replots the same data, here as a function of the time between saccade cue onset and test stimulus onset.

The results show that perception of gaze position was approximately veridical when the test was presented at the central fixation point (Figure 2, filled circles); the 50% point (the point of subjective synchrony) is close to a stimulus/saccade asynchrony of 0 (see Figure 2a). This means that when the test appears at the center subjects were able to veridically report the time of occurrence with respect to the time of their saccade, though with relatively low temporal resolution. In contrast, when the test circle appeared at the saccade target location (open circles), subjects reported they were fixating the saccade target location long before their actual saccade. The point of subjective synchrony was approximately 300 ms before the saccade in this case. A smaller amount of perceived asynchrony was found for the contralateral position as well (open triangles). Figure 2b shows the same experimental data, but now given as a function of the delay between saccade cue and test stimulus. These data suggest that, at least for the condition where the test circle appears at the target location of the future saccade, the subjective gaze shift follows the presentation of the saccade target almost without delay; it seems that as soon as the saccade cue is presented, subjects already believe they are "on target".

In the first experiment the saccades were stimulus-induced; that is, they were made in immediate response to a saccade cue. To rule out the possibility that our results were due to subjects confusing the onset of the saccade cue for the saccade itself, in Experiment 2 we examined whether a perceived asynchrony between stimulus flash and saccade would be found for voluntary (self-triggered) saccades.



**Figure 2.** Results of Experiment 1. a) Stimulus/saccade asynchrony is plotted on the abscissa; negative values mean that the test appeared before the saccade onset, and positive values mean the test appeared after the saccade onset. The hatched area indicates approximate saccade duration. The percentage of responses in which subjects said they were looking at the saccade target location when the test was presented is on the ordinate. b) Same data, now plotted as a function of the temporal interval between saccade cue and test circle presentation.

The results are shown in Figure 3, in the same manner as for Experiment 1. It can be seen that also for intentional saccades, subjects considerably misjudge their gaze position before saccades. The points of subjective synchrony were found at  $-45$  ms,  $-145$  ms, and  $-102$  ms for the test circle appearing at the center, the cue location, and the opposite side, respectively.

## 5. DISCUSSION

The results demonstrate that the perceived direction of gaze shifts a long time before the eyes move. This is true for both stimulus-induced and voluntary saccades. These results show that people don't always know what they are looking at with foveal gaze, or at least, when they are looking where. Apparently, they have no explicit knowledge about their (orbital) eye position. Further, they are unable to gain explicit knowledge about the position at which objects appear on their retinæ - otherwise, they would have noticed when the stimulus was presented in their visual periphery. Finally, subjects seem not to notice the occurrence of even large saccadic eye movements. However, because visual attention is known to shift to the location of an intended saccadic eye movement before the eyes move (Deubel and Schneider, 1996; Hoffman and Subramaniam, 1995; Kowler *et al.*, 1995; Shepherd *et al.*, 1986; Schneider and Deubel, 1995), we believe that our results are due to subjects mistaking shifts of visual attention for shifts of the eyes—when that hap-

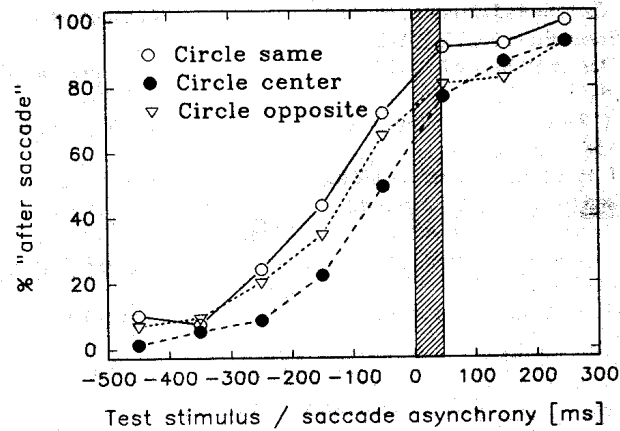


Figure 3. Results of Experiment 2.

pens, the subjective direction of gaze does not correspond to objective eye position. Visual attention moves to the saccade target location before the eyes move, making that location the new center of perceived visual space.

Our results are analogous to physiological findings that the receptive fields of individual neurons in parietal cortex in monkeys shift to new positions in space shortly before a saccade (Duhamel et al., 1992). It has been suggested that parietal cortex might be able to generate a continuously accurate representation of visual space by anticipating the retinal consequences of eye movements in this way. In a similar fashion, we find that the perceived direction of gaze shifts prior to an eye movement, at least for some positions in the visual field. Our results suggest that a global remapping of space does not occur, however; rather, it appears to be primarily the saccade target location that is affected. This agrees with recent evidence showing that information at the saccade target location is critical for linking the contents of successive eye fixations so that one perceives a stable and continuous visual world across eye movements (Deubel et al., 1996; Irwin et al., 1994; McConkie and Currie, 1996).

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