Perception, 2008, volume 37, pages 747 – 764

doi:10.1068/p5922

On the benefits of transient attention across the visual field

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Received 5 May 2007, in revised form 13 September 2007; published online 1 May 2008

Abstract. There are well-known differences in resolution and performance across the visual field with performance generally better for the lower than the upper visual hemifield. Here we attempted to assess how transient attention summoned by a peripheral precue affects performance across the visual field. Four different attentional precueing tasks were used, varying in difficulty and attentional load. When a single discrimination target was presented (experiments 1 and 2), precues that summon transient attention had very little, if any, effect upon performance. However, when the target was presented among distractors (experiments 3 and 4), the precue had a substantial effect upon discrimination performance. The results showed that asymmetries in visual resolution between the upper and lower hemifields become more pronounced with increasing eccentricity. Furthermore, when the observers performed a precued acuity task with distractors, involving the judgment of the relative position of a small disk within a larger one, there was an asymmetry in the transient attentional effect on discrimination performance; the benefits of transient attention were larger in the upper than in the lower hemifield. Areas in the visual field where visual performance is generally worse thus appear to receive the largest attentional boost when needed. Possible ecological explanations for this are discussed.

1 Introduction

There is much more information available in our visual environment than we can be expected to keep track of. Many have discussed how selective attention allows us to pick out the stimuli that are most pertinent for behaviour at any given moment (Helmholtz 1896; James 1890; Locke 1689/1975). For a more recent example, Engel (1971) investigated how the area of visual conspicuity for a number of different types of stimuli is affected by voluntary covert attention to a particular location in the visual field and found that visibility increases when attention is deployed to a particular location in the visual field independently of the locus of fixation.

Researchers have described two ways of directing attention (without shifting the direction of gaze) to different areas of the visual field. We can either deliberately maintain attention at a certain location or object (Alvarez and Scholl 2005; Bashinski and Bacharach 1980; Colegate et al 1973; Engel 1971) or our attention can be drawn towards something automatically, to something that grabs our attention (see eg Eriksen and Hoffman 1972; Franconeri et al 2005; Jonides 1980; Kristjánsson et al 2001; LaBerge 1983; Posner and Cohen 1984). The former way of attending is usually referred to as sustained attention and the latter as transient attention (Nakayama and Mackeben 1989; see also Kristjánsson 2006; Kristjánsson and Nakayama 2003; Most and Simons 2001). Transient attention has often been thought to be the attentional equivalent of the visuomotor grasp reflex (see eg Kristjánsson 2007, for review). Sustained attention is more sluggish, while transient attention allows fast covert orienting towards particular locations but requires a stimulus such as a precue (Cheal and Lyon 1991; Nakayama and Mackeben 1989) and seems to give a larger boost to visual performance than sustained attention (Nakayama and Mackeben 1989). It has been controversial, however, whether these two types of attending have comparable effects

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on visual processing (eg Carrasco et al 2001; Mackeben 1999; Nakayama and Mackeben 1989; Rezec and Dobkins 2004).

1.1 *Asymmetries in processing across the visual field*

Visual resolution generally becomes worse with increasing distance from the area projected to the fovea (Anstis 1974; Engel 1971). Many lines of evidence also indicate that observers find it easier to perceive visual stimuli on the horizontal meridian of the visual field than the vertical meridian, when eccentricity is kept constant (Altpeter et al 2000; Cameron et al 2002; Carrasco et al 2004). One reason for this could be that retinal cone density drops faster as one goes further out along the vertical meridian than it does on the horizontal meridian (Curcio et al 1987, 1990).

Visual resolution is also generally greater in the lower than the upper visual field as shown with many types of tasks (Altpeter et al 2000; Breitmeyer et al 1975; Cameron et al 2002; Carrasco et al 2004; Danckert and Goodale 2001; Lakha and Humphreys 2005; Mackeben 1999; Rezec and Dobkins 2004; Rubin et al 1996). This hemifield asymmetry might be due to a larger density of ganglion cells in the upper than the lower hemiretina (Curcio and Allen 1990).(1) Also, Van Essen et al (1984) found that a larger portion of monkey striate cortex is devoted to the analysis of information from the lower than the upper half of the visual field which could partly account for such asymmetries in visual resolution and is roughly consistent with what Curcio and Allen found.

Asymmetries in visual processing have also been found in humans with magnoencephalographic (MEG) measurements. Portin et al (1999) found that neural activity modeled with a dipole was twice as strong for stimuli presented in the lower than the upper visual field. Furthermore, Portin and Hari (1999) found that waveforms and distributions of the occipital MEG signal varied both as a function of hemifield and eccentricity, which suggests that visual stimuli lead to different neural responding depending on where they appear.

The asymmetries in visual resolution may reflect the relative importance of different locations in the visual field, with more resources weighted towards the lower visual field. When we look at a given visual scene, there is usually more information available in the lower visual field (Levine and McAnany 2005; Previc 1990). Behaviourally important items can, and will, appear at locations that are more sparsely covered in terms of visual receptors and cortical representation, however. How does the visual system respond to stimuli at those more sparsely covered locations?

1.2 *Benefits from attentional processing across the visual field*

The question under investigation here is whether the effects of visual attention vary depending on location in the visual field and, if so, whether attentional benefits may be greater for the more sparsely represented areas to compensate for poorer visual resolution. Given the differences in visual performance discussed above, this need should be asymmetrical; the upper visual field would in general be expected to require a larger attentional boost when needed than the lower visual field, and the vertical meridian would on average require greater enhancement than the horizontal meridian, for a task of comparable difficulty.

Many researchers have investigated whether and how attention affects different areas of the visual field. Carrasco et al (2001) explored the influence of transient visual attention on sensitivity to orientation of Gabor patches that appeared either with or without distractors. The target was a Gabor patch tilted slightly away from vertical, while the distractors were exactly vertical. Observers did better when the patches appeared on the horizontal than the vertical meridian, and better when targets appeared

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(1) The upper hemiretina corresponds to the lower visual field and vice versa.

in the lower than the upper visual field. Performance was enhanced when a briefly presented (40 to 67 ms) peripheral precue signalled the location of an upcoming target. Importantly, the results of Carrasco et al (2001) indicated that this effect was constant across the visual field (see also Cameron et al 2002). They did not, in other words, find any evidence for an asymmetry in the effects of transient attention. Talgar and Carrasco (2002) also observed such constancy of the effects of transient visual attention for a texture-segregation task (Julesz 1984; Karni and Sagi 1991). Since there was no statistical interaction between the precueing effect and the position of the target in the visual field in these studies, Carrasco and colleagues concluded that visual performance asymmetries reflect visual rather than attentional factors and that the effect of transient attention is constant across the visual field.

Others have, however, reported findings in seeming contrast to those of Carrasco and colleagues. Rezec and Dobkins (2004) measured motion and orientation discrimination thresholds, and found that performance differences for the upper versus lower visual field were reduced or even nullified when target location was cued in advance. This indicates that the attentional effect was larger for the upper than for the lower hemifield with identical visual displays. It is important to emphasise that Rezec and Dobkins used long cue-lead times, meaning that their study addressed the effects of sustained attention. Carrasco and colleagues used short cue-lead times so their study most likely addressed the effect of transient attention. Mackeben (1999) also argued that the benefits of sustained attention are not constant across the visual field, but this conclusion is somewhat hard to interpret since the average performance with and without a peripheral precue showed similar asymmetries, although there was a large general benefit of attention (see Mackeben 1999, table 1). Kraft et al (2007) then argued that visual-field effects on performance (following attentional precues summoning sustained attention) are larger even than the interfering effects of distractors.

The aforementioned studies raise the possibility that there is a fundamental difference between the effects of sustained and transient attention in that the former shows asymmetries across the visual field in its effects (Kraft et al 2007; Rezec and Dobkins 2004) while the effects of the latter are constant across the visual field (Carrasco et al 2001; Talgar and Carrasco 2002).

Other evidence suggests that this may not be the whole story, however. Golla et al (2004) had their observers (both monkeys and humans) judge the orientation of a briefly presented single Landolt C and found that the beneficial effects of precues (ranging from 100 to 1000 ms) became more pronounced with larger eccentricities. There was, in other words, a statistical interaction between the precueing effect and the effects of eccentricity and thus an asymmetry in the attentional effect. This is seemingly at odds with what Carrasco and colleagues have reported, since Golla et al found that the attentional benefits are not homogenous across the visual field, even with brief precues that are likely to summon transient attention.(2) Golla et al (2004) did not address the question of asymmetries in attentional effects between hemifields, however.

To summarise, evidence regarding the effects of attention across the visual field is rather mixed. Some results indicate that transient attention affects all locations equally (Carrasco et al 2001; Talgar and Carrasco 2002), but this may not be consistent with

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(2) It must be noted that it could be debated whether the study of Golla et al did address the allocation of transient attention or not. They used precues (appearing for 100 to 1000 ms) that disappeared, followed 50 to 500 ms later by the stimulus. The cue-lead time (from precue onset to target appearance) is thus at minimum 150 ms, which is a little longer than that which is thought to be the peak effect of transient attention. It should be pointed out, however, that offsets can also serve as attentional precues (Nakayama and Mackeben 1989), in which case the shortest precue lead times tested would be 50 ms. It is also relevant that the attentional effects were by far the largest for the shortest cue-lead times in the Golla et al study.

the results of Golla et al (2004). Research on sustained attention suggests that it may maximally enhance performance where it is most needed, ie in those locations where visual resolution is overall worst, such as the upper visual field (Kraft et al 2007; Rezec and Dobkins 2004). It would, in fact, seem like a plausible role for visual attention to enhance visual processing (or reduce decision noise) at locations that are more sparsely covered by the visual system. It is important to note that we are not, however, arguing that attention should necessarily favour the upper hemifield, but that the measured effects of attention could simply be stronger in the upper hemifield since visual resolution is already quite good in the lower hemifield.

1.3 *The present purposes and overview of experiments*

We set out to find out whether the effects of transient attention summoned with a briefly presented precue ($\sim$100 ms) followed immediately afterwards by a discrimination target vary depending on location in the visual field, or whether these effects are constant across all locations. As mentioned earlier, the evidence on this is somewhat mixed.

The discrimination task in experiments 1 and 3 involved judging whether a Gabor patch was tilted to the right or left of vertical. In experiments 2 and 4, observers had to judge whether a small disk within a larger one was displaced to the left or right from the centre of the larger disk. The power spectrum of the Gabor patches is, for the most part, made up of a single spatial frequency, whereas the eye stimuli are broadband. We contrasted single-spatial-frequency stimuli and broadband stimuli with the aim of checking whether attentional effects would be different for the two stimulus types. Many previous studies investigating the nature of attentional benefits have used relatively simple stimuli which might be likely to recruit early vision mechanisms, such as the orientation-selective cells of early visual cortex. Evidence both from neurophysiology and from research on visual function suggests that there are specialised receptors for the analysis of such stimuli in the visual system (Albrecht et al 1980; Haynes and Rees 2005; Hubel and Wiesel 2005; Julesz 1980; Treisman 1988; Wolfe and Horowitz 2004). By most estimates, Gabor patches match very well the receptive-field profiles of orientation-selective neurons in early visual cortex (eg Albrecht et al 1980; Campbell and Robson 1968). The stimuli in experiment 2 are, on the other hand, likely to require the involvement of higher-level visual areas since a relative judgment of the location of the smaller and larger disks is required. In experiments 1 and 2 there were three precueing conditions: a peripheral precue condition and two control conditions. In one of the control conditions, a neutral non-informative central precue was presented for the same amount of time as the cue in the peripheral precue condition, while in the other control condition no precue appeared. In experiments 3 and 4 only the neutral and valid precue conditions were used, together with a two-interval forced-choice procedure. In one of the two intervals a target was present among distractors, whereas in the other the stimuli were all the same, ie all distractors. The observers' task was to indicate which interval contained a target.

2 Experiment 1

In experiment 1, a single Gabor patch appeared at one of 24 possible locations in the visual field, preceded by a visual cue towards the target location. Observers were asked to judge whether the Gabor patch was oriented to the right or left of vertical.

2.1 *Methods*

2.1.1 *Participants.* Eight observers (four males) aged 21 to 27 years participated. All had normal or corrected-to-normal vision. Each observer took part in 4800 trials in 48 blocks of 100 trials over a period of 2 or 3 days. Data collection took about 5 h in total for each subject. There were 16 blocks of 100 trials for each precueing condition (see below). Those were run in a different random order for each participant.

2.1.2 *Materials and procedure.* Stimuli were presented on an 85 Hz CRT screen with a resolution of 1024 × 768 pixels, controlled by a 400 MHz Power PC G4 computer. Custom software, programmed in C utilising the VisionShell function library, was used for stimulus presentation. A central 'bull's-eye' serving as a fixation marker was present throughout, and observers were instructed to maintain fixation on it during the whole experiment (see figure 1). After 1200 to 1700 ms, a 1200 Hz sinusoid sound was played for 35 ms, alerting the observers to the upcoming target. At the same time, the 'precue period' began and lasted for 106 ms. During the precue period, one of three things occurred: (i) a peripheral cue appeared at the location of the upcoming target, consisting of a 1.5 deg × 1.5 deg square drawn in white (32 cd m^{-2}) with a line thickness of 6 min of arc; (ii) a neutral cue, looking exactly like the peripheral precue, appeared in the centre of the screen, surrounding the fixation bull's-eye; (iii) no visual cue was presented.

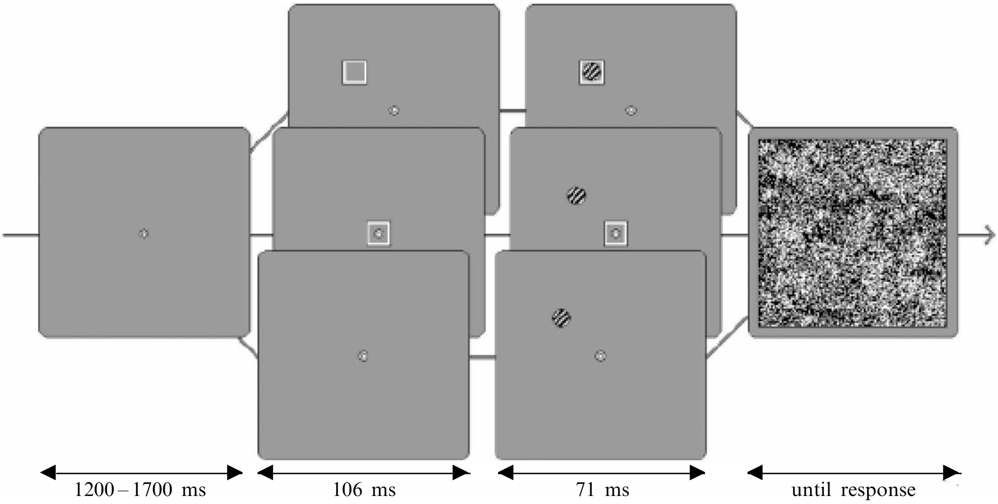

Figure 1. The sequence of events in experiment 1. Following the 1200 to 1700 ms fixation period, a valid peripheral precue, a neutral central precue, or no precue appeared for 106 ms. Thereafter, a target Gabor patch was shown for 71 ms after which a random-dot mask was presented. The task was to indicate by keypress the orientation (left or right from vertical) of the Gabor patch.

The target was a Gabor patch consisting of an achromatic grating with brightness varying sinusoidally around a mean brightness level of 17.1 cd m^{-2} (the background was also 17.1 cd m^{-2} and this applies to all four experiments) multiplied by a Gaussian patch with a standard deviation of 1.2 deg. The Michelson contrast between the brightest and darkest region of the Gabor patch was 9.5%. The target could appear at 24 different locations in the visual field: at 3 different radii (3.5, 5.9, or 7.6 deg from screen centre) and 8 different radial directions from the centre (which we call N, NE, E, SE, S, SW, W, and NW, corresponding to the polar directions). Observers had to judge whether the patch was tilted 5° to the right or left from vertical.

The target was visible on the screen for 71 ms, followed by a random-dot mask (dot size = 3 pixels) that covered the whole screen. The brightness of each dot was randomly determined from the same greyscale as the Gabor patch. Observers had their heads stabilised with a chin-rest and pressed one of two keys on a standard Apple keyboard depending on whether they thought that the target was tilted to the left or to the right.

2.2 *Results*

Figure 2 shows the effects of both the radial direction of target location and radial eccentricities. Trials with response times less than 100 ms were not included in the analysis. Those amounted to an average of 7 trials out of the 4800 for each subject.

The average percentage of correct responses was 72.9% ranging from 71.1% to 76.4% for the different observers. When a valid precue appeared, performance was 74.2% correct on average; when the central precue appeared, the average was 72.9% correct; while when no precue was presented, observers performed at 73.8% correct on average. This means that the precue did not seem to have much of an effect on discrimination performance. A three-way ANOVA with the factors precue type, radial direction, and eccentricity confirmed that the effect of precue type was far from being significant ($F_{2,14} = 1.55$, $p = 0.123$).

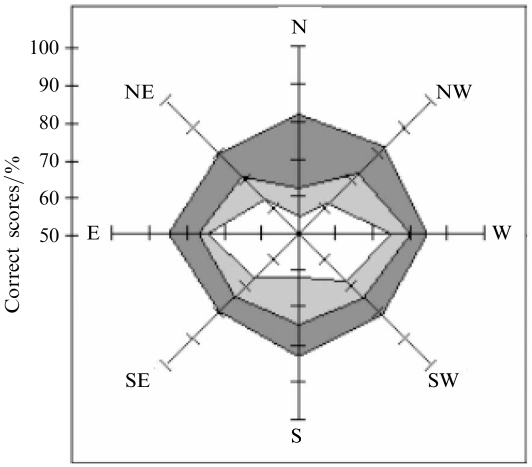

Figure 2. Average percentage of correct scores from experiment 1 for different radial directions, as a function of eccentricity (radius) of the target (denoted by the different brightness values in the polar graph).

Figure 2 also shows the main effect of the eccentricity of the target. This effect was quite significant ($F_{2,14} = 231.5$, $p < 0.001$) with the best performance for the smallest eccentricity (dark grey in figure), intermediate for the middle eccentricity (light grey), and worst for the largest eccentricity (in white).

The effect of target radial direction was significant ($F_{7,49} = 9.39$, $p < 0.001$), as was the interaction of radial direction and eccentricity ($F_{14,98} = 5.37$, $p < 0.001$). In other words, the difference in performance between the upper and lower visual hemifields became more pronounced with increased eccentricity. Performance was overall best on the horizontal meridian, and better in the lower than the upper visual hemifield, as can be seen in figure 2. These differences were virtually absent for the lowest eccentricity from the centre, however, but became more pronounced as the target appeared further out from the centre.

The three-way interaction was not significant ($F_{28,196} = 0.995$, $p = 0.479$), and neither was the interaction of precue type and radial direction ($F_{14,98} = 1.32$, $p = 0.1$), nor the interaction between precue type and eccentricity ($F_{4,28} = 1.45$, $p = 0.24$).

In short, the results of experiment 1 indicate that transient attention summoned by a peripheral precue had a very small, if any, effect on orientation discrimination for the Gabor patches. The results also show that performance becomes worse, overall, with increased eccentricity and, furthermore, that visual-field asymmetries are more pronounced with increased eccentricity.

3 Experiment 2

A valid peripheral precue did not seem to have much of an effect on discrimination performance in experiment 1. One possible reason for this is that discrimination of the orientation of single-frequency targets does not benefit much from transient attention being drawn towards them when no distractors are present (but note that this issue is still under considerable debate—see eg Carrasco et al 2000; Morgan et al 1998; Shiu and Pashler 1994, 1995).

Many researchers have, of course, suggested, in various contexts, that the visual system contains specialised receptors for orientation (eg Albrecht et al 1980; Hubel and Wiesel 2005; Julesz 1980; Marr 1980; Treisman 1988). Recent neurophysiological evidence indicates that this is the case for humans (Haynes and Rees 2005; Kamitani and Tong 2005) and earlier studies have shown this for various other species of mammals (De Valois and De Valois 1990; Hubel and Wiesel 2005). This could be the reason that attention had little or no effect on Gabor orientation discrimination in experiment 1 here, where no external noise (such as from distractors) was present.

In experiment 2, we used a task that we reasoned might benefit more from the deployment of transient attention to the location of the upcoming target. Observers had to indicate whether a small dark-grey disk (same brightness as the background) within a brighter grey disk target was shifted to the right or the left relative to the centre of the disk. This stimulus contains a number of different spatial frequencies and is thus unlikely to be analysed by a single type of receptor. The task can only be performed with a rather complex (at least compared with the Gabor orientation judgment) comparison of the relative positions of the smaller and larger disks, a task that might benefit more from attentional precueing than the Gabor orientation task in experiment 1.

3.1 *Methods*

Seven observers participated (aged 22 to 26 years; five females), all with normal or corrected-to-normal vision. As in experiment 1, each observer took part in 4800 trials over a period of 2 to 3 days.

The target consisted of a light-grey (24.6 cd m^{-2}) disk subtending a visual angle of 1.1 deg. Within this disk was a smaller dark-grey disk (same as background, size 0.2 deg) shifted by 0.05, 0.1, 0.15, 0.2, or 0.25 min of arc to the right or left from the centre of the larger disk.(3) The brightness of the smaller disk was the same as the background. Figure 3 shows the three conditions in the experiment: the peripheral precue, neutral precue, and no precue conditions. Other details of the methods were as described for experiment 1.

3.2 *Results*

Figure 4 shows performance in experiment 2 as a function of eccentricity and radial direction of the target. A three-way repeated-measures ANOVA with the factors precue type, eccentricity, and radial direction was performed on the data.

On average, performance with the valid precue was 74.5% correct; with the neutral precue it was 72.6% correct; while when no precue was presented performance was 71.6% correct. The effect of precue type was not significant ($F_{1.063,\,6.379} = 1.05$, $p = 0.191$).(4)

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(3) We were forced to collapse across all the displacement sizes in our analyses since we were unable to collect enough data for a thorough analysis of any effect of displacement size. For a reliable analysis of those effects across the visual field, five times more data for each observer would have been required. In experiment 1, individual observers took part in approximately 67 trials for each condition. To obtain as many trials for every condition of experiment 2, including all the different displacement sizes, would have required 24 000 trials for each observer.

(4) A Greenhouse–Geisser ε correction of the degrees of freedom was applied here because of a significant deviation from sphericity.

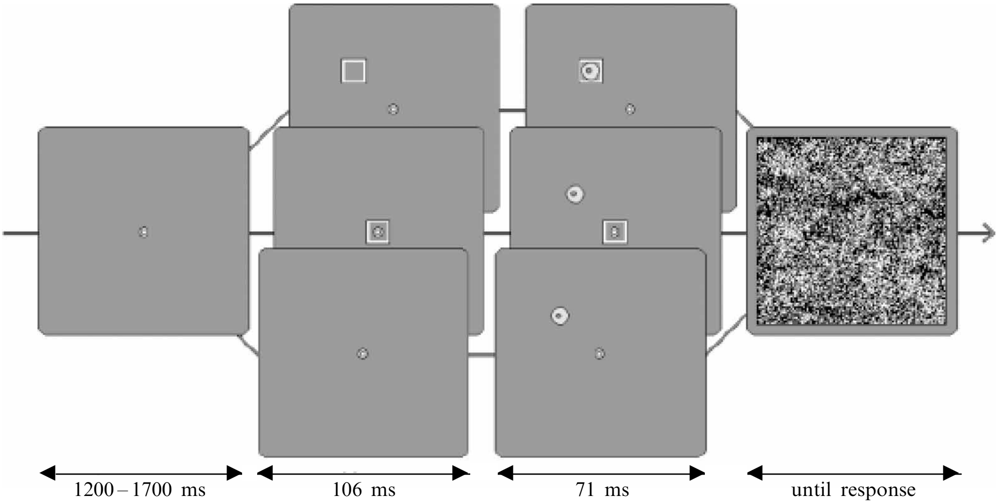

Figure 3. The sequence of events in experiment 2. All the details except for the discrimination task itself were the same as for experiment 1.

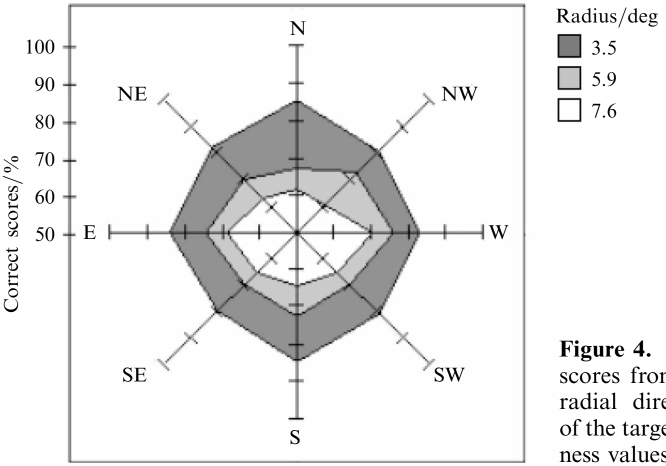

Figure 4. Average percentage of correct scores from experiment 2 as a function of radial direction and eccentricity (radius) of the target (denoted by the different brightness values in the polar graph).

The interaction of precue type and radial direction was not significant either ($F_{14,84} = 0.94$, $p = 0.259$); nor was the interaction between precue type and eccentricity ($F_{4,24} = 0.72$, $p = 0.584$); nor the three-way interaction between precue type, radial direction, and eccentricity ($F_{28,168} = 1.18$, $p = 0.255$). This is not surprising, since the valid peripheral precue did not seem to have much of an effect, thus making it infeasible to measure the symmetry or asymmetry of the effect of transient attention.

As in experiment 1, the main effect of target eccentricity was significant ($F_{2,12} = 80.47$, $p < 0.001$), as was the main effect of target radial direction ($F_{7,42} = 2.10$, $p = 0.038$), and the interaction between eccentricity and radial direction ($F_{14,84} = 2.69$, $p = 0.003$). This is evident in the data shown in figure 4, and indicates that there are asymmetries in performance between the upper and lower visual hemifields that become more pronounced with increased eccentricity, even though no such asymmetries in the effect of transient attention were found.

Overall the results of experiment 2 were quite similar to the results of experiment 1, showing, if anything, only a small hint of a precueing effect. There were asymmetries in overall performance across the visual field but no asymmetric effects of the precue were found.

4 Interim summary

The hypothesis under investigation here states that, when precues summon transient attention towards a target, performance should improve to the largest degree for regions where visual resolution is generally poorest for reasons explained in the introduction. Experiments 1 and 2 provide little evidence that this is the case, however, but this was not to be expected given that there were no benefits of the precue in the first place in those first two experiments.

It is possible that the attentional manipulations used so far are simply not powerful enough to reveal any attentional precueing effects nor spatial asymmetries for such effects. It should be noted, though, that performance is far from ceiling so there could still be room for improvement, but for some unknown reason we may simply have hit upper performance levels for the tasks as tested, ie without distractors.

We reasoned that adding distractors to our tasks might lead to a more pronounced effect of the precue and perhaps reveal some spatial asymmetries in terms of the effect of the precue. If there is anything in the literature on spatial precues that there is consensus on, it is that they help with picking out targets among distractors (eg Colegate et al 1973; Kristjánsson and Nakayama 2003; Nakayama and Mackeben 1989; Shiu and Pashler 1995; Solomon et al 1997), although it is debated whether they have such an effect without distractors (see eg Carrasco et al 2002; Kristjánsson and Nakayama 2002; Nazir 1992; Shiu and Pashler 1995; Solomon 2004, to sample the debate) and whether such benefits reflect perceptual enhancement or reduction of decision noise (see eg Carrasco 2005; Morgan and Solomon 2005, for discussion). If there are asymmetries in attentional benefits across the visual field they should, logically, be most apparent in a task that taxes attention the most. For that reason, in experiments 3 and 4 we tested performance on the same discrimination tasks as in experiments 1 and 2 while this time adding distractors to the display. Observers had to indicate which of two displays, presented for 71 ms with an 800 ms interval in-between, included a target. The other interval contained only distractors.

5 Experiment 3

5.1 *Methods*

As in experiment 1, a target Gabor patch appeared on the screen but now seven distractors were shown in each of the seven remaining radial positions (see section 2.1). Both target and distractors were displayed at 6.1 deg from the centre (see figure 5 for an example display). The parameters and brightness values for the Gabors and background were the same as in experiment 1.

A two-interval forced-choice procedure was used. The observers had to decide whether the first or second display within a trial contained the target which was present on all trials (in one of the two intervals). One of the displays thus had a target Gabor tilted by 5° away from vertical and seven vertical distractor Gabors. The other display had no target and eight vertical distractor Gabors. The order of the target and non-target intervals was random for each trial. The required response was to indicate by keypress whether the first or second display included an oddly oriented Gabor patch.

A trial started with the presentation of either a valid peripheral precue or a neutral central precue (split across different blocks of trials), presented at the centre, for 106 ms. Eight Gabor patches were then displayed for 71 ms, followed by a blank screen for 800 ms. A second precue and display of Gabor patches were then presented for the same amount of time as the first. The precue in the valid-cue condition never cued the same location in the two intervals within a trial. No mask was presented after each display since pilot trials indicated that the task would be too difficult with the mask. Other details were as described for previous experiments.

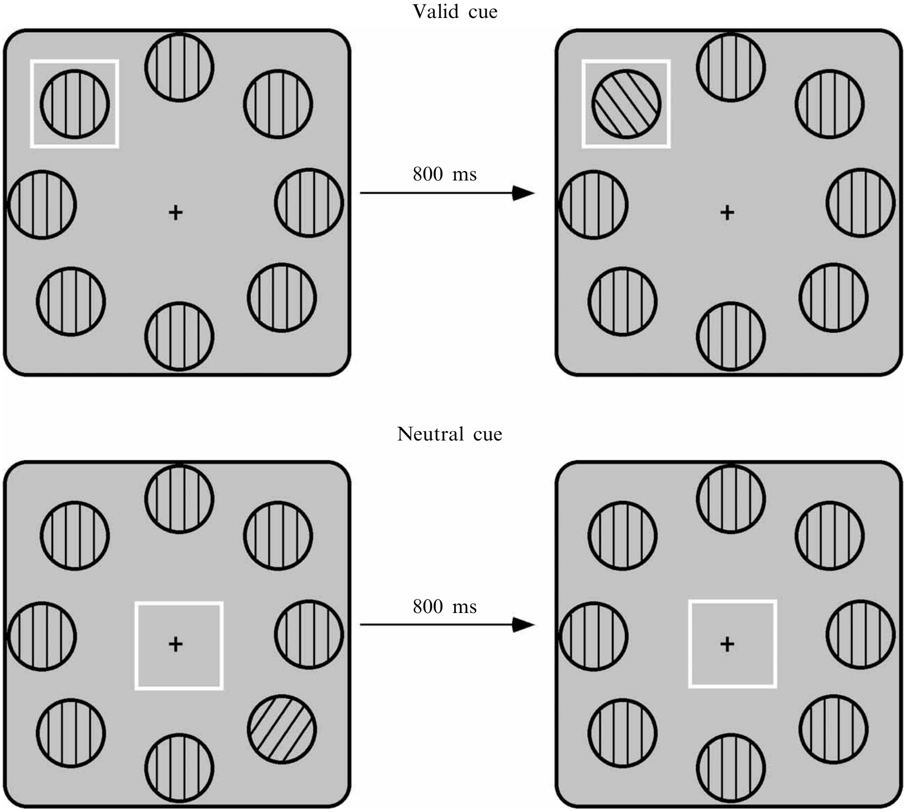

Figure 5. The task in experiment 3. Observers had to decide which of two brief displays (the second for the valid precue and the first for the neutral precue in the figure) contained an oddly oriented Gabor. The distractors were vertical Gabors. Each display of Gabors was preceded by a valid or neutral precue for 106 ms. The display was then presented for 71 ms, after which the screen went blank. The two different displays on each trial were separated by a blank screen presented for 800 ms. The cue never cued the same location across the two intervals within a single trial. The same general design was used in experiment 4 except that the task was a disk-displacement task as in experiment 2 (see figure 3).

Seven observers (five male) participated in 1600 trials each, with data collection taking about 70 to 90 min for each subject. 8 blocks of 200 trials were run in a counterbalanced order, of which 4 blocks contained only valid precues and 4 had only neutral precues.

5.2 *Results*

Figure 6a shows the precueing effect for experiment 3 calculated as d' for two-alternative forced-choice tasks.(5) Figure 7a contrasts performance with and without the peripheral precue as a function of eccentricity, while table 1 shows the standard errors of the mean for the different radial directions. A two-way repeated-measures ANOVA with the factors radial direction and precue type was run on the data. The precueing effect was significant ($F_{1,6} = 18.71$, $p = 0.005$), as was the effect of the radial direction of the target ($F_{7,42} = 3.83$, $p = 0.003$), but, importantly, there was no interaction between precue type and radial direction ($F_{7,42} = 1.34$, $p = 0.273$). This indicates that the precueing effect

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(5) $d' = 2^{1/2} Z(\rho)$, where ρ is the proportion correct and $Z(\rho)$ is the value of the cumulative Gaussian distribution corresponding to proportions, for the particular value of ρ (see eg Hacker and Ratcliffe 1979; Wickens 2002).

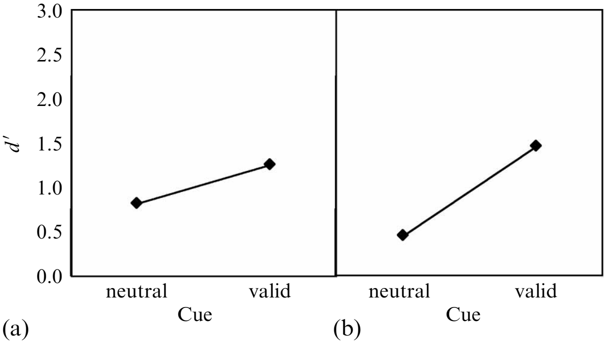

Figure 6. The precueing effect (performance difference between the valid and neutral precue conditions) in experiment 3 (a) and experiment 4 (b) shown in d' for two-alternative forced-choice tasks.

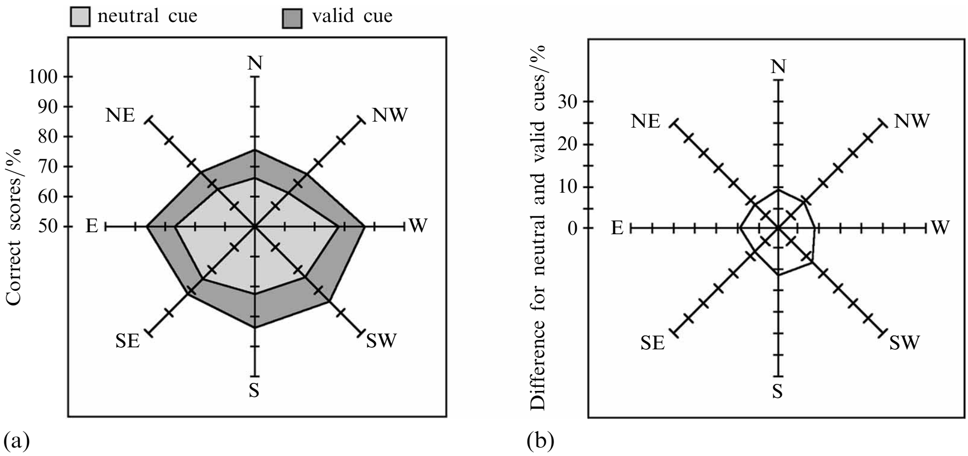

Figure 7. The results of experiment 3. (a) Performance with and without a valid peripheral precue; (b) the precueing effect (the difference between performance for the valid and neutral precues).

Table 1. Standard errors of the mean of the percentage-correct scores from experiment 3 (shown in figure 7).

Radial direction							
N	NE	E	SE	S	SW	W	NW
3.3	2.9	4.1	3.2	1.9	1.8	3.2	3.5

was not asymmetric; the effect of transient attention was approximately equal across all the radial positions, as can be seen in figure 7b which shows the difference between the valid and neutral precue conditions. There is no apparent difference in the precueing effect for the different radial directions.

In sum, there was a large effect of transient attention summoned by a peripheral precue in experiment 3 in contrast to experiments 1 and 2. This was not unexpected since the peripheral precue indicates the location of the target which may otherwise be very hard to find among the distractors. There was, on the other hand, no evidence of a differential effect of transient attention across the visual field. In other words, performance following the peripheral valid precue preserves the asymmetry between upper and lower visual fields seen for performance without such a cue. This result is consistent with the results of Carrasco et al (2001) who claimed that the effects of transient attention are constant across the visual field (see also Talgar and Carrasco 2002).

6 Experiment 4

There is much evidence for the existence of feature detectors in the visual system that are dedicated to the analysis of orientation, eg that of Gabor patches such as those tested in experiments 1 and 3, as discussed above. The discrimination task in experiment 2 may, on the other hand, draw on somewhat different resources since a comparison of the relative positions of the two disks is required.(6) Therefore we asked whether the disk displacement task used in experiment 2 might benefit more from attention being summoned towards it than the Gabor orientation task.

When the results of experiments 1 and 2 are compared, however, there seems not to be much evidence to support this hypothesis, since almost no effect of a peripheral precue was found. Adding distractors to the Gabor task in experiment 3 resulted in a considerable effect of attentional precueing. For that same reason we added distractors to the disk displacement task in experiment 4. As in experiment 3 observers performed a two-interval forced-choice task.

6.1 *Methods*

Methods were similar to those described for experiment 3 (see figure 5) except that the discrimination task was the same as in experiment 2 (see figure 3). The observers had to decide whether the first or second stimulus interval within a trial contained a target where a small disk was displaced to the right or left of the centre of a larger disk. The smaller disk was displaced by 0.1 deg from the centre of the larger one on the target. The target was presented among seven distractors where the smaller disk was at dead centre of the larger disk. The precue never cued the same locations across the two intervals of a single trial. Seven new observers (four male) participated in 1600 trials each and had to indicate which of two intervals contained a target among the distractors (see section 3.1 for a description of the stimuli).

6.2 *Results*

The overall precueing effect is shown in figure 6b. There was a large effect of the peripheral valid precue, quite a bit larger than for experiment 3, reflecting that performance with the neutral precue was much worse than in experiment 3. As we hypothesised, this suggests that the task in experiment 4 benefits more from the attentional manipulation. Importantly, the briefly presented precue (106 ms) boosts performance more for the upper than the lower visual field as can be seen in figures 8a and 8b. Table 2 then shows the standard errors of the mean for the different radial directions.

These conclusions were confirmed with a two-way repeated-measures ANOVA, which revealed a significant main effect of precue type ($F_{1,6} = 24.36$, $p = 0.002$) and radial direction of the target ($F_{7,42} = 4.34$, $p < 0.001$) and, most importantly, a robust interaction between the two factors ($F_{7,42} = 6.86$, $p < 0.001$), which confirms that the precueing effect was not constant across the visual field but improved performance to the largest extent for regions in the upper visual hemifield as can be seen by inspection of figure 8b.

Thus, experiment 4 does, indeed, indicate that transient attention can have an asymmetrical effect on performance on a visual discrimination task, boosting performance most where it is generally worst without the benefits of a valid attentional precue.

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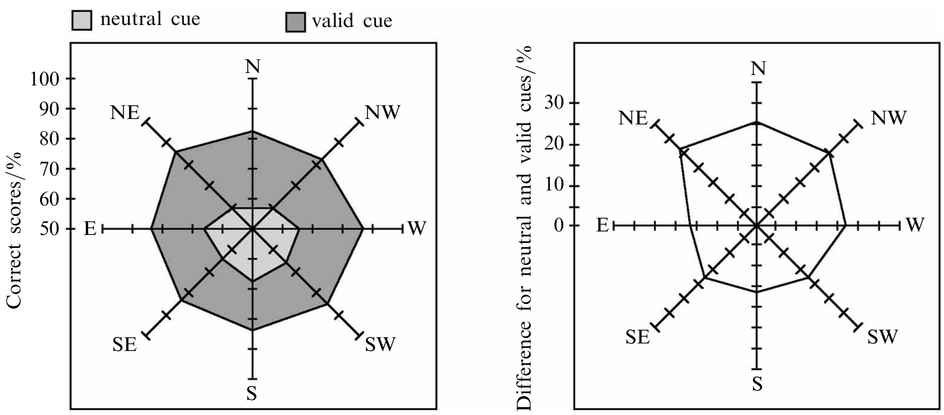
(6) Here we are, by no means, ruling out that low-level feature analysis aids performance in the acuity task (see eg Findlay 1973), but the connection between the Gabor task and known neural mechanisms is, of course, much more obvious, and orientation-selective cells in early striate areas are much more selective for the stimuli in experiments 1 and 3 than experiment 2 (eg Albrecht et al 1980).



(a) (b)

Figure 8. The results of experiment 4. (a) Performance without a valid precue and with such a precue; (b) the precueing effect (the difference between the valid precue and neutral precue conditions).

Table 2. Standard errors of the mean of the percentage-correct scores from experiment 4 (shown in figure 8).

Radial direction							
N	NE	E	SE	S	SW	W	NW
4.1	2.3	2.1	1.8	2.6	1.5	1.2	4.0

7 General discussion

The main conclusion from the experiments presented here is that transient attention, summoned by a precue in the visual periphery, can in some cases cause an asymmetrical effect on visual performance as a function of visual hemifield, yielding a larger boost in performance in the upper than in the lower visual hemifield.

It is important to note that we do not wish to argue that transient visual attention favours the upper visual hemifield, but that there is more need for improvement as well as more room for improved performance following precueing, since the upper visual field is more sparsely represented in terms of visual receptors and visual cortex as discussed in the introduction. The results of experiment 4 are consistent with the hypothesis that larger effects of brief attentional precues are seen for areas that ‘need it the most’, or, in other words, regions where visual resolution is otherwise the lowest.

In experiments 3 and 4 we found a robust precueing effect not seen in experiments 1 and 2. This can, most likely, be attributed to the added distractors presented along with the target in experiments 3 and 4. The fact that we only see the asymmetry in the attentional effect when distractors accompany the target is consistent with lower hemifield advantages for an enumeration task with distractors found by Lakha and Humphreys (2005), an asymmetry not seen when no distractors were present. Finally, the results of experiments 1 and 2 show that hemifield differences in visual performance become more pronounced the larger the eccentricity.

On the whole, our results suggest that asymmetries in the effects of transient attention arise only under certain conditions, as a task becomes more difficult or attentionally demanding. In the first two experiments, the observers did not benefit much from the precues in the first place, so no precueing asymmetries could be expected. The precueing benefits were actually quite large in experiment 3 but even more so in experiment 4, possibly explaining why the attentional asymmetry was only seen in the latter case.

Another possible reason for the discrepancy between experiments 3 and 4 may be the difference in the topological properties of the stimuli as previously discussed. This difference may also account for the seeming incongruence between the results here and those of Carrasco and colleagues (see also Talgar and Carrasco 2002), who found that the effects of transient attention are constant across the visual field. Carrasco and colleagues used Gabor orientation-discrimination and texture-segregation tasks where simple orientation differences define the targets. Our results actually confirm that no attentional asymmetries are found for such tasks, but indicate that tasks such as our disk-displacement task, reveal asymmetries in the effects of the precues, perhaps because the comparison is more complex and may not recruit the same neural mechanisms as the relatively simple orientation tasks.

A precueing asymmetry is also consistent with the results of Golla et al (2004), who found that thresholds for Landolt C orientation judgments benefited more from attentional precueing the larger the eccentricity. There is an important difference, though, in that the asymmetries there were for eccentricity rather than hemifields. An interesting question for further study might be whether precueing asymmetries as a function of eccentricity depend on the topological properties of the discrimination stimuli.

As mentioned before, Rezec and Dobkins (2004) found asymmetries in the benefits of sustained attention across the visual field. Rezec and Dobkins mentioned several reasons for this discrepancy between their results and those of Carrasco and colleagues. These were, among others, that stationary-orientation tasks may yield weaker attentional effects than the more dynamic displays they used and a second possible reason they mentioned was that this difference could be because they tested effects of sustained, rather than transient, attention. Our results here suggest that the second of these possible reasons is unlikely to be true. The results of experiment 4 indicate that asymmetries for transient attentional deployments following a precue can be found with very brief precues of around 100 ms which is approximately the temporal peak of the benefits of transient attention (Cheal and Lyon 1991; Nakayama and Mackeben 1989). There was also a hint of this in the results of Golla et al (2004) who found that there were clear benefits from a spatial precue, but that these effects became larger with eccentricity, and also as precue lead-times became shorter, and came closer to the peak of the benefits from transient attention. Golla et al did not assess differences between upper and lower visual hemifields, however, as was done here.

In light of the results presented in this paper, the former suggestion by Rezec and Dobkins is more plausible, that the critical difference accounting for the discrepancy between their results and those of Carrasco and colleagues is the type of stimuli used. Rezec and Dobkins certainly used much more complex judgment tasks than those used by Carrasco and colleagues, and we found asymmetries in the effects of transient attention only for the task assumed to require the most complex visual processing. Rezec and Dobkins argued from their results that visual attention is generally weighted towards the lower visual hemifield, but can be summoned towards upper regions in the visual field when needed, compensating for asymmetries in visual resolution. Our results here are generally consistent with these suggestions. An important difference is that their study used longer precue times, thus presumably testing performance under sustained attention. The current study indicates that attentional asymmetries may be found for transient attention as well as for sustained attention.

Possible ecological and evolutionary explanations for hemifield differences in performance may be that what appears in the lower visual field tends to be closer to us and thus perhaps more pertinent to behaviour, or even different types of behaviour than the upper visual field (Levine and McAnany 2005; Previc 1990). As an example, Levine and McAnany (2005) found that discrimination performance was actually better in the upper visual field when the task involved different apparent distances from the observer. Levine and McAnany argued:

> "The lower visual field is where the hands (or paws) work at fine tasks like separating seeds and peels from fruit, or capturing small prey. Fine color and contrast discriminations would be important for such tasks, as would sensitivity to small lateral motions. The upper field may be somewhat more concerned with approaching dangers: low tree branches, swooping predators. Recognition of depth could be important to avoid these threats. It is reasonable to assume that our visual systems have evolved to meet these needs." (Levine and McAnany 2005, page 2829)

The asymmetry between the two hemifields may also reflect that in the natural environment more visual information is on average available below than above the horizontal meridian (Previc 1990). There may also be corresponding differences in the effects of attention for the two visual fields.

7.1 *Possible neural signatures*

When attention is directed to a particular stimulus, firing rates of single neurons in the visual cortex of macaque monkeys seem to increase to a similar degree as they do when stimulus contrast is increased (McAdams and Maunsell 1999; Martinez-Trujillo and Treue 2002; Reynolds and Chelazzi 2004). Similar effects have been found in fMRI studies on humans (see eg Ress and Heeger 2005, for review). The expectation that a visual stimulus will appear in a certain location can affect neural activity in the visual cortex even without any visual stimulation (Kastner et al 1999; but see Corbetta et al 2005). This also seems to be the case when attention is transiently drawn toward a specific location in the visual field (Ruff et al 2007; Yantis et al 2002). Recent evidence, moreover, suggests that the spatial coordinates of receptive fields of neurons responsive to visual stimuli can shift to an attended stimulus (Womelsdorf et al 2006).

Given these effects on the response of visual areas, an investigation of possible asymmetries in the BOLD response following attentional precues would seem in order. Tootell et al (1998) found some hints of an asymmetry for the upper versus lower visual field in an fMRI study of attentional effects across the visual field, but the question of asymmetry was not addressed explicitly in their study, and their study addressed the effects of sustained not transient attention. To our knowledge, neural correlates of possible hemifield asymmetries in the effects of transient attention are yet to be examined with retinotopic fMRI. In light of the current results such an undertaking might be worthwhile.

8 Conclusions

The current results suggest that visual resolution is, on the whole, better in the lower than upper visual field, but that transient attention can to a certain extent compensate for poorer resolution in the upper visual field. The effect of transient attention on visual performance can thus be asymmetric, but not for all types of task. The results suggest that the largest effects of transient attention are seen in areas where such an attentional boost is most needed, as in the upper visual hemifield.

Acknowledgments. ÁK was supported by a long-term fellowship from the Human Frontiers Science Program (HFSP) and a grant from the research fund of the University of Iceland.

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ISSN 0301-0066 (print) ISSN 1468-4233 (electronic)

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