# Attentional Biases during Steering Behavior

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**Abstract.** In the current study, we examine eye movements of human operators during a combined steering and discrimination task. In this task, observers had to alternate their gaze between a central steering task and a discrimination task in the periphery. Our results show that the observer's gaze behavior is influenced by the motion direction of the steering task. Saccade reaction times (SRTs) of saccades to the discrimination target were shorter if the target appeared in the steering direction. SRTs back to the steering task were shorter when the steering target moved away from the discrimination target. These effects are likely the result of motion-related attention shifts and an interaction of the saccadic and smooth pursuit eye movement system.

**Keywords:** attention, eye movements, saccades, reaction time, steering.

## 1 Introduction

The design of human-machine interfaces in complex environments such as aircraft cockpits can benefit from approaches that model the operator's behavior in that environment [1]. One important component in such psychological models is the operator's visual attention. Attention is the process by which our perceptual system selects stimuli for further or more detailed processing [2, 3]. Understanding the factors that influence how attention is moved through the visual scene to process information is crucial for designing effective human-machine interfaces [4].

The strongest factor that influences orienting of attention are the goals of the observer. This *endogenous* influence competes with stimulus-driven or *exogenous* factors [5]. For example, an object that is very distinct in color tends to grab the attention of the observer when it suddenly appears [6]. Another stimulus property that engages exogenous orienting is object motion [7]. Objects that move through the visual field not only grab attention but also bias attentional orienting in the movement direction [8]. Such motion-induced attention shifts are particularly important in the context of machine interfaces in vehicles, which naturally deal with motion-related tasks and dynamic information. Here, attention shifts

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can result from objects that move outside the vehicle, for example, other traffic, or from on-board instruments with moving displays (e.g. augmented or synthetic vision displays [9]).

Until now, motion-induced attention shifts have been examined primarily in basic ocular pursuit tracking tasks. In these tasks, observers follow a moving spot on the computer screen with their eyes and respond to onsets of visual stimuli in the periphery either by a saccade or button press [10, 8]. The resulting behavior shows a reduction of reaction times for stimuli that appeared in the direction of pursuit – an indication for a bias of attention in this direction.

In the current study we present a more complex scenario, to test whether motion-induced attention shifts occur in the context of steering behavior. Here, the observer's eye movements are not restricted explicitly by the experimental procedure but are primarily driven by the visual needs of the ongoing steering task. We examined overt attention shifts in the form of eye movements of human operators during a manual steering task. This task resembles the control of the yaw motion of an aircraft when following a given flight trajectory [11]. We were interested in how the ongoing steering task would affect the operator's capacity to respond to and perform a secondary task that required shifts of attention to the periphery. The primary goal of the study was to establish whether motion-related attention shifts as they were observed in single-task ocular pursuit tasks [10, 8] would transfer to our steering scenario. For example, when steering to the right, shifts of attention in this direction should be facilitated.

Inferences about an observer's attention were made from measurements of saccadic eye movements. Saccades are quick eye movements that occur 3-4 times a second in normal behavior. Eye movements are closely linked to movements of visual attention. First, both movements typically coincide since eye movements are necessary to move the retinal image of an object of interest to the fovea, the area on the retina with highest acuity [12]. Second, even in the case when the regarded location does not correspond to the attended location, the properties of eye movements, for example the time required to plan and execute a saccade (saccade reaction time, SRT), can reveal which parts of the visual field received preferred processing [13, 14].

## 2 Method

Eight participants took part in the experiment (6 male, 2 female, age: 27-31 years). All participants had normal or corrected to normal vision. Written informed consent was obtained from all participants prior to experimentation. The procedures of the experiment had been approved by the ethical committee of the University of Tübingen. Participants were paid 8 EUR per hour for taking part in the experiment.

Participants sat in an adjustable chair in front of a TFT monitor (120 Hz refresh rate, resolution 1680 × 1050). A chin-rest provided support for the head at a viewing distance of 57 cm. An optical infrared head-mounted eye-tracking system was used to measure gaze at a sampling rate of 500 Hz (SR Research Eyelink II). A potentiometer joystick (0.18 ° angular accuracy, sampling rate 120

Hz) was mounted under the table within comfortable reach for the participants. With the other hand, participants pressed the cursor keys on a keyboard.

The primary *steering* task required participants to steer an on-screen cursor using a joystick (see Fig. 1 A, B). By moving the joystick to the left or right, participants controlled the horizontal velocity of the cursor. The instruction was to move the cursor "as close as possible" to a computer-controlled steering target. The steering target moved horizontally in a sinusoidal path around the center of the computer screen with an amplitude of 4.3 ° and frequency of 0.25 Hz. The steering target was a blue bar (RGB 180, 180, 255) and subtended 1.2 ° (visual angle), the cursor was an orange bar (RGB 255, 255, 100) and subtended 0.9 °. The steering task was performed continuously in blocks, each block lasting 128 s.

The secondary *object discrimination* task required participants to look at and identify an object that appeared in the periphery. This object consisted of a small square (0.2 °) of white color (RGB 200, 200, 200). A small gap was present at one of the four sides of the square (size 0.03 °, 1.8 minutes of arc). A white border was drawn around the target to make it discernible in the visual periphery. Participants were instructed to discern the side of the target where the gap was located (top, bottom, left, right). Due to the small size of the gap, a saccade to the target was necessary in order to achieve this. After participants looked at the target to determine the gap they responded with one of the four corresponding arrow keys on the keyboard.

Each steering block was subdivided into trial epochs of 8 s. During each epoch a discrimination object appeared randomly 400 ms before the zero-crossing of the steering target either 2 or 4 s from the start of the epoch, i.e., 1.3 or 3.6 s into an epoch. Targets appeared semi-randomly either on the left or right side of the screen at an eccentricity of 13 °. The discrimination task was scheduled such that discrimination objects appeared either in the same direction as the movement (to condition) of the steering target or in the opposite direction (away condition).

Data from the following trials were removed prior to saccade analysis: Trials with blinks during the critical time period shortly before or after the target onset, missed trials (no saccade or RT greater than 800 ms), and anticipatory saccades (RT smaller than 50 ms). Based on this method, 29 data points of 720 were removed (4%). The median number of data points remaining per participant and condition was 39 (min. 36).

## 3 Results

Two-tailed t-tests for paired samples were employed for the comparison of mean differences ($\alpha = 0.05$). Mean-centering was performed for the computation of confidence intervals (CI) [15]. The effect size measure reported is Glass's $\Delta$ [16].

Saccades to the discrimination object (outward) commenced after 234.0 ms on average. Saccades that were initiated while the steering target moved to the discrimination object exhibited shorter RTs (225.8 ms) compared to saccades that started when the steering target moved away (242.1 ms, $t(7) = 2.48$, $p < 0.05$, 95% CI of difference 4.3–30 ms, $\Delta = 0.27$, see also Fig. 1, C).

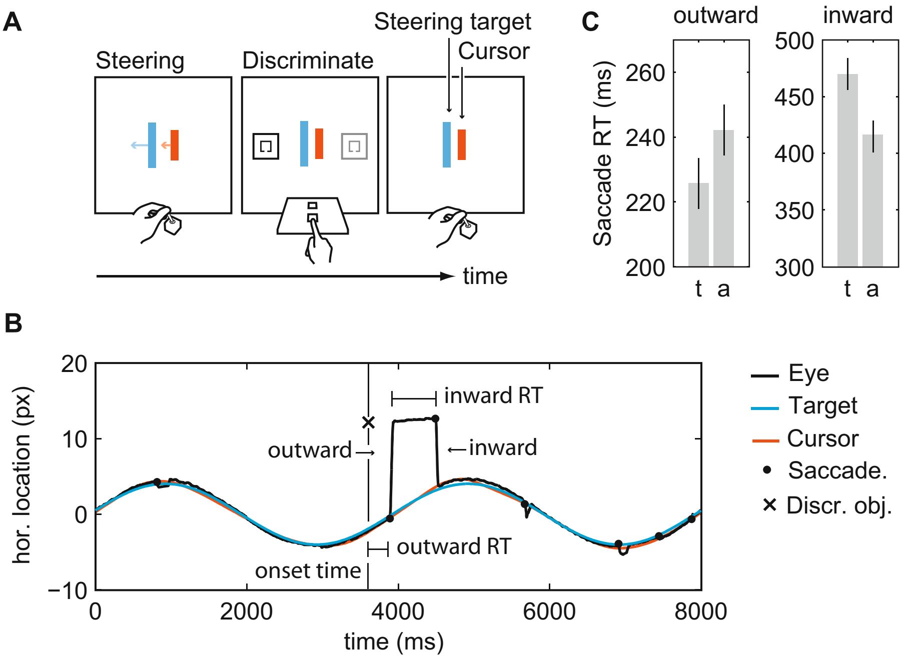

**Fig. 1.** A. Schematic of the experimental task. Participants controlled the horizontal velocity of an on-screen cursor by moving the joystick to the left or right. They were instructed to follow the sinusoidal motion of the steering target as closely as possible. The steering task was interrupted by a secondary task. This was an object discrimination task in which participants had to recognized the opening of a square symbol. B. The steering target performed two full cycles every 8 seconds (one epoch). During each epoch the discrimination object was presented randomly either 1.6 or 3.6 s into the epoch on the left or right side of the screen. The time and location defined whether the discrimination object was presented while the steering target was moving *to* the location of the discrimination object or while it was moving *away*. The plot shows the time course of stimulus presentation and a participant's response for a representative trial. The gaze movements during the same trial show periods of smooth pursuit eye movements, small catch-up saccades, and large saccades to the discrimination object (outward saccade, ca. at 4000 ms) and back to the steering target shortly afterward (inward saccade). C. Saccade reaction time (RT) results: Saccades to the discrimination object were initiated earlier when participants steered toward the location of that object (t = toward, a = away). Inward saccades were initiated earlier when the steering target moved away from the current fixation location. Error bars show 95% confidence intervals.

Saccades back to the steering target from the discrimination object (inward) took much longer than outward saccades (overall mean SRT: 442.3 ms). It is important to note that this time was measured from fixation onset on the discrimination object and therefore also comprised the time required to perform the discrimination task. Comparison of RTs between the two motion conditions showed that SRTs were shorter when the steering target moved away from the discrimination object (415.0 ms) and longer when the steering target moved to the discrimination object (469.75 ms, $t(7) = 4.6$, $p < 0.01$, 95% CI of difference 33–77 ms, $\Delta = 0.57$).

Other experiments on SRTs have reported a correlation between saccade amplitude and SRT [17]. A comparison of amplitudes in the current experiment revealed differences for both outward and inward saccades. Outward saccades were larger when the steering target moved to the discrimination object (13.0 °) and smaller when it moved away (11.4 °, $t(7) = 6.8$, $p < 0.01$, 95% CI of difference 1.2–2.1 °, $\Delta = 1.9$). Inward saccades were larger when the target moved away from the discrimination object (14.8 °) and smaller when it moved toward it (12.7 °, $t(7) = 5.6$, $p < 0.01$, 95% CI of difference 1.6–3.1 °, $\Delta = 1.3$).

## 4 Discussion

In the current study we examined visual attention shifts during steering behavior. Participants alternated their gaze between a continuous steering and a discrete object discrimination task.

Our study shows asymmetries in the observer's ability to react to the discrimination stimulus in the periphery. Reaction times of saccades (SRTs) to the discrimination stimulus (outward) were shorter when the stimulus appeared in the motion direction and longer when it appeared in the opposite location. We relate this result to earlier work on motion-induced attention shifts in basic ocular pursuit tasks [10, 8]. When pursuing a moving object with the eyes, attention is exogenously oriented ahead of pursuit, which could improve the observer's ability to respond to upcoming, pursuit-related stimuli (e.g., obstacles [8]). Our results show that this effect is robust: It is not only present when pursuit is the sole task but also in a more complex steering scenario.

Our results also show a second kind of asymmetry, namely in the timing of saccades back to the steering task (inward). These saccades occurred after the participants performed the discrimination task. The SRTs of these saccades were shorter when the target moved away from the current fixation location (the location of the discrimination target) and longer when it moved toward it. This difference may reflect the additional time that is required for basic oculomotor processing when the steering target moves toward the current fixation location. In this case, the oculomotor system must decide whether a fixation of the new target should be obtained by a saccadic or a smooth eye movement [18–20] (see Fig. 2). This decision process may in turn prolong the movement of attention toward the new target for the sake of accuracy.

An alternative explanation for both outward and inward SRT effects could be the noted differences in saccade amplitudes. These differences were primarily due to the timing of the discrimination target onsets 400 ms prior to crossing the center of the display and the average saccadic latencies of around 200 ms. Consequently, saccades to targets in the direction of the steering motion started farther away from the target than saccades to targets that appeared at the opposite location. Previous work has shown that SRTs depend on the amplitude of the saccade [17]. However, the differences in SRTs between the motion conditions of the current study are not in accord with what would be predicted based on differences in saccade amplitudes. For example, outward saccades were larger and SRTs of these saccades were shorter when the steering target moved to the discrimination target. According to [17], larger saccades should result in longer and not shorter SRTs. Similarly, inward saccades were larger and their SRTs were shorter when the steering target moved away from the discrimination target. Again, the opposite effect would be predicted purely based on amplitude differences.

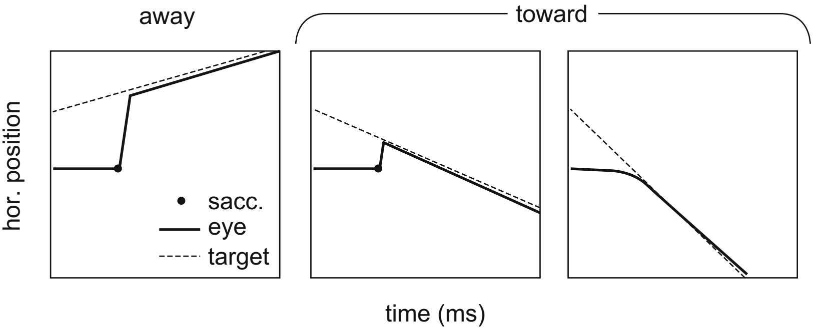

**Fig. 2.** Example for different eye movements when following a target that either moves away from the current fixation location or toward it at constant velocity. Left: When the target moves away, a catch-up saccade is performed to fixate the target. Right: When the target moves toward the current fixation location the oculomotor system has to make a decision whether a saccade would be useful or whether the motion of the target is such that it would move into focus by itself.

## 5 Conclusion

The current findings highlight the allocation of visual attention during a steering task. This is relevant to any system that requires its operator to process visual information during control itself, not just the control of a vehicle. Operator models can be developed to consider motion-induced effects on visual attention, for example, due to the motion of control instrument displays. This is useful in cases where the model should predict the operator's capacity to respond to critical situations that are indicated by peripheral visual cues (e.g., warning systems).

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