VISUAL COGNITION, 2004, *11* (2/3), 235–254

Two spatial maps for perceived visual space: Evidence from relative mislocalizations

Jochen Müsseler

Max Planck Institute for Human Cognitive and Brain Sciences, Munich, Germany

A. H. C. Van der Heijden

Leiden University, The Netherlands

When observers are asked to localize the peripheral position of a target with respect to the midposition of a spatially extended comparison stimulus, they tend to mislocalize the target as being more outer than the midposition of the comparison stimulus (cf. Müsseler, Van der Heijden, Mahmud, Deubel, & Ertsey, 1999). For explaining this finding, we examined a model that postulates that in the calculation of perceived positions two sources are involved, a sensory map and a motor map. The sensory map provides vision and the motor map contains information for saccadic eye movements. The model predicts that errors in location judgements will be observed when the motor map has to provide the information for the judgements. In four experiments we examined, and found evidence for, this prediction. Localization errors were found in all conditions in which the motor map had to be used but not in conditions in which the sensory map could be used.

The contribution of the eye-movement system to perceived visual space is known from various perceptual phenomena. On the one hand, eye movements can induce spatial distortions. For instance, when a stimulus is flashed before, during or after a saccade, the visual space around the target appears to be compressed (e.g., Ross, Morrone, Goldberg, & Burr, 2001). On the other hand, eye movements can also reduce distortions. For instance, the Müller–Lyer illusion declines when observers explore the figure with saccadic eye movements (Festinger, White, & Allyn, 1968).

Please address correspondence to: Jochen Müsseler, Max-Planck-Institut für Kognitions- und Neurowissenschaften, Amalienstr. 33 D-80799 München, Germany. Email: muesseler@psy.mpg.de

A QuickTime demo of the basic effect described here is available from http://www.psy.mpg.de/~muesseler/FlashEffect/FlashEffect.html

This research was supported by a grant (AS 179/3) of the Deutsche Forschungsgemeinschaft. We wish to thank three anonymous reviewers for helpful comments to a previous draft of the paper and Birgitt Aßfalg and Silvia Bauer for carrying out the experiments.

http://www.tandf.co.uk/journals/pp/13506285.html DOI:10.1080/13506280344000338

There are, however, also spatial illusions or distortions of perceived visual space, which, at first sight, seem to be independent from eye movements. Nevertheless it cannot be excluded that at least some of them can be related to the metrics underlying the ocular system. The present paper is concerned with a task that might produce such an illusion. In this task a small probe and a spatially extended comparison stimulus is presented under fixation (cf. Figure 1). The observers' task is to judge the peripheral position of the probe with respect to the midposition of the comparison stimulus. When both stimuli are flashed successively, the observers perceive the probe as being more peripheral than the midposition of the comparison stimulus (Müsseler, Van der Heijden, Mahmud, Deubel, & Ertsey, 1999; Stork, Müsseler, & Van der Heijden, 2004).

To explain this relative mislocalization, Müsseler and colleagues (1999) assumed it emerged from different absolute localizations of probe and midlocation of comparison stimulus. From the literature it is known that the absolute location of a briefly presented target is often perceived more foveally than it actually is (see, e.g., Kerzel, 2002; Mateeff & Gourevich, 1983; Osaka, 1977; O'Regan, 1984; Van der Heijden, Van der Geest, De Leeuw, Krikke, & Müsseler, 1999b). For explaining the relative mislocalization the assumption to add was that a spatially extended stimulus is localized even more foveally than a spatially less-extended probe. Then the probe's relative position is perceived more peripheral than the midposition of the comparison stimulus. This explanation of the relative mislocalization was successfully tested against alternative accounts (for details see Müsseler et al., 1999). Moreover, pointing to the midposition of the spatially extended comparison stimulus and pointing to the small probe revealed more absolute foveal mislocalizations for the comparison stimulus than for the probe (Müsseler et al., 1999, Exp. 4).

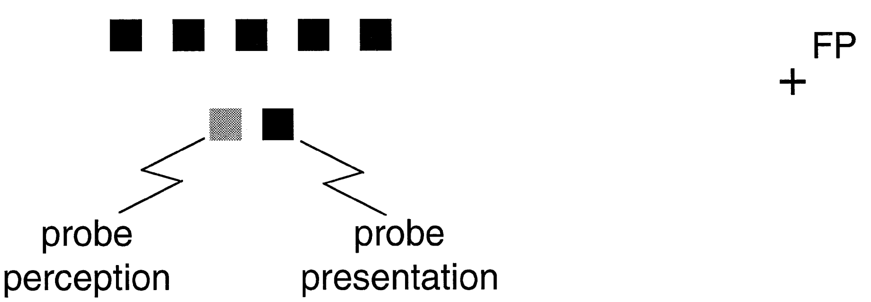

Figure 1. The spatial illusion under consideration. Observers fixate a cross in the middle of a screen. A stimulus configuration consisting of a single lower square (probe) and a spatially extended row of upper squares (comparison stimulus) are flashed successively (e.g., temporally separated by a stimulus onset asynchrony [SOA] of 100 ms) to the left or to the right of the fixation cross (here to the left). When participants' task is to judge the position of the probe relative to the midposition of the comparison stimulus, they perceive the probe as being more peripheral than the midposition of the comparison stimulus.

It is important to note that comparable foveal tendencies in absolute localizations are found in saccadic eye-movement studies. First, saccades tend to undershoot a peripheral target by about 5–10% of its eccentricity—an error that is normally compensated with a corrective saccade (see, e.g., Aitsebaomo & Bedell, 1992; Bischof & Kramer, 1968; Lemij & Collewijn, 1989). Second, the saccadic undershoot seems to increase with spatially extended stimuli (so-called centre-of-gravity effect; cf. Findlay, Brogan, & Wenban-Smith, 1993; see also Vos, Bocheva, Yakimoff, & Helsper, 1993). Moreover, the size of the saccadic undershoot is in the same range as the size of the foveal mislocalization observed in a perceptual judgement task (see Van der Heijden et al., 1999b). We recently examined and indeed observed these properties of saccadic behaviour with the probe and comparison stimulus depicted in Figure 1 (Stork et al., 2004). Thus, saccading and pointing to the (mid)position of briefly presented stimuli provides support for Müsseler et al.'s (1999) explanation of the relative mislocalization.

The close correspondence between the findings of saccadic eye-movement research and the assumptions used in Müsseler et al.'s explanation suggests an intriguing possibility: The possibility that the saccadic eye-movement system is at the basis of, provides the metric for, position judgements in position judgement tasks (see also, e.g., Van der Heijden, Müsseler, & Bridgeman., 1999a; Wolff, 1987, for this suggestion). There is, however, a serious problem with this explanation. The relative mislocalizations in Müsseler et al.'s (1999) task emerge only when the comparison stimulus and the probe are flashed successively separated by an SOA of at least 50 ms (with increasing SOAs the mislocalizations reach an asymptote at SOAs of about 200 ms). With simultaneous presentation of comparison stimulus and probe a reliable mislocalization does not occur at all (cf. Müsseler et al., 1999). So, the question emerges: Why are relative mislocalizations observed when probe and comparison are separated in time and not when presented simultaneously?

The beginning of an answer can be derived from two-factor theories of space perception as, for instance, proposed by Van der Heijden and colleagues (Van der Heijden, 2003, chap. 7; Van der Heijden et al., 1999a; for similar views, see also Koenderink, 1990; Scheerer, 1985; Wolff, 1987, 2004). The theory 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 (see Van der Heijden et al., 1999a).

With others, Van der Heijden and colleagues assume that space perception originates from two different sources. One source is a visual sensory map, the other a nonvisual motor map. The visual sensory map can be regarded as ''space filling''. It provides the ''substance'' of which the spatial structure consists (cf. Scheerer, 1985; Wolff, 1987). It contains only the neighbourhood relations, not the metric necessary to perform goal-directed eye movements. The metric in this ''space filling substance'' is provided by the nonvisual motor map. This map has to be regarded as an eye-position map, that is, a map that codes all possible (eye) positions on (map) positions. All possible eye positions are coded in terms of the movements that are required for bringing the spatially corresponding points in the visual sensory map in the middle of the fovea. In Van der Heijden et al.'s conceptualization both maps are densely connected and together determine what is seen. This can be taken to mean that the perceived positions result from the visual sensory map ''enriched'' by the motor map about the spatial positions in the visual field in terms of realized and required eye positions. Or, what is perceived results from the motor map ''enriched'' by the sensory visual map with identity information and local neighbourhood relations.

With this two-factor conceptualization of visual space perception it is not difficult to understand why relative mislocalizations are observed when probe and comparison are separated in time and not when presented simultaneously. With simultaneous presentation of probe and comparison the perceptual judgement is assumed to access the visual sensory map. This map provides adequate information about the neighbourhood relations. So, no relative mislocalizations are to be expected. With successive presentation, however, a direct visual assessment of the spatial relations in the sensory map is impossible and the motor map is assessed to provide the required position information. This map contains the metric necessary to perform goal-directed eye movements. Judgements based on information in this map will reflect the properties and peculiarities of the eye-movement system. Among these properties and peculiarities are the tendency to undershoot a target and the tendency towards a larger undershoot for a spatially extended target than for a less extended one. So, with successive presentation of comparison and probe these two tendencies will show up in the relative judgement data.

In terms of this two-factor conceptualization it becomes also clear why the relative mislocalization in Müsseler's task is observed under conditions without overt eye movements. The motor map is a complete two-dimensional map containing all possible eye-movement tendencies to all objects in a visual scene (cf. Wolff, 1987).[1] Once established by perceptual learning (cf. also O'Regan & Noë, 2001; Wolff, 1987), the map is continuously available as an enduring map, which is independent of whether eye movements are planned, initiated or executed.[2]

[1] If disparity, convergence and vergence are included, the motor map could be even a three-dimensional map. For simplicity, the present considerations are restricted to the two-dimensional map.

[2] In the literature, multiple stimulation (e.g., at opposite sides of fixation) is often introduced to examine the role of the eye-movement system with regard to a certain phenomenon. It is argued that the contribution of the eye-movement system can be negated if the phenomenon remains unaffected by multiple stimulation – after all, a saccade can be only directed to one object at a point in time. Contrary, the present account assumes that the motor map of the eye-movement system is involved in any perceived location independent of whether an eye movement is planned, initiated or executed. Thus, even multiple stimulation does not rule out the involvement of a motor map.

In sum, Müsseler et al.'s (1999) explanation of the relative position illusion is completely in line with the more general two-factor view on visual space perception. Nevertheless, the two-factor explanation can certainly use some further supporting evidence. One possibility to test the considerations and explanation further is to search for another variant of the illusion. In the conceptualization just presented the illusion is based on the general principle of hampered/eliminated access to the visual sensory map and facilitated/obligatory access to the nonvisual motor map. In the paradigm used so far to produce the illusion, this is accomplished by the SOA; an SOA > 50 ms eliminates the possibility to directly access the neighbourhood relations between the stimuli in the sensory map and consequently enforces the use of the motor map.

Another possibility is to eliminate the neighbourhood relations *per se*. This elimination of neighbourhood relations can be accomplished by presenting the probe at one side of the fixation cross and the comparison stimulus at the other side (bilateral presentation mode). The observers' task then is to judge whether the probe is further or nearer to the fixation cross than the midposition of the comparison stimulus. If our assumption is correct that in this situation—because of the elimination of the direct neighbourhood relations—the motor map is accessed, the probe has to be perceived more outer even when probe and comparison stimulus are presented simultaneously, that is the illusion has also to show up with SOA = 0 ms.

To further test the assumption, the subsequent experiments introduce a bilateral presentation mode and compare the results with those obtained in the unilateral presentation mode used in the previous studies. The stimulus configurations used in the experiments are shown in Figure 2. In Experiment 1 the unilateral configuration (1) is compared with the bilateral configuration (2). The hypothesis is that in the bilateral presentation mode a mislocalization occurs also with simultaneous presentation of probe and comparison stimulus. Experiments 2 and 3 are basic control experiments. In Experiment 2 the configuration (3) is introduced in order to compare the expected mislocalization in configuration (2) with a new baseline condition (two single squares at each side of the fixation point). Experiment 3 examined the position judgements of the inner, middle, and outer square of the comparison stimulus (configuration 4) together with configuration (3). This experiment controls for possible strategies with judgements based on the inner or outer edge of the comparison stimulus instead of the middle position. Finally, in Experiment 4 configurations (2) and (3) are presented again, but at two different eccentricities. Previous experiments with the unilateral presentation mode (1) have shown that the mislocalization increased with the eccentricity of stimulus presentation (Müsseler et al., 1999; Stork et al., 2004). If the expected effects of the bilateral presentation mode correspond with the ones of the unilateral presentation mode, an influence of eccentricity is also expected in the bilateral presentation mode.

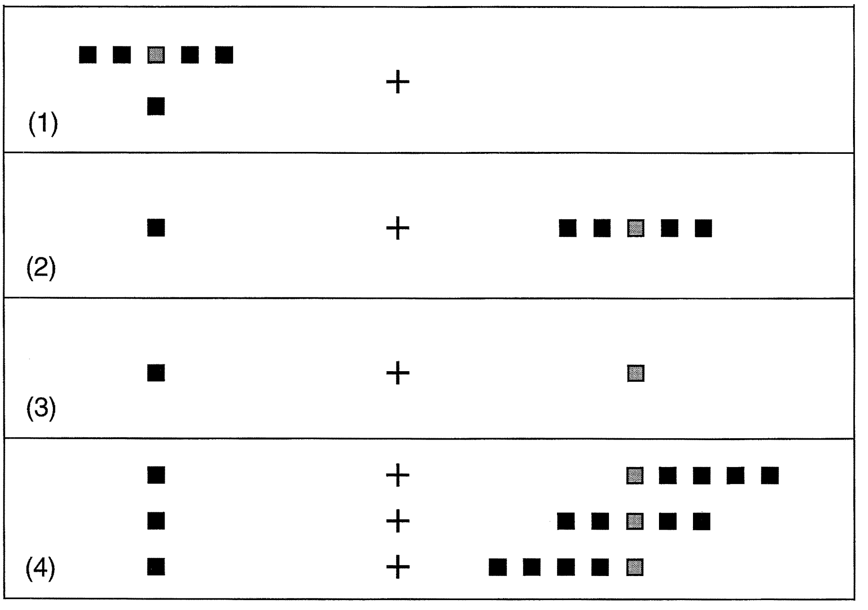

Figure 2. Basic stimulus configurations in the experiments. Light grey squares (not marked in stimulus presentation) indicate the critical square in the comparison stimulus. In Experiment 1 the unilateral configuration (1) was compared with the bilateral configuration (2). In Experiment 2 the two bilateral configurations (2) and (3) were compared. Experiment 3 examined the inner, middle, and outer square of the comparison stimulus (configuration 4) together with configuration (3). Finally, in Experiment 4 configurations (2) and (3) were presented again, but at two different eccentricities.

EXPERIMENT 1

This experiment introduces a relative position judgement task with a bilateral presentation mode in which the probe is presented at one side of the fixation cross and the comparison stimulus at the other side. The observers' task is to judge whether the probe is more outer or inner with regard to the midposition of the comparison stimulus. As elaborated in the Introduction, our assumption is that in this situation the motor map is accessed and that therefore the probe is perceived more outer even with simultaneous presentation of the stimuli.

Besides the bilateral presentation mode the experiment also involves the unilateral presentation mode used in earlier work. This allows us to compare the relative mislocalizations in the two presentation modes. In both presentation modes the SOA between stimuli is also varied.

Method

Apparatus and stimuli. The experiments were carried out on a laboratory computer with a 14-inch screen (Rhothron rho-prof 200, refresh rate 71 Hz). The stimuli (dark squares on a light background) measured $0.33 \times 0.33°$ and were presented for one vertical retrace (14 ms). The display was positioned at a viewing distance of 500 mm. Its luminance was approximately 39 cd/m^2. The subject sat at a table with a chin and forehead rest.

In the unilateral presentation mode the stimulus display consisted of a horizontal row of five upper squares (comparison stimulus), each separated by 0.33°, and a single lower square (probe, cf. Figure 3). The positions of the five upper squares were held constant, with the central square at 5°. The position of the probe had a vertical distance of 1.4° to the comparison stimulus and was horizontally varied with respect to the midposition of the comparison stimulus by ±0.2, 0.7, and 1.2°; thus the probe was presented at 3.8, 4.3, 4.8, 5.2, 5.7, and 6.2°. The stimulus display appeared unpredictably towards the right or the left of the fixation cross.

In the bilateral presentation mode, the probe is unpredictably presented at one side of the fixation cross and the comparison stimulus at the other side. The

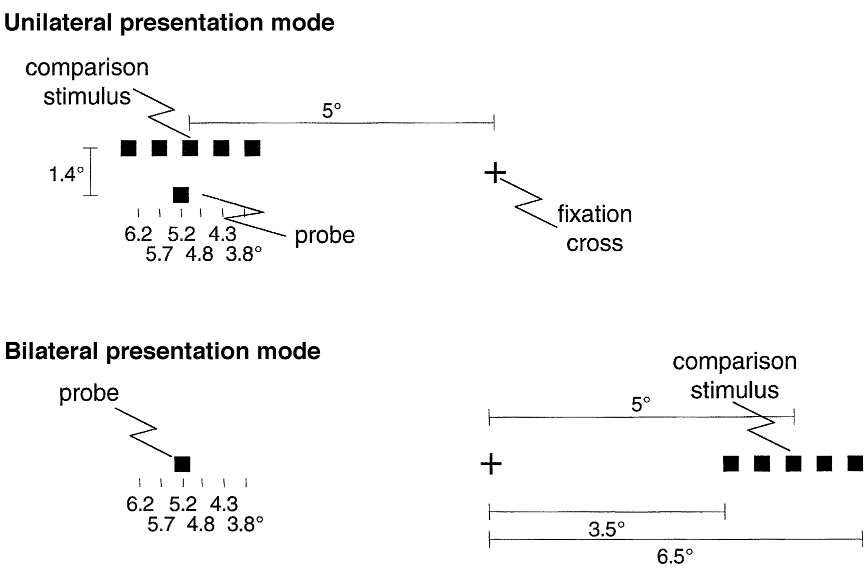

Figure 3. Stimulus presentation in the experiments. In the unilateral presentation mode, comparison stimulus and probe appeared both either in the left or the right visual field. In the bilateral presentation mode, the comparison stimulus is presented at one side of the fixation cross and the probe at the other side.

stimulus positions were the same as in the unilateral presentation mode, that is, the midposition of the comparison was at 5° and the probe was either presented at 3.8, 4.3, 4.8, 5.2, 5.7, or 6.2°.

Design. The bilateral and unilateral presentation mode were presented blockwise with the sequence of blocks counterbalanced between participants. Probe and comparison stimuli either appeared simultaneously, or the probe preceded or followed the comparison stimulus by an SOA of ±112 ms. The probe was presented at one of the six positions (3.8 to 6.2°) around the 5° midposition of the comparison stimulus. The complete set of SOA × probe position combinations was presented to all participants in a randomized sequence.

Procedure. Viewing was binocular in a dimly lit room. Participants initiated the stimulus presentations by simultaneously pressing two mouse keys. Each trial began with a beep and a centred fixation cross that remained visible until the response was given. The instruction stressed concentration on the fixation point. 300 ms after the presentation of the fixation cross, probe and comparison stimulus were either presented simultaneously or with an SOA of ±112 ms. Participants were asked to identify the more outer stimulus. In the bilateral presentation mode they answered by pressing a corresponding left or right key of a vertically arranged mouse. In the unilateral presentation mode they answered by pressing a corresponding upper or lower key of a horizontally arranged mouse. Following a response the next trial was triggered after 1 s. A training period of 36 trials and the experimental session of 576 trials lasted about 50 min.

Participants. Nine individuals, aged 23–38 years, were paid to participate in the experiment. All participants reported to have normal or corrected-to-normal vision.

Results

Probabilities of outer judgements at the six probe positions were entered in Probit analyses (Finney, 1971; Lieberman, 1983), which determined the 50% threshold points of subjective equality (PSE) for every participant and condition. Figure 4 shows the mean deviations of the PSE values with regard to the midposition of the comparison stimulus at 5°. Negative deviations indicate PSE values lower than the objective midposition and thus a tendency to more outer judgements of the probe.

With the unilateral presentation mode the mean PSE value did not deviate from the objective midpositions for the 0 ms SOA (with a mean standard error between participants of $s_e = 0.05$), but deviated from that position with –0.38°

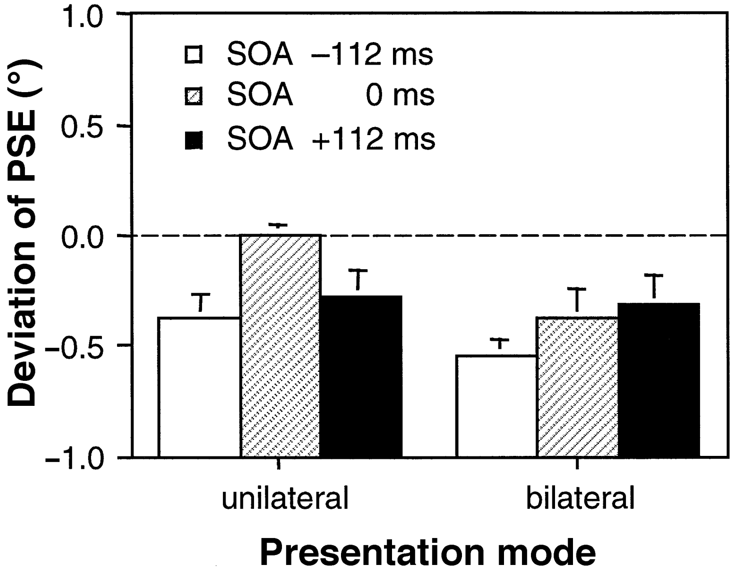

Figure 4. Mean deviations of the points of subjective equalities (PSE) from the objective position (here at 5°). Negative deviations indicate PSE values lower than the objective position and thus a tendency to more outer judgements of the probe. Bars represent the unilateral (left) and bilateral (right) presentation mode for the different stimulus onset asynchronies (SOA). Error bars indicate standard errors between participants (Experiment 1).

for the –112 ms SOA (s_e = 0.11), and –0.28° for the +112 ms SOA (s_e = 0.12). With the bilateral presentation mode the mean PSE value deviated from the objective midpositions by –0.39° for the 0 ms SOA (s_e = 0.13), with –0.55° for the –112 ms SOA (s_e = 0.08), and –0.32° for the +112 ms SOA (s_e = 0.13).

The PSE values were entered as dependent variables in a 2 (presentation mode: unilateral vs. bilateral) × 3 (SOAs of –112, 0, and +112 ms) analysis of variance (Anova). This analysis revealed an effect of presentation mode with $F(1, 8) = 5.67$, $MSE = 0.10$, $p = .044$ and of SOA with $F(2, 16) = 7.83$, $MSE = 0.04$, $p = .008$.[3] Additionally, the interaction was significant with $F(2, 16) = 3.70$, $MSE = 0.04$, $p = .049$.

Discussion

The results of the unilateral presentation mode successfully replicate previous experiments. With simultaneous presentation of probe and comparison stimulus, localization judgements are perfect but a reliable error occurs when both stimuli

[3] The *F* probabilities in the present study are corrected according to Greenhouse and Geisser.

are flashed successively. With successive presentation the probe is perceived more outer than the midposition of the comparison stimulus.

In the bilateral presentation mode the probe is perceived more outer than the midposition of the comparison stimulus with all SOAs. So, contrary to the results obtained in the unilateral presentation mode, the relative localization error is also observed with simultaneous presentation of probe and comparison stimulus. As elaborated in the Introduction, this outcome is to be expected on the basis of the two-factor theory of space perception. The interpretation of this finding is then that with bilateral presentation a direct visual assessment is hampered with all SOAs because of the lack of usable neighbourhood relations in a visual sensory map. Therefore, the perceived locations are determined by information in a motor map, in which the spatially extended comparison stimulus is placed more foveally than the less extended probe.

There are, however, at least two possible objections against this interpretation. The first objection is that the bilateral presentation mode lacks a suitable baseline condition. The experiment included no bilateral presentation condition that allows us to really evaluate the mislocalization of probe and comparison stimulus. This first objection is addressed in Experiment 2.

The second objection is that in the bilateral presentation mode a mislocalization could have occurred because observers tend to compare the inner position of the comparison stimulus, instead of the midposition, with the probe. Of course, then the comparison stimulus will be judged more inner and thus the probe more outer. This second objection is addressed in Experiment 3.

EXPERIMENT 2

In Experiment 1 the results obtained in the bilateral presentation mode are compared with the results obtained in the unilateral presentation mode. However, the baseline condition of the unilateral presentation mode (i.e., the simultaneous presentation of probe and comparison stimulus) is not an adequate baseline condition for the bilateral presentation mode. The present experiment introduces such a baseline condition. Because in the present context only those mislocalizations, which result from the different spatial extensions of the stimuli, are of interest, a bilateral condition with one single square at each side of the fixation cross is a suitable baseline condition. Therefore this experiment compares the two bilateral configurations (2) and (3) shown in Figure 2.

Method

Stimuli, design, and procedure. These were the same as in the previous experiment with the following exception. The conditions of the unilateral presentation mode of Experiment 1 were replaced by conditions, in which a single square appeared at each side of the fixation cross (configuration 3 in

Figure 3). Conditions were again presented blockwise with the sequence of blocks counterbalanced between participants.

Participants. Eleven observers, aged 21–43 years, were paid for participation.

Results and discussion

The findings of the bilateral presentation mode with a spatially extended comparison stimulus successfully replicated the results obtained in Experiment 1. Reliable mislocalizations occurred with all SOAs: –0.41° (s_e = 0.14) with the –112 ms SOA; –0.35° (s_e = 0.10) with 0 ms SOA; and –0.24° (s_e = 0.08) with +112 ms SOA. In the baseline condition with one single square at each side of the fixation cross, the mean PSE values showed only minor deviations from the objective midposition: –0.08° (s_e = 0.06) with the –112 ms SOA, 0.02° (s_e = 0.03) with the 0 ms SOA, and 0.19° (s_e = 0.05) with +112 ms SOA. Correspondingly, a two-way Anova revealed a significant difference between presentation modes with $F(1, 10) = 17.17$, $MSE = 0.14$, $p = .002$ (cf. Figure 5).

Additionally, the Anova showed a significant effect of SOA with $F(2, 20) = 5.16$, MSE = 0.05, $p = .036$. Inspection of Figure 5 readily shows that in the

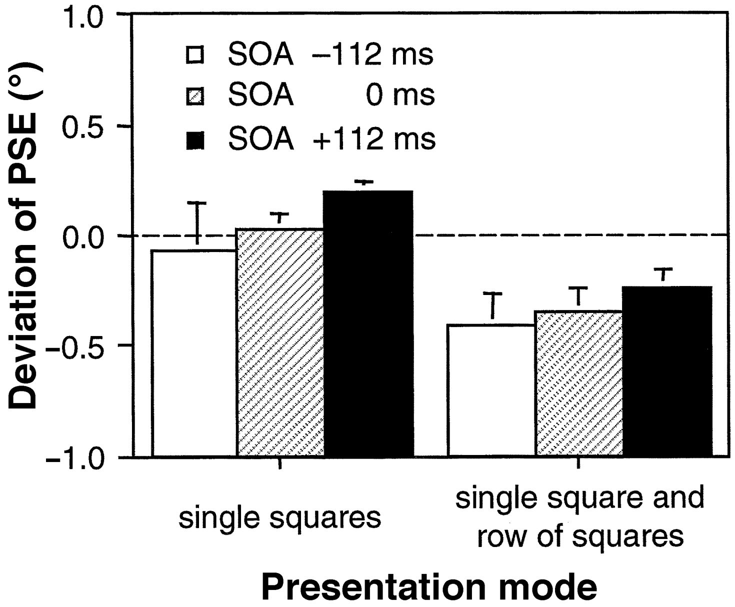

Figure 5. Mean PSE values of the baseline condition (left—single squares are presented at each side of the fixation cross) and the bilateral presentation mode (right—the probe is presented with the spatially extended comparison stimulus) (Experiment 2).

experimental condition and in the baseline condition the number of outer judgements gradually decreases with increasing SOA, –112, 0, +112 ms. (Note, that the same tendency is also present in the data of Experiment 1; cf. Figure 4.) This effect of SOA reflects a general tendency towards more outer judgements for the stimulus presented first—a tendency independent of the spatial extend of the first and second stimulus.

Two remarks with regard to this significant SOA effect are here in order. Firstly, at present no adequate explanation for this effect is available. We are presently running experiments that further investigate this effect. Secondly, when the results obtained in the experimental condition are ‘‘corrected’’ for this SOA effect, it appears that the tendency to perceive the probe as more outer than the comparison is largely independent of SOA. In other words, when this SOA effect is taken into account, the data in the right part of Figure 5 truly reflect the effect of probe extend and comparison extend on the relative judgements.

EXPERIMENT 3

With unilateral presentation appreciable relative mislocalizations are only observed with successive presentation of probe and comparison (i.e., when the two stimuli are separated by an SOA), not with simultaneous presentation (see Experiment 1; see also Müsseler et al., 1999). With bilateral presentation mislocalizations are also observed with simultaneous presentation of probe and comparison. With successive presentation, as well as an effect due to the different spatial extends of probe and comparison, an SOA effect also shows up; there is a tendency towards more outer judgements for the stimulus presented first (see Experiment 2; see also Müsseler et al., 1999, especially their Exp. 5). This pattern of results indicates that the simultaneous condition in the bilateral presentation mode is the adequate condition for investigating the extend effect. In this condition the effect of spatial extend and/or other spatial properties of probe and comparison is not confounded with the effect of SOA. Consequently in the subsequent experiments only this bilateral simultaneous exposure condition is used.

The present experiment investigates a main objection that can be raised against, what we just called, ‘‘the adequate condition’’ in Experiments 1 and 2. That objection is that in this simultaneous condition in the bilateral presentation mode observers could have tended to judge the location of the comparison stimulus by its foveally most nearby position, that is, by its inner edge. As Figure 2 shows, the inner edge of the comparison stimulus is much closer to the fixation point than the inner edge of the probe. If the observers employ one or another variant of such an ‘‘inner-strategy’’, the comparison stimulus will be judged more inner and, consequently, the probe more outer. And this is what the data showed.

One way to control for and to investigate such strategies is to make—by means of the instruction—different components of the comparison stimulus task relevant. Consequently, the inner edge, the midposition and the outer edge were made task relevant in the present experiment (cf. Figure 2, configuration 4). If in Experiment 1 and 2 observers based their judgement on the inner position of the comparison stimulus only (instead of on its midposition), the foveal displacement of the probe is expected to disappear with a task relevant inner edge. Moreover, if subjects base their judgements invariantly on the inner edge of the comparison stimulus and ignore the task instruction, a substantial significant effect of condition, inner, middle, outer, is to be expected (see the configurations in Figure 2, panel 4). Of course, these predictions are formulated to control for an inner-strategy account. They do not reflect our expectations.

Method

Stimuli, design, and procedure. These were the same as in the previous experiments except for the following changes. The inner, middle or outer positions of the comparison stimulus were presented at 8° eccentricity (cf. Figure 2, configuration 4). Further, the baseline condition of Experiment 2 with one single square at each side of the fixation cross was added to the procedure (configuration 3). In three different blocks the observers were instructed to identify the more outer stimulus by basing their judgement on either the inner, the middle or the outer position of the spatially extended comparison stimulus—or, in the baseline condition, to simply indicate the more outer stimulus. The sequence of blocks were randomized between participants. For the reasons set out above only simultaneous presentation of stimuli was used in the present experiment.

Participants. Eleven observers, aged 21–36 years, were paid for participation.

Results and discussion

In the baseline condition the mean deviation of PSE values was again rather small (0.01°, $s_e = 0.04$; cf. Figure 6). In contrast, when the inner position of the comparison stimulus was judged together with the probe, a reliable mislocalization occurred (–0.28°, $s_e = 0.13$). A *t*-test showed that the difference between these two conditions is significant with $t(10) = 2.34$, $p = .021$, one-tailed. This outcome provides no evidence whatsoever for the objection that in the simultaneous condition of the bilateral presentation mode of Experiments 1 and 2 the observers judged the location of the comparison stimulus by its foveally most nearby position. Reliable mislocalizations were also obtained in the conditions where the middle position (–0.50°, $s_e = 0.20$) and the outer position (–0.55°, $s_e = 0.23$) of the comparison stimulus were task relevant.

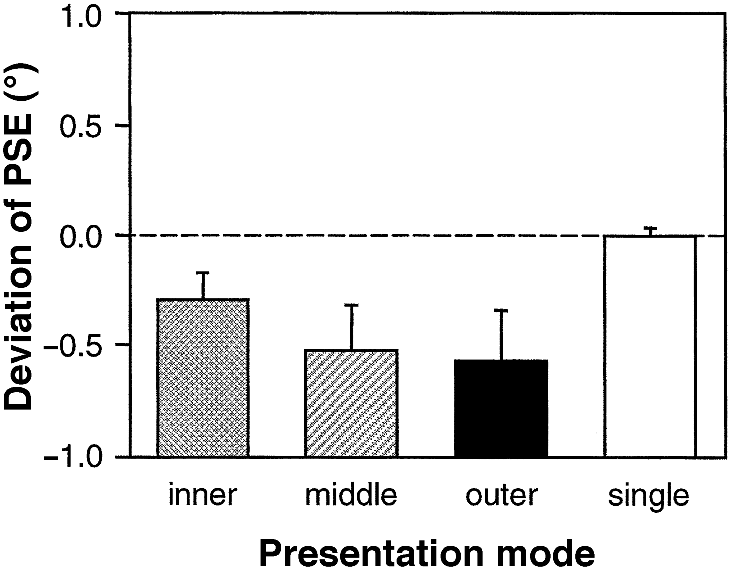

Figure 6. Mean PSE values of the baseline condition (single squares) and the presentation mode with a critical inner, middle, or outer edge of the comparison stimulus (Experiment 3).

A one-way Anova showed a significance between all the four conditions with $F(3, 30) = 4.66$, $MSE = 0.15$, $p = .023$. When the baseline condition was removed from the analysis, however, the differences between conditions disappeared with $F(2, 20) = 1.76$, $MSE = 0.13$, $p > .20$. Indeed, additional comparisons among means with a Scheffè Test failed to show differences between the inner, middle and outer condition (all $p > .10$). So, while there is possibly a trend, ''the substantial significant effect of condition, inner, middle, outer'', to be expected on the basis of the ''inner edge'' strategy, clearly fails to show up.

In sum, the condition with a task-relevant inner square of the comparison stimulus provides no evidence for the objection that in the simultaneous bilateral presentation mode the observers used the inner position of the comparison stimulus (instead of the midposition) for their relative judgements. Moreover, the results revealed no evidence for differences between the inner, middle, and outer condition. Thus, the present data suggest that a spatially extended stimulus is shifted by about the same amount towards the fovea, irrespectively of whether the inner, middle, or outer position is to be judged.

EXPERIMENT 4

The simultaneous condition in the bilateral presentation mode was assumed to be the most adequate condition for investigating extend effects in relative judgement tasks. This conclusion is, of course, only correct when the simultaneous condition in the bilateral presentation mode and the +112 and –112 SOA conditions in the unilateral presentation mode address the same underlying phenomenon, i.e., investigate the same underlying spatial illusion.

So far, we found no evidence that the findings obtained with the simultaneous condition of the bilateral presentation mode (cf. Figure 2, configuration 2) deviated from the findings observed with positive and negative SOA conditions of the unilateral presentation mode (configuration 1). In other words, the successive unilateral conditions and the simultaneous bilateral condition can still be regarded as two different approaches to one and the same underlying spatial illusion. In the present experiment we will further examine this point. If for assessing the spatial illusion the bilateral presentation mode is simply an alternative for the unilateral presentation mode, its results should vary with the same variables as the unilateral presentation mode. With the unilateral presentation mode the illusion increases with the eccentricity of presentation (cf. Müsseler et al., 1999; Stork et al., 2004). The present experiment examines this effect with the bilateral presentation mode.

Method

Stimuli, design, and procedure. These were the same as in the previous experiments with the following exceptions. The baseline condition (configuration 3) is compared with the bilateral presentation mode of the illusion (configuration 2) at the eccentricities of 3.5 and 6.5°. Probe and comparison stimulus were always presented simultaneously. All conditions were presented blockwise with the sequence of blocks randomized between participants.

Participants. Sixteen observers, aged 21–37 years, were paid for participation.

Results and discussion

In the baseline condition PSE judgements deviated only little from the objective positions (0.01° at 3.5°, $s_e = 0.02$; 0.03° at 6.5°, $s_e = 0.02$). In contrast, with the spatially extended comparison stimulus reliable mislocalizations were observed. They increased from –0.24° at 3.5° eccentricity ($s_e = 0.08$) to –0.48° ($s_e = 0.09$) at 6.5° eccentricity (cf. Figure 7).

Correspondingly, a two-way Anova showed a significant the main effect of eccentricity, $F(1, 15) = 6.03$, $MSE = 0.03$, $p = .027$, and of presentation mode, $F(1, 15) = 28.67$, $MSE = 0.08$, $p < .001$. Additionally, the interaction between both factors was significant with $F(1, 15) = 5.24$, $MSE = 0.05$, $p = .037$. Therefore, we can conclude that the eccentricity effect observed previously with the +112 and –112 SOA conditions in unilateral presentation mode emerges also with the simultaneous condition in the bilateral presentation mode. This is further evidence for the point of view that the simultaneous-unilateral

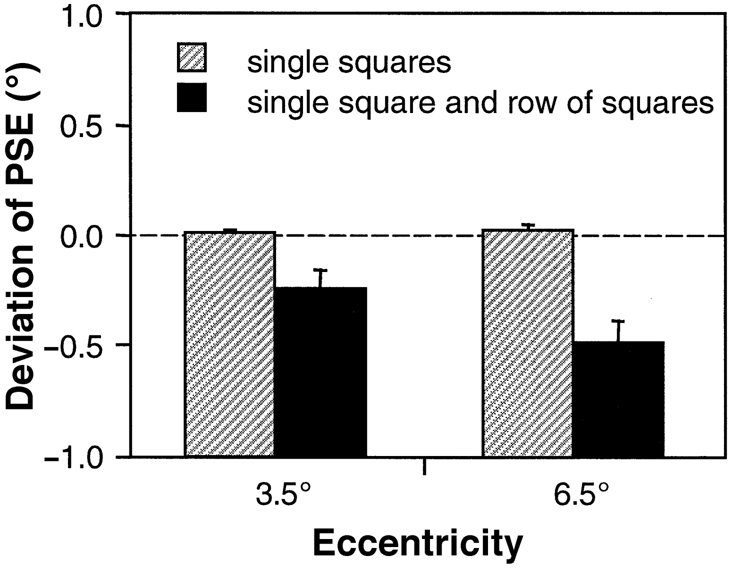

Figure 7. Mean PSE values of the baseline condition (single squares) and the bilateral presentation mode (single square and row of squares) at the two different eccentricities of 3.5 and 6.5° (Experiment 4).

and successive-bilateral presentation conditions constitute two comparable approaches to one and the same underlying spatial illusion.

GENERAL DISCUSSION

The present study was concerned with an illusion first reported by Müsseler et al. (1999). That illusion consists of a relative mislocalization observed with unilateral presentation of two short-duration stimuli of different spatial extensions. Asked to judge the peripheral position of a small probe with respect to the midposition of a spatially extended comparison stimulus, observers tended to localize the probe as being more outer than the midposition of the comparison stimulus. This mislocalization is observed when both stimuli are flashed successively separated by an SOA, but not when the stimuli are presented simultaneously. Müsseler et al. explained the mislocalizations in terms of properties of the saccadic eye-movement system.

The explanation in terms of properties of the saccadic eye-movement system, however, failed to answer the question why mislocalizations are observed when probe and comparison are separated in time by an SOA and not when presented simultaneously. The two-factor theory of visual space perception can answer this question. With simultaneous presentation the perceptual judgement is assumed to be based on information in a visual sensory map, which images perfectly the neighbourhood relations of the stimuli. With successive presentation, however, access to the visual sensory map is hampered and the perceptual judgements are assumed to be based on information in a motor map, which contains the metric necessary to perform goal-directed eye movements. Basic saccadic eye-movement research strongly suggests that (1) in this map the probe and the comparison stimulus are localized more towards the fovea than they really are, and (2) the spatially extended comparison stimulus is even localized more foveally than the spatially less-extended probe (for details and further empirical evidence see Müsseler et al., 1999; Stork et al., 2004; Van der Heijden et al., 1999a). These properties of the motor map directly explain the mislocalizations obtained with successive presentations.

If the explanation derived from the two-factor model of visual space perception is correct, a bilateral presentation mode with the probe at one side of the fixation point and the comparison at the other should reveal an interesting and important variant of the illusion. With bilateral presentation there are no usable neighbourhood relations between probe and comparison in a sensory map. Because of the absence of the neighbourhood relations, the motor map is accessed. So, from the two-factor model it follows that with bilateral presentation mislocalizations will not only be observed with successive presentations but also with simultaneous presentation.

The present experiments examined this prediction. In Experiment 1, the bilateral presentation mode was compared with the unilateral presentation mode. The experiment revealed (1) corresponding mislocalizations in the unilateral and bilateral presentation mode, and (2) the predicted mislocalizations in the bilateral presentation mode when probe and comparison stimulus were presented simultaneously. In Experiment 2 this finding was replicated with an appropriate new baseline condition (two single squares at each side of the fixation point). Experiment 3 ruled out strategy effects, that is, ruled out the possibility that observers based their judgements on the inner or outer edge of the comparison stimulus instead of on the midposition. Finally, Experiment 4 examined whether the eccentricity effect, observed previously with the unilateral presentation mode (Müsseler et al., 1999; Stork et al., 2004), could reliably be demonstrated with the bilateral presentation mode. The mislocalizations observed seemed to correspond with the pattern of mislocalizations previously reported.

Taken all together, the results reported in this contribution clearly support the predictions derived from the two-factor theory of visual space perception and thereby support Müsseler et al.'s (1999) contention that the system controlling the saccadic eye movements is at the basis of, and imports its properties in, the relative judgement task. This conclusion, however, immediately raises a critical question.

As stated in the Introduction, basic eye-movement research has shown that (1) saccades tend to undershoot a peripheral target, and (2) this effect is stronger for a spatially extended target than for a less extended one. The critical question is, of course, why saccadic eye movements show this undershoot and why the system does not adapt to this error—as it does with other externally forced distortions (cf. the prism adaptation).

At present no agreed upon answer to this question can be given. In the literature some suggestions can be found. One speculation is that the undershoot is an inherent property of any motor system, probably because it is easier to adjust a movement in its direction than in the opposite direction. This is certainly true for head and arm movements with their large mass components, but the eye is light and quite flexible embedded in its orbit.

Another answer is that with an undershoot the retinal image of the target remains in the same cortical hemifield. When the system attempts to be exactly on target, some saccades will overshoot the target. With an overshoot a target representation that was in the left(right) hemifield will move to the right(left) hemifield. Undershoots prevent these drastic relocalizations (see, e.g., Becker, 1972; Henson, 1978).

It has also been argued that the undershoot emerges from the interaction with head movements under more ecological conditions. If the eyes are moved together with the head to a target, eye movements have to be smaller as they would be when only the eyes are moved to the target. In this sense, the undershoot compensates for possible head movements. The head–eye combination can be seen as an adaptive attempt to minimize the saccadic flight time for maximizing the time for clear vision (Harris, 1995).

A final, but probably not last possibility comes from considering even more ecological conditions. Usually, targets do not enter the visual field instantaneously; in particular the ecologically more dangerous targets *move into* it. Maybe the saccadic undershoot is a mechanism to anticipate this movement. This idea matches the observation that the system is more sensitive for foveopetal than for fovefugal movements (Mateeff, Yakimoff, Hohnsbein, Ehrenstein, Bohdanecky, & Radil, 1991; Müsseler & Aschersleben, 1998).

At present, it is impossible to decide which answer or combination of answers approaches the truth. Fortunately, for our explanation of the mislocalization results that answer is not really required. Our explanation is not concerned with why there is an undershoot. There is an undershoot and that is all that is required for our explanation.

REFERENCES

Aitsebaomo, A. P., & Bedell, H. E. (1992). Psychophysical and saccadic information about direction for briefly presented visual targets. *Vision Research*, *32*, 1729–1737.

Becker, W. (1972). The control of eye movements in the saccadic system. In J. Dichganz & E. Bizzi (Eds.), *Cerebral control of eye movements and motion perception* (pp. 233–243). Basel, Switzerland: Karger.

Bischoff, N., & Kramer, E. (1968). Untersuchungen und Überlegungen zur Richtungswahrnehmung bei willkürlichen sakkadischen Augenbewegungen. *Psychologische Forschung*, *32*, 185–218.

Festinger, L., White, C. W., & Allyn, M. R. (1968). Eye movements and decrement in the Müller–Lyer illusion. *Perception and Psychophysics*, *3*, 376–382.

Findlay, J. M., Brogan, D., & Wenban-Smith, M. G. (1993). The spatial signal for saccadic eye movements emphasizes visual boundaries. *Perception and Psychophysics*, *53*, 633–641.

Finney, D. J. (1971). *Probit analysis*. Cambridge, UK: Cambridge University Press.

Harris, C. M. (1995). Does saccadic undershoot minimize saccadic flight-time—a Monte-Carlo study. *Vision Research*, *35*(5), 691–701.

Henson, D. B. (1978). Corrective saccades: Effects of altering visual feedback. *Vision Research*, *18*(1), 63–67.

Kerzel, D. (2002). Memory for the position of stationary objects: Disentangling foveal bias and memory averaging. *Vision Research*, *42*(2), 159–167.

Koenderink, J. J. (1990). The brain a geometry engine. *Psychological Research*, *52*, 122–127.

Lemij, H. G., & Collewijn, H. (1989). Differences in accuracy of human saccades between stationary and jumping targets. *Vision Research*, *29*, 1737–1748.

Lieberman, H. R. (1983). Computation of psychological thresholds using the probit technique. *Behavior Research Methods and Instrumentation*, *15*, 446–448.

Mateeff, S., & Gourevich, A. (1983). Peripheral vision and perceived visual direction. *Biological Cybernetics*, *10*, 111–118.

Mateeff, S., Yakimoff, N., Hohnsbein, J., Ehrenstein, W. H., Bohdanecky, Z., & Radil, T. (1991). Selective directional sensitivity in visual motion perception. *Vision Research*, *31*, 131–138.

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

Osaka, N. (1977). Effect of refraction on perceived locus of a target in the peripheral visual field. *Journal of Psychology*, *95*, 59–62.

O'Regan, J. K. (1984). Retinal versus extraretinal influences in flash localization during saccadic eye movements in the presence of a visible background. *Perception and Psychophysics*, *36*, 1–14.

O'Regan, J. K., & Noë, A. (2001). A sensorimotor account of vision and visual consciousness. *Behavioral and Brain Sciences*, *24*(5), 939–1011.

Ross, J., Morrone, M. C., Goldberg, M. E., & Burr, D. C. (2001). Changes in visual perception at the time of saccades. *Trends in Neurosciences*, *24*(2), 113–121.

Scheerer, E. (1985). *The constitution of space perception: A phenomenological perspective.* Paper presented at the Sensorimotor Interactions in Space Perception and Action, Center of Interdisciplinary Research, Bielefeld, Germany.

Stork, S., Müsseler, J., & Van der Heijden, A. H. C. (2004). Saccadic eye movements and relative mislocalizations with briefly presented stimuli. *Manuscript submitted for publication*.

Van der Heijden, A. H. C. (2003). *Attention in vision: Perception, communication and action*. Hove, UK: Psychology Press.

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

Van der Heijden, A. H. C., Van der Geest, J. N., De Leeuw, F., Krikke, K., & Müsseler, J. (1999b). Sources of position–perception error for small isolated targets. *Psychological Research*, *62*, 20–35.

Vos, P. G., Bocheva, N., Yakimoff, N., & Helsper, E. (1993). Perceived location of two-dimensional patterns. *Vision Research*, *33*, 2157–2169.

Wolff, P. (1987). Perceptual learning by saccades: A cognitive approach. In H. Heuer & A. F. Sanders (Eds.), *Perspectives on perception and action* (pp. 249–271). Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Wolff, P. (2004). Position of code and code for position: From isomorphism to a sensorimotor account of space perception. *Visual Cognition*, *11*(2/3), 137–160.