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Cueing attention by relative motion in the periphery of the visual field

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Abbreviations: 4 ANFC = four-alternative non forced-choice; RMC = relative-motion cue; SOA = stimulus onset asynchrony

Abstract. Sudden changes of visual stimulation attract attention. The observer's body motion generates retinal flow field patterns containing information about his own speed and trajectory and relative motion of other objects. We investigated the effectiveness of relative motion as an attentional cue and compared it with conventional cueing by appearance of a frame in the far periphery of the visual field.

In a group of ten subjects, contrast thresholds for the perception of static Gabor grating orientation (4 ANFC task) were determined at 20°, 30°, 40°, and 60° eccentricity. Subsequently, near-threshold discrimination performance of Gabor pattern orientation without vs. with a ring-shaped cue was measured at the same positions. The same Gabor patterns were then presented embedded in a random-dot flow field, and uncued discrimination performance was compared with performance after presentation of a relative-motion cue (RMC), i.e. a small random-dot field with motion in the opposite direction of the flow field.

Both, the conventional ring cue and the RMC induced significantly increased discrimination performance at all test locations. With the parameters chosen for this study, the RMC was slightly less effective than the conventional cue, but its effects were somewhat more pronounced in the far periphery of the visual field.

Thus, relative motion is a powerful cue to attract attention to peripheral visual objects and improves performance as effectively as a conventional ring cue. The findings have practical relevance for everyday life, in particular for tasks like driving and navigation.

Introduction

A. General background

Under everyday life viewing conditions, our perceptual world is constantly moving. This is in part due to the motion of objects around us, but mainly it is created by the movements our own body, head, and eyes (Gibson 1966; Warren and Hannon 1990). The patterns of motion perceived by the observer contain important information, including the trajectory of external objects and the motion path of the observer himself (Nakayama and Loomis 1974).

Since the brain cannot analyze all objects in a complex environment, it needs to select the most relevant ones to guide action. Attention is considered the crucial mechanism of selection, especially in perceptual processes (James 1890; Gazzaniga 2000). The relevant criteria for attracting attention and for selection obviously depend on the context. However, one general mechanism has been demonstrated by Yantis and Jonides (1984): sudden onset of a stimulus is prone to capture the observer's attention and direct it to the location of the change.

When the observer is moving – which is true for most situations in real life – he generates a flow field through his own motion, thereby creating a context which increases the predictability of trajectories of other objects in that context. Hence, a stimulus should not be conspicuous as long as its motion is concurrent with the motion of the other context elements. On the other hand, the motion of an object disturbs the self-generated perceptual context if the characteristics of its motion (e.g. the direction or speed) deviate from those of the other elements in the flow field. Such divergence from the expected motion pattern of the self-generated flow field should be interpreted as object motion, independent of the observer's trajectory (Regan 1986; Snowden 1992). From a Gestaltist's point of view, the elements of the observer's context follow the Gestalt law of shared common fate as the observer moves through his environment. Any element of the context that does not follow the general motion trajectory cannot be integrated into a common Gestalt (Royden et al 2001; Yuille and Grzywacz 1988). Since this information is important for safe navigation (e.g. to predict and to avoid a collision), any such event should be powerful in attracting attention.

For example, while driving a car, the observer moves through a flow field generated by the motion of the vehicle. This produces a regular pattern of all static elements, such as trees, traffic signs, or parked cars, moving radially through the visual field from the observer's heading point into the periphery. If one of these stationary objects (e.g. a parked car) suddenly starts to move, it disturbs the flow field pattern by deviating from the predictable radial motion. The driver should be alerted to this change so that a collision can be avoided. Note that the cue in this situation is quite different from the "sudden onset" connected with object appearance as described by (Yantis and Jonides 1984): In the example of the driving observer, the object had been continuously present and perceptible as moving within the contextual flow field, but only the onset of its motion relative to the driver's self-generated flow field created an unpredictable event within that context. While the situation described above undoubtedly captures the driver's attention, we were interested in finding out whether, and how effectively, relative motion alone can attract attention compared with conventional techniques of manipulating spatial attention in the laboratory.

B. Motion perception

Motion is an important and intensely investigated aspect of visual perception. Motion perception has been studied psychophysically (e.g. Johnston and Wright 1985, 1986; McKee and Nakayama 1984; Van de Grind et al 1987; Van de Grind et al 1993), electrophysiologically (e.g. Demb et al 2001; Joly and Bender 1997; Treue and Maunsell 1999), and more recently also using neuro-imaging methods (e.g. Greenlee 2000). The existence of pathways specifically subserving motion processing, is well established, starting from the M-pathway in the retina and LGN and continuing though primary visual areas (Hubel and Wiesel 1965, 1968; Silvanto et al 2005) and area MT/ V5 (Greenlee 2000; Koch et al 1989; Sincich et al 2004).

The periphery of the visual field plays a significant role in motion detection and processing (Foster et al 1989; McKee and Nakayama 1984; Van de Grind et al 1987; Wang et al 1997): the larger receptive fields and the better temporal summation in the periphery (Melcher et al 2004) seem to make these areas particularly sensitive to the detection of motion. However, some authors reported that motion sensitivity is reduced in the periphery: The just noticeable difference in velocity of two stimuli increases with eccentricity (Metha et al 1994; Orban et al 1985). Notably, the same motion stimulus appears to be slower in the periphery of the visual field than in the center (Johnston and Wright 1986). However, the increased motion thresholds can be compensated for by M-scaling the stimuli (Johnston and Wright 1985), i.e. by scaling their size with an estimate of the cortical magnification factor. Thus it seems that motion thresholds are constant across the visual field at the representational level in area V1, and that motion information is processed relative to the spatial resolution of the visual system at any given position. The underlying mechanisms of motion processing could be the same as those for processing flow fields which are of interest here.

While numerous aspects of motion perception have been studied, comparatively little experimental work has been done on the perception and effects of relative motion within a context of moving elements. Regan (1986) describes four different types of relative motion: (1) velocity differences of stimuli with the same linear direction of motion (positive or negative), (2) shearing motion (i.e. motion perpendicular to the original direction of motion), (3) rotational motion (all of which can be perceived monocularly), and (4) the ratio between velocities on the left and right eye's retina, i.e. motion in depth. According to Regan, the analysis of relative motion is necessary to recover three-dimensional information from a two-dimensional retinal image and allows an analysis of the flow fields that is invariant with eye movements.

For the computation of the trajectory of other objects relative to the observer's trajectory, shearing motion provides the most relevant aspects of information. The percentage of moving elements sharing the same direction of motion (e.g. in random dot patterns) influences the general percept of motion in that pattern (Treue and Maunsell 1999; Warren et al 1988). Moreover, a systematic arrangement of motion patterns within a context of motion can create the impression of two-dimensional or three-dimensional forms (e.g. Mestre et al 2001). While our visual system is highly sensitive to motion (produced by simple spatial displacement), the sensitivity to shearing motion between adjacent objects is about twice as high as that for simple displacement motion (Snowden 1992). Thus, relative motion dominates over the perception of absolute displacement, especially in the perception of small details. The same conclusion can be drawn from the findings of McKee and Nakayama (1984) who examined motion detection and velocity discrimination in the peripheral visual field. They found that the minimum angle at which one can detect relative motion (shear) between adjacent visual stimuli is lower than the minimal angle of resolution at all retinal loci tested (i.e. up to 40° eccentricity).

C. Cueing and spatial attention

Attention has been conceptualized as the main mechanism of selection even in the early days of psychology (James 1890), and its role in perceptual processes has been intensely investigated since then (for reviews see Gazzaniga 2000; Van der Heijden 1992; Reynolds and Chelazzi 2004). In studies of visuo-spatial attention (Eriksen and Rohrbaugh 1970; Eriksen and Yeh 1985; Posner 1980; Nakayama and MacKeben 1989), the beneficial effects of focusing attention on a specific region of the visual field have been demonstrated with a variety of techniques and dependent variables. In the classical studies, two methods of attentional cueing have been used to direct the attention focus to a specific area (Averbach and Coriell 1961; Posner 1980; Posner 1995). Symbolic, or endogenous, cueing of attention involves the interpretation of a sign, like an arrow pointing towards a visual hemifield or a color code inducing a subject to voluntarily shift the focus of attention to the indicated location. Alternatively, spatial attention can be attracted to the target site by a direct, or exogenous, cue that is located at or around the target position, like a small dot presented right above the target or a frame enclosing the target area (Eriksen and Rohrbaugh 1970; Posner 1980; Posner 1995; Nakayama and Mackeben 1989). A voluntary shift of attention in response to a symbolic cue is a slow and sustained reaction, while a direct cue commonly induces an involuntary quick and transient shift of the attentional focus (Nakayama and MacKeben 1989). Benefits of cueing include, for example, reduced reaction times (Eriksen and Rohrbaugh 1970; Posner et al 1978), improved detection of a target (Tassinari et al 1987; Posner 1995; Poggel et al 2004) and improved discrimination of similar targets (Corbetta et al 1990; MacKeben 1999; Carrasco and McElree 2001). This higher performance level is achieved without changing the observer's response criterion, as was demonstrated in experiments based on Signal Detection Theory (Green and Swets 1966; Macmillan and Creelman 1991; Wickens 2002), indicating that attention increases perceptual sensitivity within the attention focus (Bashinski and Bacharach 1980; Downing 1988; Heinze and Mangun 1995). The amount of benefits (or costs) induced by attentional cueing depends on the time interval between the presentation of the cue and the target (stimulus onset asynchrony, SOA, see Eriksen and Collins 1969; Nakayama and MacKeben 1989).

Psychophysical measurements can give an indication of the effectiveness of a cue: by comparing performance in unattended with that in attended conditions, the amount of the benefit induced by the cue can be determined (Nakayama and MacKeben 1989; Posner 1980, 1995). The effectiveness of a cue depends on its distance from the target position (Kristjansson and Nakayama 2002; Nothdurft 2002), the stimulus onset asynchrony (SOA) between cue and target onset (Eriksen and Collins 1969), the validity of the cue, and many other factors (Posner 1995;

Parasuraman 1998). Cueing is particularly effective when perceptual conditions are difficult, i.e. near the detection threshold (Dosher and Lu 2000; Poggel 2002; Poggel et al 2004).

As mentioned above, the onset of a stimulus generally captures the observer's attention (Yantis and Jonides 1984). Franconeri and Simons (2003) found that motion can also capture attention, but it has been argued that the attentional effect might again be caused by the *onset* of motion rather than motion per se (Abrams and Christ 2003). In a similar way, the sudden onset of *relative* motion within a flow field might act as a direct cue and should thus be able to improve perceptual performance. Since the M-pathway is predominant at early stages of motion processing, sudden-onset cues and the attraction of attention by motion could activate the same mechanism. In a behavioral context, transient attention has been assigned a role as a precursor to eye scanning movements (Fischer 1987), which is also supported by psychophysical data (MacKeben and Nakayama 1993).

The lateral intraparietal area (LIP) in the primate brain presumably acts as a cortical salience map and responds well to sudden-onset (flashing) stimuli as well as to abrupt motion onsets and potentially relevant saccade targets (Kusunoki et al 2000). In humans, area LIP is a candidate for mediating the shifting of spatial attention (Yantis et al 2002, Poggel et al., 2005).

The potential of relative motion to attract attention, particularly in the periphery of the visual field, is relevant for everyday life, especially for driving motor vehicles. Inability to detect relative motion and to shift attention to peripheral objects which move on a potential collision trajectory relative to the observer's own motion path should increase the number of accidents.

In this study we investigated the effectiveness of relative motion in a flow field as an exogenous cue for improving visual performance under near-threshold conditions at various visual field positions up to 60° eccentricity. We also compared the effectiveness of a relative-motion cue (RMC) with the benefits induced by a direct cue, i.e. a ring-shaped frame around the target.

Methods

Subjects

Ten naïve subjects (7 female) with normal or corrected-to-normal vision were recruited for the study. The median age was 22 years (range 19 to 28 years). All volunteers gave their informed consent to participate and were paid for taking part in the experiment. The study had been approved by the local ethics committee and was in agreement with the tenets of the Declaration of Helsinki.

Experimental setup

Testing was performed in the driving simulator (Reiner Foerst, Gummersbach, Germany) at the Generation Research Program (GRP). The subject was seated at 220 cm distance from a fixation mark located straight ahead on a large projection screen in a darkened room (illuminance = 8.8 lx). Stimulus background luminance was kept at a constant mean grey value (24.7 cd/m^2) throughout all test blocks. The left eye was covered by an eye patch so that all stimuli were presented monocularly in the right eye's temporal hemifield. This setup was chosen because, due to traffic regulations in most countries, attraction of attention to the right is more important than to the left. Stimuli were generated by custom software on a standard personal computer and projected onto two adjacent projection screens. Each half of the image on the computer screen was projected onto one of the projection screens using two conventional light projectors driven by a Matrox graphics card. The total display subtended ± 22.7° vertically and ± 65.7° horizontally; the fixation mark was placed at 15.7° to the left of the screen, so that the projection area extended from 15.7° to 81.4° on the right. Stimuli were presented at 20°, 30°, 40°, and 60° eccentricity on the horizontal meridian in all trials. The subject's verbal responses were entered by the experimenter using the computer keyboard. Tests were self-paced, i.e. a trial started only after the subject's response had been entered, and another key had been pressed. Total test time was approximately 60 minutes. Subjects were free to take a break at any time, and they could also take longer breaks between the blocks of trials to minimize fatigue.

Test programs

The full experiment consisted of a threshold test and four blocks of trials designed to test visual performance under unattended and attended conditions using direct cueing by a ring cue and relative-motion cueing (RMC), respectively.

a) Threshold test

We first determined contrast thresholds for the orientation discrimination of Gabor gratings at all four test positions in order to avoid ceiling effects. Based on these threshold values, the degree of difficulty of the discrimination tasks in the subsequent test blocks was adjusted to a level comparable between all test locations and also between individuals.

The test stimuli were Gabor patterns in cosine phase with a spatial frequency of 4 cpd (Figure 1). Their size was M-scaled according to an estimate of the cortical magnification factor (Horton and Hoyt 1991). The E_2 value used in the scaling was 1°, i.e. sizes followed the function $S = (1 + E / E_2)\ S_0$, with foveal size $S_0 = 0.3°$. At 20° eccentricity, the diameter of the Gabor pattern (sigma of the Gaussian envelope) was approximately 7.0°. In each trial, one Gabor patch was presented for 200 ms at one of the four test positions (20°, 30°, 40°, or 60° eccentricity), and target locations varied randomly across trials. The orientation of the grating could be either horizontal, vertical, 45° tilted to the right, or 45° tilted to the left. The subject's task was to indicate its perceived orientation. In case of doubt, a neutral answer ("I don't know") was allowed ("non-forced choice" task, see below; Kaernbach 2001). The testing procedure consisted of interleaved adaptive measurements of the contrast thresholds at the four stimulus locations by four independent staircase procedures. The adaptive algorithm used for this test was originally proposed by Kesten (1958; see Treutwein 1995 for a review). Starting contrast was 60%, which is well above threshold. After a correct response, stimulus contrast was reduced by 0.8 step widths and after an incorrect or neutral response it was increased by 1.5 step widths or 1.2 step widths, respectively. Step width was reduced after every other reversal n by a factor of $n / (n + 2)$; i.e. step widths followed the series 1, 1/2, 1/4, 1/6 etc., after 0, 2, 4, 6 etc. reversals, respectively. Testing was terminated at each location after ten reversals. The mean of the last 6 reversals was taken as threshold.

Based on the threshold contrast at each test position, contrast levels for all Gabor targets and distracters of the subsequent test blocks were fixed at a value just above the threshold. If subjects could not perceive any of the targets or were able to see all of them in a short practice series before the start of the experiment proper, the contrast value was increased or decreased at that specific position until performance was just above chance level and subjectively difficult. These contrast values were then entered into the software and used for stimulus presentation throughout the remainder of the experiment. Contrast was defined according to the Michelson measure, i.e. $C = (L_1 - L_2) / (L_1 + L_2)$, with L_1, L_2 denoting the maximum and minimum luminance in the Gabor pattern, respectively.

b) Uncued orientation discrimination with distracters

In the first part of the experiment, baseline performance of orientation discrimination under uncued conditions was determined. Data from this test condition served as a comparison (unattended condition or equally distributed attentional resources) for the subsequent block that introduced a direct cue (see Section c) for deploying attention at one of the four locations in the visual field. Note that the selection of the target location in the sequence of trials was independent of the task, i.e. there was no information on the direction of the Gabor pattern present in the spatial cue. Test conditions were essentially the same as for the threshold test described above, except that in this block distracters were always presented at the three non-target positions. The target was a Gabor patch that appeared at one of the four possible locations in random sequence, with indicating grating orientation (horizontal, vertical, right, left) as the task. The contrast of the grating was kept constant at the near-threshold value described above. The distracters consisted of plaids constructed by superimposing two Gabor gratings with 45° tilt to the right and left, respectively. Their contrast was set to the same value as the near-threshold contrast value of the target Gabor patches, so that the subject could not discriminate the target from the distracters based on differences in stimulus contrast. Targets and distracters were presented for 200 ms, followed by a mask of 100 ms duration which was identical with the distracter plaid stimulus. At each location, ten targets were presented within a test block, i.e. one block consisted of 40 trials. The number and percentage of correct responses was determined for each position.

c) Orientation discrimination with ring cue

The second test block used a classical direct-cueing paradigm and was otherwise identical to the first block. The cue consisted of a gray, ring-shaped frame surrounding the position of the circular target Gabor patch that was subsequently presented at that location (Figure 1a). The size of the cue frame was M-scaled as were the stimulus patches (cue line thickness: 0.26°, line luminance: 19 cd/m^2). The cue was presented for 100 ms, the stimulus onset asynchrony (SOA) was 200 ms. Cue validity was 100%, i.e. the cue reliably predicted the target position so that the subject could deploy attention to the cued location in the visual field. After the presentation of the cue, the target appeared at the cued location, and the distracters appeared simultaneously at the three uncued test positions (Figure 1a). All stimuli were followed by a mask as described above. As in the previous blocks, the subject's task was to indicate the perceived orientation of the target Gabor grating. The number/ percentage of correct responses was determined for each test position.

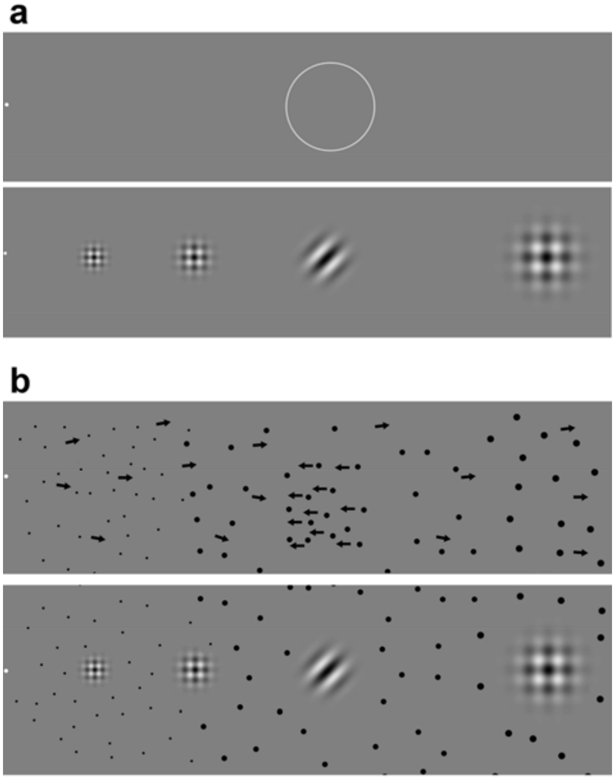

Figure 1. Stimulus arrangement. a) Schematic representation of stimuli displayed during the trials with conventional cueing: In cued trials, a ring (upper panel) appeared before the presentation of the target (at the cued location) and the distracters (at the remaining locations; lower panel). Note that for the purpose of illustration stimulus contrast was increased and stimulus sizes/ locations are approximate only. b) Schematic representation of stimuli displayed during the trials with relative-motion cueing (RMC): In cued trials, a group of dots that moved in opposite direction to the flow field (RMC, upper panel) was presented before the target and the distracters were shown (lower panel). Arrows indicate the direction of motion of the flow field elements.

d) Uncued orientation discrimination in a flow field

The third experiment block was again similar to the first (uncued orientation discrimination with distracters; see Section a), except that the stimuli were presented on the background of a flow field of random dots (Figure 1b). The origin of the motion was the center of the visual field (i.e. the left border of the display panel), close to the fixation point. All elements moved away from that position in a radial pattern, creating the impression of a (half) tunnel within which the observer rapidly moves forward. The random dots were black and their size and spacing were M-scaled (diameter 0.15° in the center of the display, 0.52° in the periphery). The average speed of motion was approximately 0.14 m/s.

The presentation of this flow field started with the initiation of the trial by the experimenter. After five seconds, the test stimuli were presented on the background of the flow field (Figure 1b), followed by the mask with the same timing parameters as described for the first block of the experiment (see Section b). The display then stopped and disappeared until the next trial was started.

e) Orientation discrimination with relative-motion cueing

The fourth experiment block introduced the crucial RMC cueing condition to test its effect on orientation discrimination. Otherwise this block was identical to the third part of the experiment (see Section d), including the presentation of masks after targets. After an interval of 4.5 sec following the onset of the flow field, and for a period of 500 ms, the random dots in a window centered on the later target position moved in a direction opposite to the flow field (Figure 1b). The choice of dots moving opposite to the flow field (as opposed to using static dots) was based on the ecological validity of this situation: an object moving from right to left is a potentially threatening event, e.g. in traffic situations, and should thus attract attention in a more powerful manner than an RMC consisting of a static dot field.

This RMC was presented longer than the ring cue because it seemed that the effect of the motion had to "build up" (Melcher et al 2004); a suitable RMC presentation time had been determined in pilot testing with several durations. For an RMC duration of 100 ms, i.e. the same duration as for the ring cue, performance was at chance level, which means that the subjects could simply not take advantage of the cue. When the RMC was presented for 500 ms, the degree of difficulty in the ring cue and RMC paradigm was comparable. From the subjective impression that the experimenters obtained during performing the tests on themselves, the largest part of the longer SOA in the RMC condition was needed to build the perception of the random dot field and to segregate it from the flow field background. Only after the perception of the RMC was completed, attention could be reliably deployed to the target location. Immediately after the RMC field disappeared, the target was shown at that position with 100% cue validity, while at all other test locations the distracters were shown (Figure 1b). Again, the subject was instructed to indicate the orientation of the target. The number/ percentage of correct responses served as performance measure.

Data analysis

Data were analyzed using SPSS software (Version 12.0, SPSS Inc., Chicago, IL). Wilcoxon Test, Friedman Test, and repeated-measures analysis of variance with a two-sided alpha of 0.05 were performed, with appropriate alpha adjustment when multiple comparisons were made.

The main outcome variable was the number of correct responses in the 4-alternative forced-choice orientation discrimination task (0 – 10 correct answers out of 10 possible). Performance under cued conditions was compared with uncued performance by calculating the difference of the number of correct responses between the two conditions (number of correct answers cued – number of correct answers uncued). For the descriptive presentation of the data from individual subjects, we used the benefit ratio B as an indicator of the advantage of cued performance over uncued performance by calculating the number of correct answers cued divided by number of correct answers uncued. For equal performance under cued and uncued conditions, $B = 1$, i.e. there is no benefit induced by the cue. A benefit ratio below 1 indicates better performance under uncued than under cued conditions. For $B>1$ there is an advantage for cued over uncued conditions, and B indicates how many times better performance was when the cue was presented before the Gabor grating.

Since the ring cue and the RMC were processed in different visual sub-modalities and the mechanism of sensory modulation was also different between the two cue types, a general quantitative comparison between those conditions was not possible. Based on the experimental parameters chosen here, we cannot draw conclusions about how much more effective one cue type was than another one, but we could only perform comparisons limited to the parameters chosen in the present study.

Results

Central in our study was the comparison of our new RMC to a conventional direct cue in the periphery of the visual field (20° to 60° eccentricity). Performance in a 4-alternative non-forced choice (4 ANFC) task of orientation discrimination of static Gabor gratings served as the measure of the effect.

Baseline performance of Gabor direction discrimination in the uncued condition (see Methods part b) did not show any significant differences between the four test positions (Friedman Test: $\chi^2 = 4.341$; df = 3; p = 0.227). Hence, the adjustment of the level of task difficulty by using the individually determined thresholds (see Methods, part a) had yielded the expected results. Similarly, there were no performance differences between the test positions in the uncued condition with the flow field background (see Methods, part d; Friedman Test: $\chi^2 = 2.056$; df = 3; p = 0.561). However, mean performance in the two uncued conditions was different, performance in the uncued condition without the flow field (mean number of correct answers: 4.3 ± 0.35 S.E.M.) being significantly better than that *with* the flow field (2.25 ±0.25; Wilcoxon Test: Z=-2.708; p=0.007).

The raw data plotted separately for each subject show that the conventional ring cue improved discrimination (benefit ratio B>1) performance in almost all subjects and at all eccentricities (Figure 2b). Only a few subjects failed to show a cueing effect. The same plot of single-subject raw data for the benefit induced by the RMC also showed successful cueing of attention (see Figure 2d). This effect was found in almost all subjects over all positions and was slightly more pronounced in the far periphery of the visual field (40° and 60°).

The baseline plots show that we were successful in keeping the baseline at an intermediate level (to avoid ceiling effects). The variability of the cue effects was high, however.

Statistical testing, i.e. the comparison of the percentage of correct responses between uncued and cued trials for the ring cue and the RMC, respectively, yielded significant or near-significant results at all positions, for both cue types (Table 2).Thus, despite the small sample size, performance under cued conditions was significantly better than in uncued trials for both, the ring cue and the RMC.

Similarly, the mean number of correct responses, averaged over all four test positions, differed significantly between uncued and cued conditions for both cues (Table 3). The overall increase of performance was comparable for the two cue types.

Comparing the two cue types with each other, the mean difference of performance between uncued and cued conditions, averaged over all four positions, was larger for the ring cue (mean ±S.E.M. = 25.8 ± 6.4) than for the RMC (mean ±S.E.M. = 19.4 ± 3.1), and this difference was of marginal significance (Wilcoxon Test: Z=-1.963; p=0.050). Thus, on average, the ring cue was more effective than the RMC. When tested separately at each location, however, the individual differences did not reach significance (Table 4).

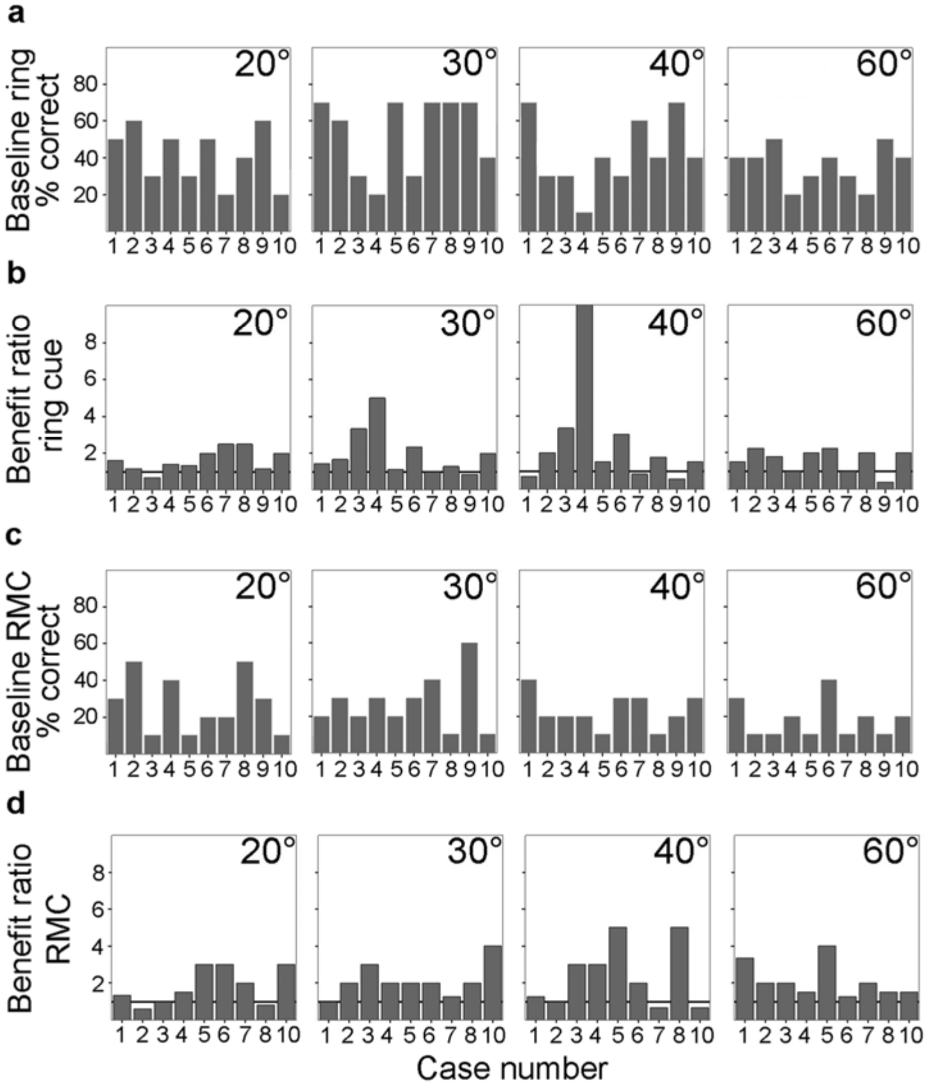

Figure 2. Single-subject data of cue benefits. Baseline performance under uncued conditions (a) and benefit ratio (cued/uncued performance (b) of the ring cue, and baseline performance (c) and benefit ratio (d) of the RMC, for each subject at the four test positions in the visual field.

Table 1. Descriptive statistics of the benefit induced by the two cue types. Mean differences (per cent correct responses) of cued and uncued conditions for the ring cue and the RMC, S.E.M., median, and ranges at the four test positions.

	Ring 20°	**Ring 30°**	**Ring 40°**	**Ring 60°**	**RMC 20°**	**RMC 30°**	**RMC 40°**	**RMC 60°**
Mean Diff. % corr.	23.0	32.0	26.0	22.0	12.2	23.3	21.1	21.1
S.E.M. %	6.5	9.0	12.4	8.1	6.0	4.1	7.9	7.0
Median Diff. % corr.	20.0	35.0	25.0	25.0	20.0	30.0	30.0	10.0
Minimum	-10.0	-10.0	-30.0	-30.0	-20.0	0	-10.0	10.0
Maximum	60.0	80.0	90.0	50.0	40.0	40.0	50.0	70.0

Table 2. Statistical comparison between cued and uncued conditions. Left four columns: ring cue; right four columns: relative-motion cue (RMC); mean values are in % correct; Z: z-value of mean performance compared between uncued and cued condition (Wilcoxon Test); p: significance level in the Wilcoxon Test for comparison of cued and uncued conditions (two-sided)

	Ring 20°	**Ring 30°**	**Ring 40°**	**Ring 60°**	**RMC 20°**	**RMC 30°**	**RMC 40°**	**RMC 60°**
Uncued mean ± S.E.M.	41.0 ± 4.8	53.0 ± 6.5	42.0 ± 6.1	36.0 ± 3.4	27.0 ± 5.0	27.0 ± 4.7	23.0 ± 3.0	18.0 ± 3.3
Cued mean ± S.E.M.	64.0 ± 8.3	85.0 ± 4.8	68.0 ± 6.8	58.0 ± 9.2	37.8 ± 5.2	45.6 ± 5.6	43.3 ± 6.0	37.8 ± 8.5
Z	-2.568	-2.499	-1.793	-2.040	-1.653	-2.555	-1.995	-2.807
p	.010	.012	.073	.041	.098	.011	.046	.005

Table 3. Mean cueing effects for ring cue and RMC, averaged over positions. Mean percentage of correct responses for uncued and cued trials for the two cue types. See Table 2 for abbreviations.

	Ring	**RMC**
Uncued (mean ± S.E.M.) (%)	43.0 (±3.5)	22.5 (±2.5)
Cued (mean ± S.E.M.) (%)	68.8 (±4.1)	41.1 (±3.4)
Difference (%)	25.8 (± 6.4)	19.4 (±3.1)
Z	-2.552	-2.668
p (2-sided)	.011	.008

Table 4. Differences between effectiveness of ring cue and RMC. Wilcoxon Tests for differences between cue effectiveness (difference of cued and uncued conditions) between ring cue and RMC at the four test positions. See Table 2 for abbreviations.

	Difference RMC vs. ring cue				
	20°	**30°**	**40°**	**60°**	**avg.**
Ring cue: Mean difference (± S.E.M.) cued-uncued % correct	23.0 ± 6.5	32.0 ± 9.0	26.0 ± 12.4	22.0 ± 8.1	25.8 ±6.4
RMC: Mean difference (±S.E.M.) cued-uncued % correct	12.2 ± 6.0	23.3 ± 4.1	21.1 ± 7.9	21.1 ± 7.0	19.4 ±3.1
Difference of cue effect	10.8	8.7	4.9	0.9	6.4
Z	-1.279	-1.725	-1.172	-.655	–1.963
P	.201	.084	.241	.512	.050

Figure 3 shows these data graphically. The degree of the ring cue superiority seems to decrease towards the periphery of the visual field. For a statistical test of such a decrease (i.e. to test for an interaction between the cue types and eccentricity), we performed a multifactorial repeated-measures analysis of variance. The interaction did not reach statistical significance, however (p=0.701).

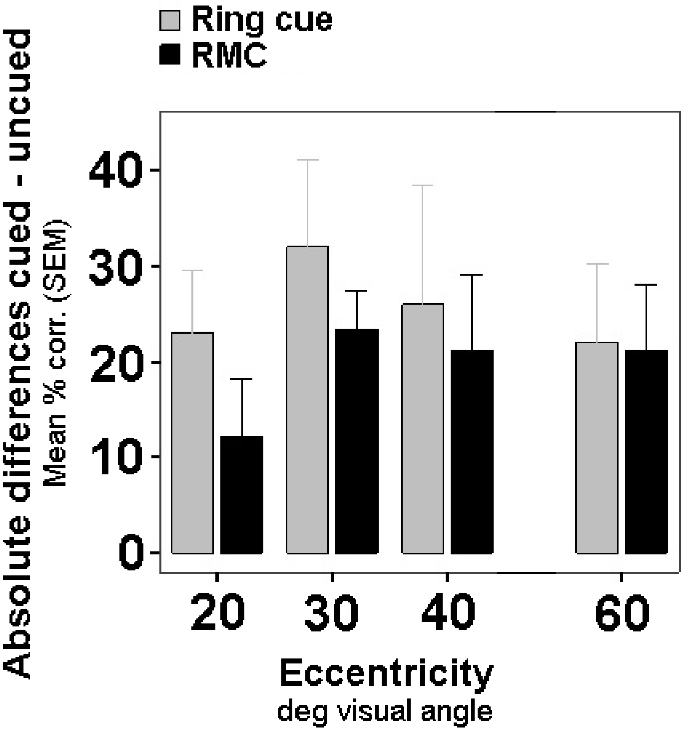

Figure 3. Relative cue advantage at different test locations. Absolute differences between the mean number of correct responses under cued vs. uncued conditions of the ring cue and the RMC for the four eccentricities tested.

Discussion

We tested the effects of a conventional ring cue (direct cueing) on performance in a near-threshold orientation discrimination task and compared it with a new type of cue: a relative-motion cue (RMC), which consists of a random dot pattern moving in the opposite direction of a contextual flow field.

In the first two blocks of experiments using the ring cue, we replicated earlier results (Nakayama and MacKeben 1989; Carrasco and McElree 2001). The results showed that a ring-shaped frame can act as a direct cue and attract attention to the location of the frame: Performance in a 4 ANFC task of orientation discrimination of a Gabor grating was significantly improved at all test locations. This attention effect was slightly more pronounced in the near periphery than at far eccentric positions.

The RMC also improved subject performance at all test locations, and this improvement in trials cued with the RMC was slightly stronger at the more peripheral locations (30° - 60°) than in the near periphery (20°). Averaged over all test positions, the effectiveness of the ring cue was higher than that of the RMC, but the benefit induced by the RMC was not significantly different from that of the ring cue when cue effects were compared at the individual positions. However, a general quantitative comparison between the ring cue and the RMC is not possible because the two cue types were processed very differently in the visual system and therefore the mechanisms of influencing target processing also differed. Based on our pilot experiments, the RMC duration was adjusted so that the degree of difficulty between the ring cue and RMC condition was comparable. However, because of these methodological differences our goal was not to determine the absolute difference in effectiveness to attract attention between the ring cue and the RMC.

The slightly less pronounced cueing effect in the RMC than in the ring condition could have been caused by a difference in difficulty levels in the former.

Our findings confirm our hypothesis that relative motion in a flow field can attract attention and increase near-threshold visual performance.

The absolute numbers of correct responses were lower in those conditions (cued and uncued) where a flow field was presented as compared to target and distracters only, i.e. there was a baseline difference between ring cue and RMC trials. Since performance was adjusted over eccentricities by using the predetermined thresholds (obtained without a flow field background), the presence of the flow field thus masked Gabor discrimination to some extent. The effect of the RMC could thus also be interpreted as de-masking. Subjects also stated that it was more difficult to perceive the static Gabor patches after the flow field had been presented for several seconds. The nature of this masking – a general inhibition of static Gabor discrimination or a masking by a motion aftereffect within the window where motion was reversed – cannot be determined here.

The raw data from the single subjects and the statistical tests comparing the attention effects of the two cue types both showed a trend of an interaction between the cue type and the eccentricity of the test position: The ring cue was most effective at the more central locations (20° and 30°) than in the far periphery. The RMC effect was level at the more peripheral positions but lower in the near periphery. The advantage of the ring cue over the RMC vanished toward the far periphery. This interaction did not become significant in a simultaneous comparison using the General Linear Model, which was presumably due to the small sample size and the substantial inter-individual variability of the data. Some subjects had difficulties making use of the RMC, while in others attention seemed to have been attracted quite easily to the site of the relative motion disturbing the flow field pattern. Such inter-individual differences in the effects of RMC could not be tested systematically in the pilot study presented here, but may be interesting to follow up in a larger sample where subgroups can be formed meaningfully.

Attention is the crucial mechanism allowing an observer to select relevant aspects of information in a complex environment. Sudden onset of a stimulus is an indicator for relevance and acts as a powerful cue to attract attention to the site of that change (Yantis and Jonides 1984). In our study, the suddenly appearing ring cue indeed improved performance which – in line with previous research – we interpret as evidence for a sudden stimulus onset attracting spatial attention. However, as we have shown here, a sudden onset need not be that of a new stimulus in an otherwise empty visual field, but can instead be the sudden change of a specific stimulus characteristic, like motion direction of a stimulus that had already been present (and moving) before (Abrams and Christ 2003; Franconeri and Simons 2003). The experimental condition in our RMC trials resembles the situation in everyday life when the observer moves (i.e. eye, head and body motion) and thereby creates a contextual flow field which helps to determine the observer's own trajectory as well as the motion pathway of other objects in the visual scene. Any deviation from the regular context of the flow field is an indication of a relevant change in the motion of other objects and should thus attract attention. Indeed, as we have shown here in an abstracted display, this seems to be the case. Even though the target itself was stationary, performance in near-threshold orientation discrimination was improved in the trials where a RMC was applied before the presentation of the target Gabor pattern.

Based on everyday experience, one may assume that the periphery of the visual field should be superior with respect to motion processing. Indeed, the physiological characteristics of the retina and higher processing levels in the visual pathway support this hypothesis: Receptive fields of neurons early in the visual pathway which represent the periphery are larger and temporal summation is more pronounced in visual regions of eye and brain (Melcher et al 2004). Psychophysical studies using M-scaled stimuli have demonstrated, however, that (absolute) motion thresholds are constant across the visual field (Johnston and Wright 1986). Interestingly, the sensitivity for the detection of relative motion across the visual field is higher than that for absolute motion (McKee and Nakayama 1984; Snowden 1992). Furthermore, the minimum displacement for detecting relative motion is smaller than the minimal angle of resolution (MAR) for static patterns at all measured positions in the visual field (McKee and Nakayama 1984). Presumably, the detection of relative motion does not depend on the receptive field size only, but may be strongly influenced by computations in higher-order cortical areas like area V5/MT (Greenlee 2000). As has been found for hyperacuity tasks, the spatial resolution at different visual field positions can be much higher than expected from the sizes of receptive fields at that specific location (Westheimer 1982). The detection of relative motion within stimulus patterns could possibly be based on a "motion hyperacuity" that is, at least partially, independent of receptive field sizes and computations on the retinal level. Naturally, the far periphery should be more sensitive to disturbances of motion patterns as an alarm system for approaching enemies or other relevant information based on motion processing in the course of evolution.

Steinman et al. (1997) explained the robust cueing effect of sudden-onset stimuli with the activation of the M-pathway of the visual system overriding cues targeting the P pathway. The same mechanism possibly underlies the attraction of attention by sudden-onset cues and by (relative) motion, since both types of stimuli activate the M-system. The new RMC in our study involves both, the sudden onset of the stimulus event (the change of motion direction) and the presentation of motion per se. This may explain that the RMC was nearly as powerful as the ring cue in attracting attention to the target site. Sudden-onset cues further activate the lateral intraparietal area (LIP), which is presumed to act as a salience map in the cortex, subserving the selection of relevant targets for a saccade (Kusunoki et al 2000). Thus, the activation of area LIP is likely to be independent of the stimulus dimension that underlies the sudden onset (e.g. a change of luminance contrast or color, shape, or motion).

Presumably, the strong activation of the M-pathway by the flow field and also the RMC itself may have inhibited the P-system. This may be the neural basis for the reduced baseline of orientation discrimination in those trials that involved motion stimuli. In non-human and human primates, the ratio of P/M cells decreases with eccentricity (Azzopardi et al 1999; Baseler and Sutter 1997). The relatively stronger representation of M-pathway in the periphery of the visual system may be an explanation for an increase of the RMC effect towards the periphery.

The differences between the SOA in the conventional ring cue condition and the RMC condition that were necessary to adjust task difficulty to comparable levels in both types of trials, hint at differences between the cueing mechanisms in the two conditions. While in the ring cue trials, the cue was clearly and immediately perceptible due to its size, its contrast to the background, and its sudden appearance, in RMC trials, several hundred milliseconds were necessary to segregate the random dot field of the RMC as a separate entity from the background of the flow field. Only after that time, i.e. when a stable percept had been created, the attraction of attention to the target site was possible in the RMC trials. Thus, despite the differences in the SOAs between the two conditions, task difficulty was comparable and cannot explain differences in subject performance between RMC and ring cue trials.

In this study, eye movements were not monitored using an eye tracker, but the experimenter observed the subject's eye position. Therefore the systematic use of large eye movements to targets in the far periphery can be excluded, but the subjects may have made occasional eye movements to the target site as well as micro-saccades that could not be detected by the experimenter. However, making saccades to the target site would have improved performance considerably to a perfect or almost perfect level. This was not found in any subject participating in the study. Moreover, eye movements would not explain the differences between the topographical distributions of the ring cue and RMC cueing effects. Thus, we believe that the effect of eye movements in our data is small and separate from the cueing effects reported here.

The results of our study begin to shed light on mechanisms of motion processing and the interaction between visual and attention networks in the brain. However, we also believe that our findings may be of practical value: As has been indicated in the examples from everyday life, the processing of motion relative to the observer's self-generated flow field is a crucial capacity for safe navigation in a complex environment. Especially the driving performance of an individual should critically depend upon the ability to detect relative motion in the visual field periphery and to use that information as a warning signal which attracts attention to the source of the disturbance in the contextual flow field pattern. There may be large inter-individual differences in this ability, e.g. depending on other attentional functions, on strategies of visual information processing but also on individual characteristics such as age or gender. Based on our experimental design, assessment of a potential connection of relative-motion processing in the periphery of the visual field and the individual's fitness for driving a motor vehicle can be easily achieved.

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