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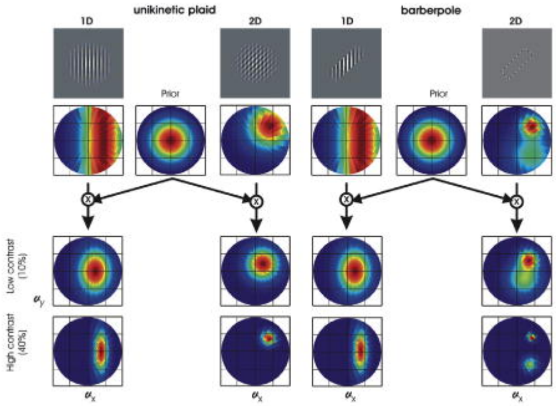
An International Journal for Functional Aspects of Vision



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ISSN 0042-6989 | Volume 48 | Number 4 | February 2008

Available online at www.sciencedirect.com
ScienceDirect
Vision Research 48 (2008) 611–617
Vision Research
www.elsevier.com/locate/visres

Localizing the onset of moving stimuli by pointing or relative judgment: Variations in the size of the Fröhlich effect

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Received 24 October 2007; received in revised form 11 November 2007

Abstract

In the Fröhlich effect, the perceived onset of a moving stimulus is displaced in the direction of motion. Previously, we observed that pointing movements produced a Fröhlich effect only when the onset position was highly predictable. Here, we show that relative judgments are not affected by spatial predictability if the relative judgment task is performed in isolation. However, when the two tasks vary randomly from trial to trial, effects of spatial predictability carry over to the perceptual task. Thus, observers' intentions before stimulus onset determine the way position signals are processed. An account in terms of sensory and motor maps is discussed.

Keywords: Space perception; Localization; Moving stimuli; Pointing task; Relative judgment task

1. Introduction

Localization errors of moving stimuli have been discussed since the first half of the last century. When observers were asked to indicate where a moving stimulus entered a window, they did not report the initial position to be at the edge of the window. Rather, they mislocalized the onset position of the moving target in the direction of motion, at a distance from the edge (the Fröhlich effect). Originally attributed to the time needed to generate the sensation of a stimulus ('Empfindungszeit'; Fröhlich, 1923, see also Kreegipuu & Allik, 2003), the illusion is nowadays explained by various—partly contradictory—accounts including attention, masking, or extrapolation (see e.g. Geer & Schmidt, 2006; Kerzel & Müsseler, 2002; Kirschfeld & Kammer, 1999; Müsseler & Aschersleben, 1998; Nijhawan, 2002; Whitney, Cavanagh, & Murakami, 2000).

All previous accounts of the Fröhlich illusion were concerned with explaining localization errors in the direction of motion. However, at the beginning of the present century, some authors also reported the reverse error. In the onset repulsion effect, the targets' onset is consistently mislocalized opposite to motion (Thornton, 2002; see also Actis-Grosso & Stucchi, 2003; Hubbard & Motes, 2002). So far, mislocalization opposite the direction of motion was reported in studies that did not produce mislocalization in the direction of motion, thereby failing to reconcile the two contradictory observations.

In an effort to explain the discrepancy between the two sets of studies, Müsseler and Kerzel (2004; see also Müsseler, Brinkmeier, & Stork, 2004) analyzed the stimulus conditions in which the Fröhlich and onset repulsion effects were observed. It turned out that the spatial predictability of the target onset position varied between studies. For example, in the study by Müsseler and Aschersleben (1998) the target appeared at a fairly 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

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doi:10.1016/j.visres.2007.11.024

positions were highly predictable. In contrast, the onset-repulsion effect was observed when target onset positions were completely unpredictable. For example, in the study of Thornton (2002, see also Hubbard & Motes, 2002) 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, Müsseler and Kerzel (2004) systematically varied the spatial predictability of target onset positions. In the condition where onset predictability was high (constant-context condition), targets appeared at a fairly constant eccentricity to the left and right of fixation and always moved outward. When onset predictability was low (random-context condition), the target's onset was random within a large square field centered on fixation and movement direction could either be inward or outward. In a fraction of the trials of the random-context condition (1/6 of the trials), the same onset positions as in the constant-context condition were presented. Only these identical trials entered the statistical analysis and were compared. A strong effect of trial context was observed. Onset mislocalization was in the direction of motion (i.e. the Fröhlich effect) 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, judgments were shifted opposite the true onset position or very close to it. Thus, localization of the adjusted onset position varied with trial context.

Although these findings successfully pinpoint the stimulus conditions leading to the Fröhlich and onset repulsion effects, the underlying mechanism was left unexplained. The difference between the constant-context and random-context condition may 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 results from some kind of perceptual adaptation. Or they may indicate that the cursor-pointing task, with which perceived position was judged in the experiments, was no reliable measure of perceived position. Possibly, pointing movements reflect perceived position in one condition, but not in the other. Previously, Kerzel (2002) noted that the onset repulsion effect was only observed with mouse-pointing, but not with relative judgments.

The explanation for the difference between perceptual judgments and pointing was that only the latter were influenced by an attempt to correct for possible errors. An obvious error when judging the onset position is to err in the direction of motion and point toward subsequent target positions instead of the first target position. Observers might have attempted to compensate for potentially "late" judgments by extrapolating back from the perceived onset. This strategy may have produced "overcompensation" because observers moved back beyond the true onset position toward positions that were never occupied by the target. Given that uncertainty was high in the random-context condition, observers may have increased their effort to avoid "late" judgments, which eliminated the Fröhlich illusion and produced onset repulsion. As onset predictability in the constant-context condition was high, observers might have been surer about their judgments, which decreased compensation and allowed for the Fröhlich effect to emerge.

In the present experiments, we asked whether the modulation of onset localization observed with pointing responses would also carry over to perceptual judgments. At first sight, the finding that pointing movements are influenced by trial context is odd if considered within the two-visual-streams hypothesis (e.g., Goodale & Milner, 2004). In some classic, albeit disputed studies, it was claimed that motor measures were less influenced by the visual context than perceptual judgments (Aglioti, DeSouza, & Goodale, 1995). However, in their review of ten years of experimentation on this issue, Smeets and Brenner (2006) arrive at the conclusion that effects of illusions depend on the specific spatial attributes needed to solve the task, rather than the distinction between perception and action.

In the current context, this conclusion may be taken to mean that predictability changes how a certain spatial attribute is processed within the same task. As laid out above, strategies of error-avoidance induced by uncertainty may modulate how weak position signals are used. The question we ask is whether the same modulation occurs with relative judgments. In our relative judgment task, only the near context was necessary to judge whether the onset position of the moving target or the simultaneously presented stationary probe was at the more outer position (i.e., further away from fixation). Arguably, probe and onset are perceived at the same time and the answer to the question can be read out from visual memory. In contrast, when reproducing the onset position of a moving object with a mouse cursor, participants have to consider the broader context. For instance, they may judge the distance between the onset and the fixation point or the edge of the screen, or they may even try to localize the target with respect to the own body. Compared to relative judgments, the mouse pointing seems to involve much more uncertainty because references are further away and therefore more difficult to use. Thus, it may well be that relative judgments are less affected by the spatial predictability of the target. The present set of experiments sets out to clarify this issue.

2. Experiment 1

The first experiment aimed at replicating the basic finding of Müsseler and Kerzel (2004) with slightly different proportions of constant and random trials. In the constant-context condition, the onset position of moving stimuli varied only slightly around two possible positions at about 6.6° to the left or to the right. In half of the trials of the random-context condition, the target appeared unpredictably in a large area of the screen centered on the fixation cross. The other half of the trials in the random-context condition resembled those of the constant-context condition. Only comparable trials with onset positions around 6.6° entered the data analysis. Because the proportion of "constant" relative to random trials (50% constant) in the random-context condition was higher than in the previous paper (17% constant) we thought it necessary to replicate the basic pattern of results.

2.1. Method

2.1.1. Apparatus and stimuli

The experiments were run on a Macintosh G3 computer with a 20" color CRT monitor (Philips C2082DAS/II, 75 Hz refresh rate, 1024 × 768 pixels). Participants sat in a dimly lit room with their head placed on a chin-and-cheek rest 500 mm in front of the monitor and the line of gaze straight ahead. Stimulus presentation was controlled by the Matlab Software Package using the Psychophysics Toolbox extension (Brainard, 1997; Pelli, 1997). The stimuli were presented on a light gray background of about 37 cd/m^2. A dark gray disc of 0.6° visual angle with a luminance of 19 cd/m^2 was used as moving stimulus. Stimuli moved at a velocity of 28.5°/s for 254 ms yielding a trajectory length of 7.2°.

Two context conditions were compared: In the constant-context condition, stimuli appeared always at 6.6 ± 0.5° to the left or to the right of the fixation cross and moved away from the fovea. In the random-context condition, the same applied for half of the trials; for the other half, the onset positions varied randomly within a square of 30.8 × 30.8° centered on the fixation cross. As in the constant-context condition motion was always foveofugal.

2.1.2. Design

The constant-context and random-context conditions were presented separately in consecutive blocks to each participant with the order of blocks counterbalanced between observers.

2.1.3. Procedure

The central fixation cross was visible throughout the experiment. Each trial started with an auditory warning signal. After a delay of 500 ms, the target stimulus appeared to the left or to the right of the fixation cross and moved horizontally outward towards the edge of the screen. The instruction stressed to hold fixation while the target was moving. One second after stimulus presentation a second auditory signal was presented and a mouse cursor appeared at the central position of the screen. The observers' task was to adjust the cursor to the position where they had first perceived the moving stimulus. The adjustment cursor was a replica of the target and was only visible during the adjustment phase. While moving the cursor to the perceived starting position, observers were allowed to move their eyes freely. Adjustment was finally confirmed by a mouse click, which initiated the next trial after a one second delay. All participants worked through 144 trials lasting about 30 min including the eye calibration procedure, a training block, and a short break.

2.1.4. Control of eye fixation

In the present and the subsequent experiments the horizontal position of the left eye was monitored with a head mounted and infrared light reflecting eye-tracking device (Skalar Medical B.V., IRIS Model 6500). If a saccade was detected during the presentation of the target stimulus, the data of the corresponding trial was excluded from analysis. In the present experiment the mean exclusion rate was 17% in the constant-context condition and 18% in the random-context condition.

2.1.5. Participants

Ten individuals between 21 and 34 years of age ($M = 26.3$ years) were paid to participate in the experiment. All participants in the present and the subsequent experiments reported normal or corrected-to-normal vision.

2.2. Results and discussion

Mean differences between the adjusted and the true onset position were calculated for each observer and condition. Positive values indicate mislocalizations in the direction of motion whereas negative values indicate mislocalizations opposite to the motion direction. Fig. 1 (left panel) shows that both conditions produced a mean localization error in the direction of motion (i.e., a Fröhlich illusion). However, compared to the constant-context condition, a large reduction of the Fröhlich effect was observed in the random-context condition. Mean deviations from the true onset position were 1.5° ($s_e = 0.4°$) visual angle

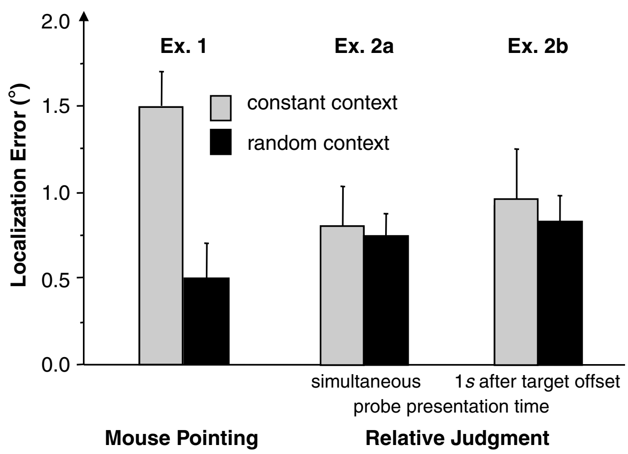

Fig. 1. Mean localization error and between-subject standard error of the first position of a moving stimulus. In Experiment 1 mouse pointing was used. In Experiments 2a and 2b relative judgments were used and individual localization errors were determined by the 50% threshold of subjective equality. The probe was presented simultaneously with the target's onset (Experiment 2a) or 1s after target's offset (Experiment 2b). Positive values indicate errors in the direction of motion.

in the constant-context and 0.5° ($s_e = 0.4°$) in the random-context condition. The conditions differed significantly, $t(9) = 3.34$, $p = .009$. The constant-context condition differed significantly from zero, $t(9) = 4.17$, $p < .001$, whereas the random-context condition did not, $t(9) = 1.04$, n.s. *T*-tests reported here were always two-tailed.

The present results successfully replicated the study by Müsseler and Kerzel (2004) and showed that the trial context is able to exert a strong influence on participants' localization judgments. When the initial position was highly predictable because the target always appeared close to two possible positions, observers localized the target's onset clearly too far in the direction of motion (Fröhlich illusion). This effect was strongly reduced when the target onset was spatially unpredictable, but it was not reversed as in the onset-repulsion effect (Thornton, 2002). A tendency towards an onset-repulsion effect was observed in three of four experiments in the previous study (Müsseler & Kerzel, 2004). The main difference between the present and the previous experiments was that in the random-context condition of the present experiment, stimuli appeared to the left or to the right of fixation in one half of the trials, while in the previous study they appeared at these positions in only one sixth of the trials. Thus, stimulus' onset in the random-context condition was much more predictable than in Müsseler and Kerzel (2004). This might be the reason why localization errors tended to be in the direction of motion in both conditions. However, the difference between predictable and unpredictable conditions remained remarkably stable.

3. Experiments 2a and 2b

In the previous experiment 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 measure perceived location in a rather indirect manner. It has been shown, for example, that the starting position of the mouse cursor (Müsseler, Van der Heijden, Mahmud, Deubel, & Ertsey, 1999, Experiment 4) affects localization judgments. As pointing movements were comparably slow, it might further be that localization errors originated from errors in memory rather than from errors in perception. Moreover, since percept involves a visual event depicting change in stimulus position away from its first location, the attempt to 'counteract' this change of positions by stepping back from the last perceived position in the opposite direction may have led to the localization error. Therefore, onset localization was evaluated with a relative judgment task in the present experiment. Two parallel experiments were conducted: In Experiment 2a the onset position of the moving stimulus was judged relative to the position of a simultaneously flashed probe. To investigate distortions in memory, the probe was presented 1 s after the target had disappeared from the screen in Experiment 2b.

3.1. Method

3.1.1. Stimuli, design, and procedure

These were the same as in Experiment 1 save the following changes. A stationary vertical line (0.1 × 0.8° of visual angle) was used as the probe, which appeared at one of six possible horizontally varying positions 0.8° above the onset position of the moving target. The horizontal position of the line differed by ±0.4°, ±1.1°, and ±1.9° from the onset position. Negative values indicate that the probe appeared before the target's trajectory, and positive values indicate that the probe appeared along the trajectory. The probe appeared simultaneously with onset of the moving target (Experiment 2a) or followed the targets' disappearance after 1 s (Experiment 2b) and remained visible for the rest of the trial.

Observers' task was to indicate whether the probe position or the onset position was the more outer position (i.e., further away from fixation). Judgments were made by pressing the upper (for the probe) or lower button (for the onset position of the moving target) of a horizontally arranged mouse.

3.1.2. Participants

Eight individuals, between 19 and 28 years of age ($M = 24.1$ years), were paid to participate in Experiment 2a. Eight individuals, between 21 and 33 years of age ($M = 25.8$ years), were paid to participate in Experiment 2b.

3.2. Results and discussion

For every participant and condition the frequency of trials were counted in which the target's onset was perceived further away from fixation than the probe. These frequencies were fed into the psignifit software (bootstrap-software.org, cf. Wichmann & Hill, 2001), which fitted Gaussian cumulative functions to the data and determined the 50%-threshold points of subjective equality (PSE) for every participant and condition. The mean PSE values, which estimate the localization error, are shown in Fig. 1 (right panels).

There was no significant difference between context conditions when the probe was presented simultaneously with target onset (Experiment 2a), $t(7) = 0.30$, n.s., or when the probe was presented 1 s after target offset (Experiment 2b), $t(7) = 0.94$, n.s. Significant Fröhlich effects were observed with a simultaneously presented probe, $t(7) = 3.60$ and $t(7) = 5.56$, both $p < .001$, and tendencies with a probe presented 1s after target offset, $t(7) = 2.20$ and $t(7) = 2.02$, both $p < .10$.

The results ruled out that memory distortions accounted for the localization errors observed in Experiment 1. Further, the relative judgment task in the present experiment did not yield any differences between random- and constant-context conditions that were repeatedly confirmed with the mouse-pointing task.

What can account for the divergent findings of Experiments 1 and 2? Two hypotheses come to mind. First, it may be that judgments in the probe task better reflected perception or perceptual memory, while the pointing task was contaminated by participant's response strategies (i.e., error avoidance). Second, it may be that the intention to localize the target's onset position by mouse-pointing changed the perception of the onset position. To test the two hypotheses, we cued participants about which task to perform after stimulus presentation. If the intention to perform the pointing task changes perception, we expect the difference between random and constant context to also emerge in the relative judgment task because upon stimulus presentation, it is unclear which task will have to be performed. If only the different task demands determine whether a difference between random and constant context emerges, we expect the difference to be present in the pointing task and absent in the relative judgment task.

4. Experiment 3

In the present experiment, the two tasks were randomly interleaved and observers were informed at the end of the trial which task they should perform.

4.1. Method

4.1.1. Stimuli, design, and procedure

These were the same as in the previous experiments save the following changes. After stimulus presentation, the task to be performed was cued in the following way: if a cursor was presented at fixation, observers had to adjust the perceived onset position of the moving target with the mouse. This task was performed with the right hand. If a question mark was presented at fixation, observers judged the relative position using the buttons of a second mouse operated with the left hand.

4.1.2. Participants

Fifteen fresh students, between 22 and 34 years of age ($M = 24.7$ years) were paid to participate in the experiment. The data of two participants were excluded from analysis because they obviously confused mouse buttons in the relative judgment task. One participant was excluded, because her/his mean values exceeded the criterion of two standard deviations (between-participants). The exclusion did not change the results essentially.

4.2. Results and discussion

The localization error of the cursor-pointing task (mean of individual adjustments) and of the relative judgment task (PSE determined by method of constant stimuli) were entered in a 2 (constant-context vs. random-context condition) × 2 (pointing task vs. relative judgment task) analysis of variance with repeated measurements. The analysis revealed a significant main effect of context condition, $F(1,11) = 17.07$, $MSe = 0.17$, $p = .002$. No other effects were observed ($p > .15$). In particular, the absence of a significant interaction between context condition and task, $F(1,11) = 0.22$, $MSe = 0.06$, n.s., shows that the effect of context was of similar size for pointing and relative judgments, which is in striking contrast to the results of Experiments 1 and 2. Remember that pointing in Experiment 1 showed a clear effect of context, while relative judgments in Experiments 2 were not influenced by context. Here, both judgment types are equally affected by the context.

Fig. 2 shows the mean localization errors. In the pointing task, the mean localization errors in motion direction were 1.07° ($s_e = 0.20$) in the constant-context condition and 0.55° ($s_e = 0.19$) in the random-context condition. Although not significant, localization errors were somewhat smaller with the relative judgment task. With relative judgments, the localization error was 0.82° ($s_e = 0.25$) in the constant-context condition and 0.37° ($s_e = 0.21$) in the random-context condition.

For the pointing task, t-tests against zero revealed significant Fröhlich illusions in the constant-context condition (1.07°), $t(11) = 5.35$, $p < .001$, and random-context condition (0.82°), $t(11) = 2.85$, $p = .016$. In the relative judgment task, a reliable error in movement direction was observed in the constant-context condition (0.82°), $t(11) = 3.23$, $p = .008$, and a tendency in the random-context condition (0.37°), $t(11) = 1.74$, $p = .11$.

In sum, when observers were informed only at the end of the trial which task they were to perform, a difference between context conditions was also found with relative judgments. When the spatial position of the target onset was predictable, observers localized the target's onset too far in the direction of motion (Fröhlich effect), while this mislocalization was considerably reduced with spatially unpredictable positions. The present results support the idea that the intention to point to the onset position changes the localization performance in the perceptual task.

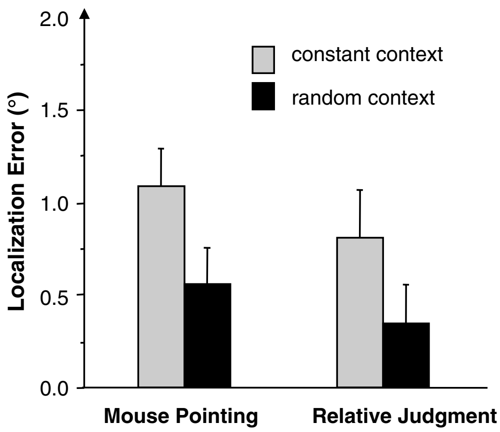

Fig. 2. Mean localization error and between-subject standard error in Experiment 3. Mouse pointing and relative judgments were used.

5. General discussion

We investigated the localization of the onset of a moving target with two different methods, pointing and relative judgment task. When performed in isolation, the two methods were differentially affected by predictability. Pointing errors in the direction of motion decrease in unpredictable trials, but no effect of predictability was confirmed for relative judgments. When performed together, the difference between the two methods disappeared and both showed an effect of predictability. This pattern of results rules out that processes occurring during the adjustment phase of the pointing task account for the findings. Rather, a specific intention that preceded stimulus presentation determined how the visual information was processed. Apparently, the error avoidance strategy induced by pointing leads to backward corrections in relative judgments as well. That is, the same position signals are interpreted or seen differently. With high uncertainty, observers again try not to miss the first part of the trajectory, which changes their relative judgments.

However, the localization error was only reduced in the random-context condition, but it was not reversed as in the onset-repulsion effect (Thornton, 2002). The main reason might be that in the present study stimulus' onset was not completely unpredictable. Predictability was only reduced as the stimulus appeared still to the left or to the right of fixation in one half of the trials. If the stimulus appeared at these positions in only one sixth of the trials—as in the study of Müsseler and Kerzel (2004)—a tendency towards an onset-repulsion effect was observed in three of four experiments. Anyway, the difference between predictable and unpredictable conditions remained remarkably stable and the present experiments demonstrated that the task demands determine what is seen.

Similar effects of task demands have been reported for the induced Roelofs effect. When observers are asked to judge the position of a small target in complete darkness, a large frame surrounding the target may induce an illusory displacement of the target. A frame offset to the right produces a displacement of the target toward the left and vice versa. It was hypothesized that the localization error was due to shifts of the subjective straight-ahead toward the frame. Illusory displacement of the target occurred for perception, but not for pointing movements (Bridgeman, Peery, & Anand, 1997). However, the effect of the frame in perception vanished when observers did not know whether they were to judge the position of the target or the position of the frame until after stimulus presentation (de Grave, Brenner, & Smeets, 2002). Thus, increased awareness of variations in the position of the frame eliminated the difference between perception and action. As in the present study, observers' intention or task set modulated the localization error.

Beyond the empirical demonstration of effects of task set on localization, we would like to frame our results within the idea of separate sensory and motor maps. This interpretation is compatible, but clearly distinct from Goodale and Milner's (2004) two-visual-streams hypothesis. With others we have already assumed that space perception originates from two maps: a visual sensory map and a non-visual motor map (Van der Heijden, Müsseler, & Bridgeman, 1999; Müsseler & Van der Heijden, 2004; for similar views, see also Koenderink, 1990; Wolff, 2004). Both maps are densely connected and together determine what is seen. The visual sensory map can be regarded as 'space filling'. It contains the neighborhood relations between objects, but not the metric necessary to perform goal-directed movements. This metric is provided by the non-visual motor map. This map has to be regarded as a position map for goal-directed movements, that is, a spatial map that codes all possible goal-directed positions on map positions. The spatial codes on this map do not exist per se, but they are build-up by sensorimotor experience. In other words, this map represents the stored sensorimotor relationships to perform goal-directed movements successfully.

The two-map conceptualization offers a general framework to account for various classical problems in the field of visual space perception, for instance, the inverted image problem, the size constancy problem, and the stable perceptual world problem (for details see Van der Heijden et al., 1999). With the two-map account of visual space perception it is also not difficult to understand why the relative judgment task revealed results different from the pointing task. The relative judgment task is assumed to mostly access the visual sensory map and the pointing task is assumed to mostly access the non-visual motor map. When observers are unsure about which task to perform, both maps are equally accessed by both tasks. In this case, the errors of the pointing task carry over to the perceptual task.

Acknowledgments

We wish to thank Ellen Brinkmeier and Silvia Bauer for carrying out the experiments. This research was supported by a grant from the Deutsche Forschungsgemeinschaft to the first author (DFG MU 1298/4).

References

Actis-Grosso, R., & Stucchi, N. (2003). Shifting the start: Backward mislocation of the initial position of a motion. *Journal of Experimental Psychology: Human Perception and Performance, 29*(3), 675–691.

Aglioti, S., DeSouza, J. F., & Goodale, M. A. (1995). Size-contrast illusions deceive the eye but not the hand. *Current Biology, 5*(6), 679–685.

Brainard, D. H. (1997). The psychophysics toolbox. *Spatial Vision, 10*, 433–436.

Bridgeman, B., Peery, S., & Anand, S. (1997). Interaction of cognitive and sensorimotor maps of visual space. *Perception and Psychophysics, 59*, 456–469.

de Grave, D. D., Brenner, E., & Smeets, J. B. (2002). Are the original Roelofs effect and the induced Roelofs effect caused by the same shift in straight ahead? *Vision Research, 42*(19), 2279–2285.

Fröhlich, F. W. (1923). Über die Messung der Empfindungszeit (Measuring the time of sensation). *Zeitschrift für Sinnesphysiologie, 54*, 58–78.

Geer, M., & Schmidt, W. C. (2006). Perception of initial moving target signals: Support for a cumulative lateral inhibition theory. *Journal of Experimental Psychology: Human Perception and Performance, 32*(5), 1185–1196.

Goodale, M. A., & Milner, A. D. (2004). *Sight unseen: An exploration of conscious and unconscious vision*. Oxford, UK: Oxford University Press.

Hubbard, T. L., & Motes, M. A. (2002). Does representational momentum reflect a distortion of the length or the endpoint of a trajectory? *Cognition, 82*(3), B89–B99.

Kerzel, D. (2002). Different localization of motion onset with pointing and relative judgements. *Experimental Brain Research, 145*(3), 340–350.

Kerzel, D., & Müsseler, J. (2002). Effects of stimulus material on the Fröhlich illusion. *Vision Research, 42*(2), 181–189.

Kirschfeld, K., & Kammer, T. (1999). The Fröhlich effect: A consequence of the interaction of visual focal attention and metacontrast. *Vision Research, 39*(22), 3702–3709.

Koenderink, J. J. (1990). The brain a geometry engine. Special Issue: Domains of mental functioning: Attempts at a synthesis. *Psychological Research, 52*, 122–127.

Kreegipuu, K., & Allik, J. (2003). Perceived onset time and position of a moving stimulus. *Vision Research, 43*(15), 1625–1635.

Müsseler, J., & Kerzel, D. (2004). The trial context determines adjusted localization of stimuli: Reconciling the Fröhlich and Onset Repulsion Effects. *Vision Research, 44*(19), 2201–2206.

Müsseler, J., & Aschersleben, G. (1998). Localizing the first position of a moving stimulus: The Fröhlich effect and an attention-shifting explanation. *Perception and Psychophysics, 60*(4), 683–695.

Müsseler, J., Brinkmeier, E., & Stork, S. (2004). The trial context and the perceived onset position of moving stimuli. In U. Ilg, H. Bülthoff, & H. Mallot (Eds.), *Dynamic perception* (pp. 119–124). Sankt Augustin: Infix.

Müsseler, J., Van der Heijden, A. H. C., Mahmud, S. H., Deubel, H., & Ertsey, S. (1999). Relative mislocalization of briefly presented stimuli in the retinal periphery. *Perception and Psychophysics, 61*, 1646–1661.

Müsseler, J., & Van der Heijden, A. H. C. (2004). Two spatial maps contributing to perceived space. Evidence from a relative mislocalization. *Visual Cognition, 11*(2-3), 235–254.

Nijhawan, R. (2002). Neural delays, visual motion and the flash-lag effect. *Trends in Cognitive Sciences, 6*(9), 387–393.

Pelli, D. G. (1997). The VideoToolbox software for visual psychophysics: Transforming numbers into movies. *Spatial Vision, 10*, 437–442.

Smeets, J. B. J., & Brenner, E. (2006). 10 years of illusions. *Journal of Experimental Psychology: Human Perception and Performance, 32*(6), 1501–1504.

Thornton, I. M. (2002). The onset repulsion effect. *Spatial Vision, 15*(2), 219–243.

Van der Heijden, A. H. C., Müsseler, J., & Bridgeman, B. (1999). On the perception of positions. In G. Aschersleben, T. Bachmann, & J. Müsseler (Eds.). *Cognitive contributions to the perception of spatial and temporal events advances in psychology* (Vol. 129, pp. 19–37). Amsterdam: Elsevier.

Whitney, D., Cavanagh, P., & Murakami, I. (2000). Temporal facilitation for moving stimuli is independent of changes in direction. *Vision Research, 40*, 3829–3839.

Wolff, P. (2004). Position of code and code for position: From isomorphism to a sensorimotor account of space perception. *Visual Cognition, 11*, 137–160.