The Trial Context and the Perceived Onset Position of Moving Stimuli

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Abstract. It is long known that observers make localization errors in the direction of motion when asked to point to the perceived onset position of a moving target (*Fröhlich effect*). However, recent studies also revealed the contrary: In the *onset repulsion effect*, the pointing error is opposite to the direction of motion. We demonstrate that the conflict between these findings is resolved by considering the trial context. When the stimuli appeared at predictable positions in the visual field, pointing responses to the perceived onset position were displaced in motion direction. In contrast, when the stimuli appeared at unpredictable positions, pointing errors were displaced opposite to motion. These differences between conditions were observed with a pointing task and saccadic localization task, but not with a relative judgment task. These findings have far reaching methodological and theoretical implications.

1 Introduction: Two contradictory illusions with moving stimuli

Under optimal viewing conditions our ability to localize objects in space is known of being of high precision. Under less than optimal viewing conditions, spatial localization is much poorer. For example, with fast moving stimuli observers make systematic localization errors when asked to point with the mouse or the finger to a certain location. The present paper is concerned with two illusions of this kind: the Fröhlich and onset repulsion effect.

The Fröhlich effect. When observers are asked to localize the initial position of a moving target, they do not localize it at the onset position, but rather at a position ahead of the targets' motion. This localization error was discovered in the first half of the last century and is referred to as Fröhlich effect. Originally attributed to the so-called *Empfindungszeit* (i.e. the time needed to generate the sensation of a stimulus, [4]), the illusion is nowadays explained by various – partly contradictory – accounts including attentional mechanisms, priming, or extrapolation of target positions (see e.g. [2, 6, 8, 10, 13, 16]).

This research was supported by a grant of the Deutsche Forschungsgemeinschaft (AS 79/3) to the first author.

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Ilg, U., Bülthoff, H. & Mallot, H. (2004, Eds.) Dynamic Perception (pp. 119-124).
Sankt Augustin: Infix.

The onset repulsion effect (ORE). All of the interpretations of the Fröhlich effect were concerned with explaining mislocalizations in the direction of motion; however, recent studies also found the reverse error. In the onset repulsion effect (ORE), the targets' onset is consistently mislocalized opposite to motion ([14]; see also [1, 5]). An increase in stimulus velocity accentuates the difference between the Fröhlich effect and ORE: While the backward error (opposite to motion) increased with increasing stimulus velocity in the ORE [14], the forward error (in the direction of motion) also increased with increasing velocity in the Fröhlich illusion.

So far, both illusions were observed in independent series of experiments and the discrepancy between both effects has not been resolved. We start with analyzing the stimulus conditions, which lead to the different illusions, and report a first study, in which both illusions were observed within a single experiment.

2 The critical conditions of the Fröhlich and onset repulsion effects

An analysis of the stimulus conditions, in which the Fröhlich and onset repulsion effects were observed, revealed different spatial predictabilities of target onset positions. For example, in the Fröhlich study of Müsseler and Aschersleben [9] the target onset was almost at a constant eccentricity to the left or right of fixation and it always moved outwards. That is, there were only two narrow regions of space in which the target could appear such that target onset position was highly predictable. In contrast, ORE was observed when target onset positions were completely unpredictable. For example, in the study of Thornton ([14], see also [5]) the target onset was random within a larger square field. Additionally, target motion could be in one of four directions (up, down, left or right).

Consequently, we systematically varied the spatial predictability of target onset positions in a recent experiment [12]. In the condition where onset predictability was high (constant-context condition), targets could only appear at a constant eccentricity to the left and right of fixation and moved always outward. When onset predictability was low (random-context condition), in 6/7 of the trials the target's onset was random within a large square field centered on fixation and movement direction could either be inward or outward. In the remaining 1/7 of the trials which were intermixed, targets were presented as in the constant-context condition. Only these identical trials entered the statistical analysis and were compared to those of the constant-context condition. We found a strong effect of trial context (cf. Fig. 1). A mislocalization in motion direction (i.e. the Fröhlich effect) was observed when the spatial predictability of target onset was high (constant-context condition). In contrast, when the stimuli appeared at unpredictable positions in the visual field, pointing errors were displaced opposite to motion (i.e. the ORE) or at least drastically reduced. Thus, localization of the adjusted onset position varies with the trial context.

The difference between the constant-context and random-context condition was found within observers in successive blocks of trials. This means that observers' responses changed within an experiment. To determine the exact time course of this changeover, naïve subjects participated in a further experiment in which we looked at the localization error especially in the very first trials ([12], Exp. 4). As to be expected, localization errors did not differ at the very beginning of the experiment but the difference between the two context conditions was reliable after only 22 trials. In other words, a contextual assimilation occurred in only a few trials.

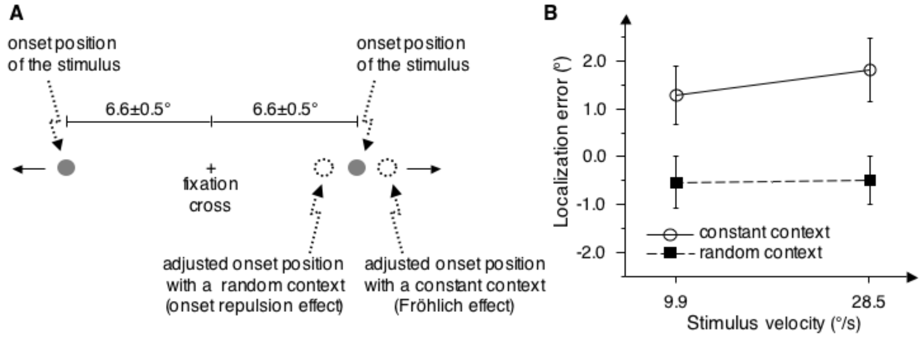

Fig. 1. Stimulus presentation (A) and data (B) of a study by Müsseler and Kerzel ([12], Exp. 1). (A) A stimulus appeared to the left or to the right of fixation and moved outward. Adjusted onset positions were in the direction of motion in the Fröhlich effect and opposite the direction of motion in the onset repulsion effect. (B) Mean localization errors (and standard errors of the mean between observers) of the onset position of a moving stimulus. Positive and negative values indicate errors in and opposite the direction of motion, respectively.

Although these findings determine successfully the stimulus conditions of the Fröhlich and onset repulsion effects, they leave unexplained the underlying mechanism. The difference between the constant-context and random-context condition may either be taken to indicate that the perception of the onset position in a trial changes with the spatial predictability of the onset positions. In this case the difference between conditions emerges from some kind of perceptual adaptation. Or they may indicate that pointing movements are no reliable dependent measure of perceived position. Possibly, pointing movements reflect perceived position in one condition, but not in the other. Alternatively, pointing movements may be an unreliable measure in general.

3 Localizations with saccadic pointing and relative judgments

In the Fröhlich and ORE study reported above, perceived location was indicated with a mouse-pointing task, that is, after stimulus presentation observers pointed with the mouse to the position where they had perceived the onset of the target. Such pointing tasks gather perceived location in a more or less indirect manner. It has been shown, for example, that the starting position of the mouse cursor ([11], Exp. 4) or the point in time [7], when the cursor is presented, exerts an influence on adjusted localization. Therefore, we further tried to evaluate experimentally the difference between the constant-context and random-context condition with other dependent measures, that is, with a saccadic pointing task and a relative judgment task. The basic procedure remained as in the previous experiments except that in the random-context condition the targets' onset was spatially uncertain in only one half of the trials, while in the other half targets were always presented to the left or right of fixation (as in the constant-context condition). This allowed for more economical experimentation.

In a first experiment with the saccadic pointing task, observers were instructed to move their eyes immediately from the fixation point to the position where they had perceived the onset of the target. The deviations of the eye position from the objective onset position determined the localization error (cf. Fig. 2A). Findings showed reliable localization errors in direction of motion in both conditions — maybe a consequence of the increased spatial predictability in the random-context condition. Additionally, the two context conditions did not differ when the saccades were executed with short saccadic latencies, but they differed significantly, when executed with long saccadic latencies.[1] Obviously, only in the latter case top-down mechanisms were able to modulate saccadic amplitudes in accordance with perceived position.

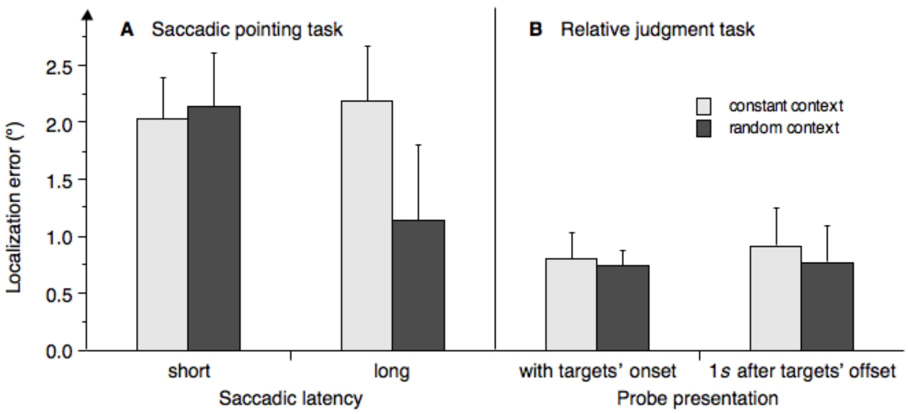

Fig. 2. Mean localization errors of the onset position of a moving target in a saccadic pointing task (A) and a relative judgment task (B).

In the experiment with the relative judgment task, a stationary probe stimulus was presented with the onset of the moving target or 1 *s* after the target had disappeared from the screen. Observers task was to judge whether the probe or the onset of the moving target was the more eccentric stimulus.[2] The results showed again in both conditions a systematic localization error in motion direction, but no difference

[1] Short- and long-latency saccades were determined by a median split. Short saccades had a mean latency of 185 ms, long saccades of 313 ms.

[2] To estimate the localization error in the relative-judgment task, a psychometric function was employed which associates the probe position with the probability of the judgment "target's onset more eccentric than the probe." From this function, estimates for the points of subjective equality (PSE) were obtained. The difference between the PSE values and the point of objective equality determined the localization error depicted in Fig. 2B.

between conditions with the relative judgment task (cf. Fig. 2B). Obviously, this task did not deliberate the differences between conditions observed with the mouse pointing and the saccadic pointing task.

4 Conclusion

The findings showed that stimulus context strongly modulated adjusted localization of the onset position of a moving target when a mouse pointing task or a saccadic pointing task was used. However, the difference between conditions only occurred with long but not with short saccadic latencies and it was completely absent in the relative judgment task. Is therefore mouse pointing (or slow saccadic pointing) a less reliable measure of perceived location than relative judgments (or fast saccadic pointing)? Not necessarily. It is known that perceptual space can be distorted by the presentation of an additional stimulus — as might be the case with the probe (e.g. [15]). Further, it is assumed that the perceptual latency of a stationary stimulus (i.e. the probe) is longer than the latency of a moving stimulus (e.g. [16]). This means that during the consolidation phase of the probe the target might continue to move. As a consequence, the perceived position of the target after the probe's consolidation is necessarily different from the perceived onset position.

There are also problems with the view that fast saccades are per se a more reliable measure of localization than slow saccades. The fixated location must not necessarily agree with the perceived locations. It is likely that fast saccades are more stimulus driven than slow saccades, but with moving stimuli this means that fast saccades are more detracted from the onset position towards the offset position. Therefore, only with slow saccades top-down mechanisms might be able to modulate saccadic amplitudes in accordance with perceived position.

With predictable starting positions — as is the case in the constant-context condition — observers already know the approximate onset position of the target in advance. In this case, visual top-down mechanisms might play the critical role. It is known that sensorimotor behavior easily adapts to situations with predictable starting positions and motion directions. For instance, when a stationary target is displaced systematically with every onset of a saccade, an adaptive change of the saccadic amplitude is observed after only a few trials (e.g. [3]). The interesting open question is whether this adaptation affects only the motor system or whether it also exerts an influence on the perceptual system as indicated by the present results. Certainly, this problem needs further experimentation.

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