

Temporal limits of long-range phase discrimination across the visual field

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Abstract

When two flickering sources are far enough apart to avoid low-level motion signals, phase judgment relies on the temporal individuation of the light and dark phases of each source. The highest rate at which the individuation can be maintained has been referred to as Gestalt flicker fusion [Van de Grind, W. A., Grüsser, O. -J., & Lunkenheimer, H. U. (1973). Temporal transfer properties of the afferent visual system. Psychophysical, neurophysiological and theoretical investigations. In R. Jung (Ed.), *Handbook of sensory physiology* (Vol. VII/3, pp. 431–573). Berlin: Springer, Chapter 7] and this has been taken as a measure of the temporal resolution of attention [Verstraten, F. A., Cavanagh, P., & Labianca, A. T. (2000). Limits of attentive tracking reveal temporal properties of attention. *Vision Research*, 40, 3651–3664; Battelli, L., Cavanagh, P., Intriligator, J., Tramo, M. J., Henaff, M. A., Michel, F., et al. (2001). Unilateral right parietal damage leads to bilateral deficit for high-level motion. *Neuron*, 32, 985–995]. Here we examine the variation of the temporal resolution of attention across the visual field using phase judgments of widely spaced pairs of flickering dots presented either in the upper or lower visual field and at either 4° or 14° eccentricity. We varied inter-dot separation to determine the spacing at which phase discriminations are no longer facilitated by low-level motion signals. Our data for these long-range phase judgments showed that temporal resolution decreases only slightly with increased distance from center of gaze (decrease from 11.4 to 8.9 Hz between 4° to 14°), and does not differ between upper and lower visual fields. We conclude that the variation of the temporal limits of visual attention across the visual field differs markedly from that of the spatial resolution of attention.

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1. Introduction

Individuation of objects in the world is essential for selecting items for further analyses. In the spatial domain, individuation refers to the ability to select an item independently of its neighbors in order to access the properties—location, color, identity—that belong to it alone. The resolution of spatial selection can be easily demonstrated in a “counting” task as first noted by Landolt in 1891. He reported that bars spaced more closely than 5 arc min of visual angle could be seen, but not counted even when looking right at them: “You get to a point where you

can no longer count them at all, even though they remain perfectly and distinctly visible.” (Landolt, 1891). If the observer fixates and the bars are presented outside the fovea, the demonstration is even more dramatic as bars spaced by even 1° of visual angle (at 3° eccentricity) cannot be counted one by one (Intriligator & Cavanagh, 2001).

He, Cavanagh, and Intriligator (1996, 1997) proposed that spatial individuation relied on attentional mechanisms and that its limit served as a measure of the resolution of spatial attention. For example, if the spacing of bars in a grating is finer than this individuation limit but not finer than the limit of visual acuity, observers can see the bars (and differentiate the grating from a uniform field and report its orientation) even though the bars cannot be counted. Thus, in this view, the spatial resolution of

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attentional selection is far worse than the spatial resolution of vision. Previous studies have shown that the spatial resolution of visual selection is not homogenous across the visual field, dropping sharply with increasing distance from the center of gaze (Intriligator & Cavanagh, 2001). In addition to the inhomogeneity due to eccentricity, the spatial resolution of attentional selection is coarser in the upper visual field compared to the lower visual field (He, Cavanagh, & Intriligator, 1996; Intriligator & Cavanagh, 2001).

The same concept of individuation in space is also applicable to time. When a white disc is turned on and off on a gray background at a temporal rate of up to 7–10 Hz, the light appears to alternate between “on” and “off” states and observers are able to individuate successive states of light, leading to the experience of steady light–dark alternation. Above this rate, so-called the Gestalt flicker fusion rate, the light is experienced as a constant flicker without individual light and dark states (Grüsser & Landis, 1991; Van de Grind et al., 1973). The temporal limitation of 7–10 Hz is also found in several other tasks. Battelli and colleagues reported temporal rates of 8–10 Hz as thresholds when subjects had to discriminate between apparent motion and synchronous presentation of stimuli (Battelli et al., 2001). Verstraten et al. (2000) showed that the maximum rate at which observers could attentively track a bistable moving display or report the direction of unambiguous apparent motion or track a continuously moving target was around 4–8 Hz. Temporal rates for phase discrimination of flickering lights show similar temporal limitations (He, Intriligator, Verstraten, & Cavanagh, 1998; He & McLeod, 1993; Rogers-Ramachandran & Ramachandran, 1998). In addition, the temporal rate at or above which direction discrimination of cyclopean motion fails is 8 Hz (Patterson, Ricker, McGary, & Rose, 1992). These and other data have led several authors to propose both a slow and a fast mechanism for detecting phase differences (Rogers-Ramachandran & Ramachandran, 1998; Forte, Hogben, & Ross, 1999; Victor & Conte, 2002) where the fast mechanism can only work over short distances whereas the slow mechanism can operate over very large distances. The temporal limit of the slow mechanism has been linked to the temporal resolution of attention where the individuation of the light and dark phases of the flicker is assumed to be mediated by visual attention (Battelli, Cavanagh, Martini, & Barton, 2003; Verstraten et al., 2000). Note that this temporal limit is much lower than the temporal resolution of vision, which is around 30–50 Hz (Andrews, White, Binder, & Purves, 1996; Rovamo & Raninen, 1984). Thus, homologous to the spatial resolution of attention, the temporal resolution of visual attention is much coarser than the temporal resolution of vision.

The origin of the variations of spatial resolution of attention across the visual field may arise from the properties of the cortices where attention operates. The mapping from retina to cortex (the cortical magnification factor) has different organization for different visual cortices (Gattass, Gross, & Sandell, 1981; Gattass, Sousa, & Gross, 1988).

The underlying assumption is that an “attentive field” has a constant size on the visual cortex on which it operates, so that the scaling of the attentional field with eccentricity reflects the cortical magnification factor of that particular cortex. Parietal areas are often implicated in the control of spatial attention (Culham et al., 1998; Posner, Walker, Friedrich, & Rafal, 1984, 1987). Parietal areas receive more input from the lower visual field compared to the upper visual field (Maunsell & Newsome, 1987), a factor that may contribute to the finer resolution of spatial attention in the lower visual field.

In contrast, there is no corresponding temporal cortical magnification factor yet identified. The flicker fusion rate does not vary across the visual field either as a function of eccentricity or as a function of visual field (upper vs. lower) (Rovamo & Raninen, 1984). This suggests that the temporal resolution of low-level (visual) mechanisms is relatively homogeneous across the visual field. Will high-level, attention-based temporal mechanisms follow the pattern of flicker fusion or that of spatial attention? If temporal and spatial attention show similar limits across the visual field, it would suggest that spatial and temporal attention rely on a common resource.

We used phase judgments between two flickering dots to evaluate the temporal resolution at two eccentricities separately in the upper and lower visual fields. When two flickering discs are close to each other, they may both fall inside the receptive field of a directionally selective unit in primary visual cortex. In this case, a strong motion percept accompanies even small phase shifts between the two flickering dots and the rates that support discrimination between in-phase and out-of-phase flicker approach flicker fusion rates (Anstis, 1980; Boulton & Baker, 1993). As the spacing between the discs increases, the contribution of low-level motion signals diminishes, and in the limit, the phase discrimination relies solely on high-level signals (including high-level motion if elicited). In this case, observers can perform the task only at much lower temporal rates (Anstis, 1980; Battelli et al., 2001). It has been shown that with large displacements between the stimuli, attentional mechanisms are necessary, requiring the detection of appearances and disappearances and combining these events, which consequently leads to motion perception (Dick, Ullman, & Sagi, 1987). We expect that as we increase the inter-dot spacing, phase judgments will deteriorate up to a particular point (representing the limit of low-level motion) and stay relatively constant for spacings beyond that point.

The properties of slow and fast mechanisms for temporal phase judgment were studied by Forte et al. (Forte et al., 1999). They presented a regular array of flickering gaussian spots where the spots in one quadrant were out-of-phase with those in the other quadrants. Their results showed that the fast mechanism could operate only when the separation between spots of different phase was 0.4° or less. The array used by Forte et al. (1999) covered all quadrants and the separation between the differing phase

spots always lay along the horizontal and vertical meridian stretching from the fovea to about 5° eccentricity. As a result, their data offer no information about the effects of eccentricity or visual field on the temporal limits of the slow mechanism. Victor and Conte (2002) also reported that the fast phase mechanism is severely impaired by separation between the stimuli. However, they did not evaluate the effects of eccentricity or visual field either.

The aim of this study was to look at rate thresholds of phase discrimination for pairs of flickering discs to see whether the thresholds change when stimuli are presented at different eccentricities and across (upper vs. lower) visual fields. The spacing between the discs was varied, and the threshold at which observers could report the relative phase of the flickering discs at 75% accuracy was considered as the threshold at each inter-disc spacing. As discussed above, presenting the stimuli at different inter-disc spacings allows us to separate the contribution of low-level and high-level signals in the task. In our study we obtained thresholds for stimuli presented at two different eccentricities of 4° and 14° and in each of the four quadrants (upper and lower, left and right).

2. Obtaining thresholds at 4° and 14° eccentricity

2.1. Methods

2.1.1. Observers

Four observers (two females and two males) ranging in age from 26 to 31 years participated in this experiment. All observers had normal or corrected-to-normal visual acuity. One of the observers was the author (SMA) and three others were experienced observers naïve to the purposes of the experiment.

2.1.2. Apparatus

The stimuli and the psychophysical experiment were programmed in MATLAB, using the Psychophysics Toolbox extensions (Brainard, 1997; Pelli, 1997). Images were displayed on an Apple color monitor, $800\text{H} \times 600\text{V}$ pixel resolution (120 Hz refresh rate) controlled by a Macintosh G4 computer. Observers were placed in a dark room and viewed displays binocularly while their heads were fixed

on a chin and forehead rest. The viewing distance was 44 cm.

2.1.3. Stimuli

The fixation point was a black dot with a diameter of 0.22° (0.06 cd/m^2). Stimuli were a pair of white circular discs (86.4 cd/m^2) presented on a uniform gray background (20.4 cd/m^2). The stimulus pair was presented either at 4° or 14° eccentricity, each subtending 1° or 2.25° , respectively. The size of the discs at the more eccentric location was increased using M-scaling to account for cortical magnification. At each eccentricity both discs were located on the circumference of an imaginary circle with a radius of the corresponding eccentricity and with equal distance from the 45° or 135° lines drawn from the fixation point.

The center-to-center separation between the discs was set at six different levels for each eccentricity. The inter-disc spacings used for the 4° eccentricity included 1.25° , 1.75° , 2.4° , 3° , 3.75° and 4.5° . For the 14° eccentricity, the spacings we used included 2.81° , 3.94° , 5.4° , 6.75° , 11.25° and 15.75° . The separation between the discs at 14° was increased to match the eccentricity and larger size of discs. The spacing between the discs always insured that both remained in the same quadrant.

Two sets of temporal frequencies at which the discs flickered were used: at both eccentricities, for the three smaller inter-disc separations, the frequencies tested were 6, 7.5, 8.5, 10, 12, 15, 20 and 30 Hz. For the three larger inter-disc separations, the frequencies tested were 5, 6, 7.5, 8.5, 10, 12, 15 and 20 Hz.

2.1.4. Procedure

Before each trial, there was a pre-trial phase of 33 ms, during which both discs were flashed simultaneously for two cycles (Fig. 1). This was done in order to prevent observers making their phase judgments based on the cue in the first frame (i.e., seeing one disc in the out-of-phase presentation or two discs in the in-phase presentation).

During each trial, the two discs were presented flickering either in-phase or 180° out-of-phase (i.e., both discs appearing at the same time or one appearing when the other one disappeared). The relative phase of the two discs was randomly assigned and the observer's task was to

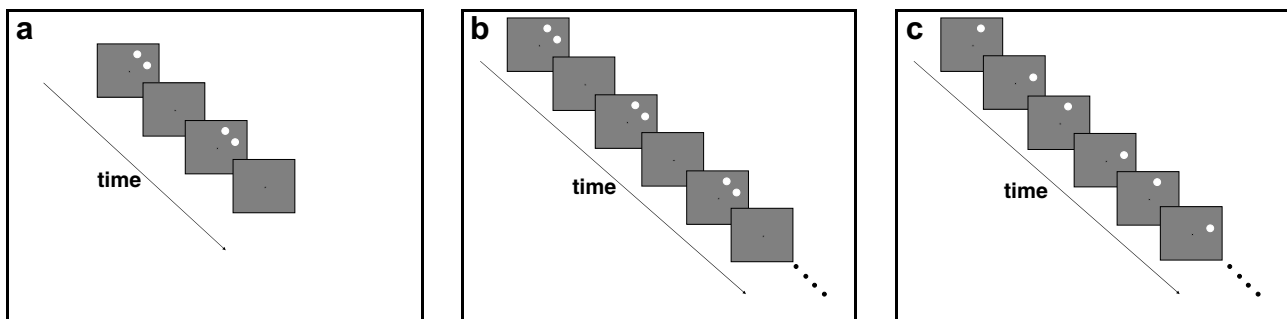


Fig. 1. The experimental paradigm. Observer's task was to report whether the flickering dots appeared in-phase or out-of-phase. (a) The pre-trial condition. During this period, both stimuli flashed for two cycles. The pre-trial condition preceded both the in-phase and the out-of-phase presentation of the stimuli. (b) In-phase presentation of the stimuli. (c) Out-of-phase presentation of the stimuli. The presentation time was 500 ms.

report their relative phase using either of a pair of keys on the computer keyboard. Exposure time for each trial was set to 500 ms. The next trial proceeded after a 1 s inter-trial interval.

In each trial the inter-disc separation, the quadrant in which the stimulus appeared and the flickering rate of discs were randomly assigned at the beginning of each block. Each block consisted of 384 trials (stimulus type (2) \times visual quadrant (4) \times spacing (6) \times temporal frequency (8)), and each observer performed 10 blocks.

3. Results

The phase discrimination threshold was determined for each inter-disc separation, eccentricity and visual field, separately for each observer. No difference was observed between any observer's performance in the left and right hemifield and thus the data for the left and right hemifields were pooled. The data were fit with a Probit function and the temporal rate at which observers could discriminate in-phase vs. out-of-phase presentation of the flickering discs with 75% accuracy was taken as the discrimination threshold at that particular inter-disc separation (Fig. 2).

After deriving the thresholds for each inter-disc separation, these values were plotted against inter-disc spacings (Figs. 3 and 4, dots). The threshold vs. inter-disc spacing data showed an exponential drop in the frequency limit as a function of spacing as the low-level motion contribution decreased. In each case, the frequency limit settled to a steady value that indicated the performance when no low-level motion responses contributed. To recover this asymptotic value for the long-range phase judgments, each subject's data was fit with an exponential function ($y = a \cdot \exp(-b \cdot x) + c$) for each eccentricity and upper vs. lower visual field. At each eccentricity, we fitted all eight curves (four subjects \times two visual fields) simultaneously, fitting one decay rate (b parameter) for all curves and recovering

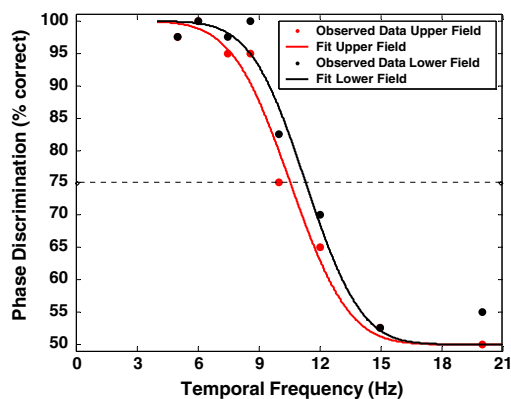


Fig. 2. Sample phase discrimination performance as a function of temporal frequency at 14° eccentricity for subject TY. The inter-disc separation is 6.75°. The curves are the Probit functions fit separately to the upper and lower visual field data. Red and black colors show data and fits for upper and lower visual fields, respectively. The dashed line shows 75% correct values. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

a separate a (starting value) and c (the asymptotic limit) for each curve. The asymptote of the fitted model was the temporal frequency at which each observer could perform the phase discrimination task with 75% (or higher) accuracy, independently of low-level motion signals.

Fig. 5 compares the asymptotic values (long-range phase judgment thresholds) obtained for each eccentricity and visual field in each individual subject. To study the effect of eccentricity and visual field across all subjects, a two-way ANOVA with repeated measures [eccentricity (4° vs. 14°) and visual field (upper vs. lower)] was performed on the long-range phase thresholds (i.e., the asymptote value for each curve in Figs. 3 and 4). A significant effect was found for the effect of eccentricity ($F(1, 3) = 38.43$, $P < 0.01$). No significant effect was found for the effect of visual field ($F(1, 3) = 4.67$, $P = 0.12$, *NS*) nor for the interaction between eccentricity and visual field ($F(1, 3) = 4.01$, $P = 0.14$ *NS*). As shown in Fig. 5, the eccentricity effect did not show significance in the data of individual subjects and the effect became significant only in the group data.

We also compared the cut-off point for the contribution of low-level mechanisms in the drop-off of performance as dot spacing increased. We took the $1/e$ value for this cut-off spatial separation (spacing = $1/b$) for the two different eccentricities. We expect this value to be larger at the greater eccentricity as the receptive field size for low-level motion detectors increases with eccentricity, as indicated by physiological measures (Hubel & Wiesel, 1974) and by D_{\max} measures (Baker & Braddick, 1985). The $1/e$ range of the low-level mechanisms suggested from our data was about 0.91° at 4° and 1.75° at 14° (See Section 4 for additional comments).

Finally, we ran a control to examine the effect of the pre-trial frames where both dots were present simultaneously. These were present to mask any obvious cues to phase in the initial test frame. Specifically, the first frame had two dots in the in-phase trials, but only one in the out-of-phase trials. The pre-trial frames may not have been effective or may have provided other cues to phase. Also we did not, in the main experiment, add any trailing frames to mask the offset cues to phase. Control data were collected in three conditions: the original condition, a condition where there were no pre-trial frames and a condition where there were both a pre-trial and a post-trial frames (the post-trial phase was identical to the pre-trial phase, except that it followed the stimulus presentation). We tested only one spatial separation (asymptotic separation) and one temporal rate (threshold rate) and looked at percent correct to see whether there was any effect of the presence of the pre- and post-trial phase. Data was collected from two subjects who had previously participated in the original experiment. A two-way ANOVA analysis [visual field (upper vs. lower) and presentation condition (only pre-trial vs. no pre-trial vs. both pre-trial and post-trial)] was performed. No effect was found for presentation condition ($F(2, 11) = 0.18$; P -value = .84). Thus, while we inserted the pre-trial phase as a cautionary measure, their presence apparently neither helped nor hindered observers.

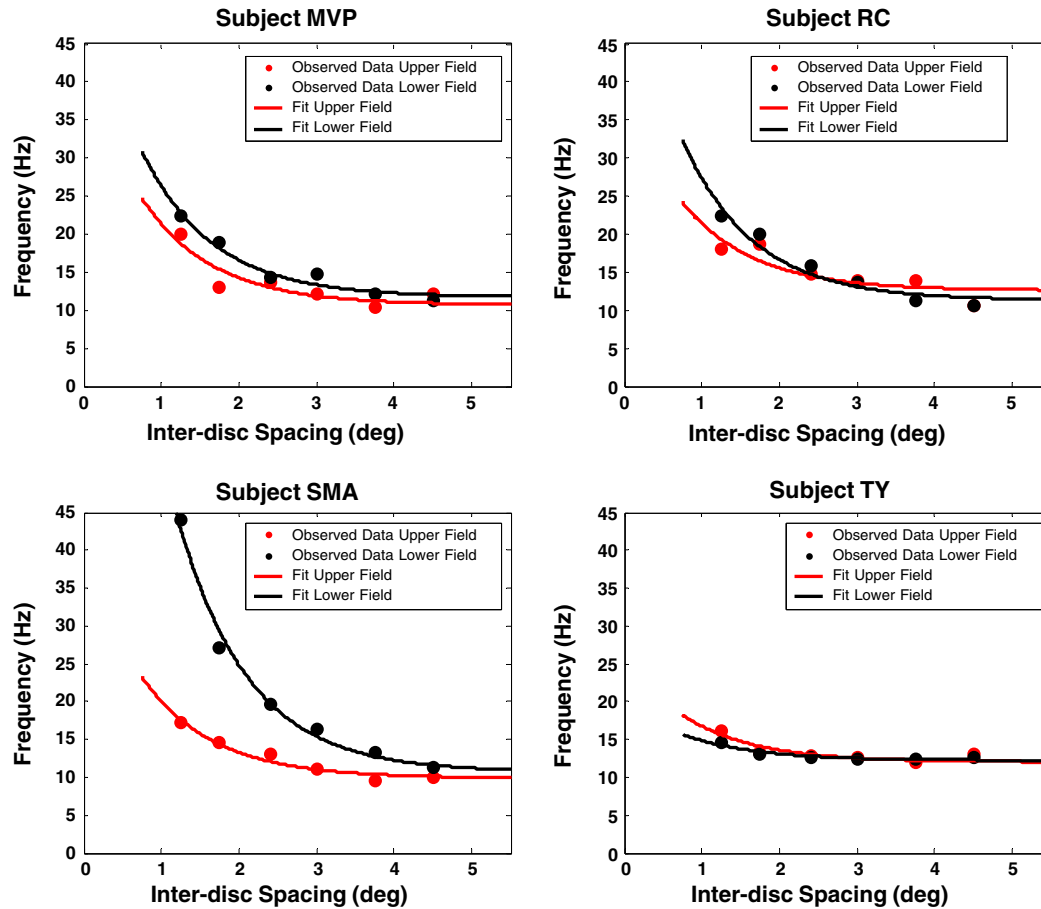


Fig. 3. Temporal frequency thresholds for phase judgments as a function of inter-disc separation at 4° eccentricity. Data for each subject is shown separately. Each dot represents the temporal frequency that allowed 75% correct performance at that particular inter-disc spacing (as shown in Fig. 2). The curves are the exponential fits to the data. Red and black colors show data corresponding to upper and lower visual fields, respectively. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

4. Discussion

Our results show that, as measured by long-range phase judgments, the temporal limits of visual selection do not differ between the upper and lower visual fields, and decrease only moderately with eccentricity. We claim that the temporal limits we have measured reflect the temporal resolution of attention. This claim is based on the assumption that attention is required to individuate the phases of the flickering stimuli: without individuation (via attention), the flickering stimuli cannot be broken down into discrete phases and, in the absence of low-level motion cues, it is no longer possible to compare the instantaneous phases of the two flickering dots.

Our data show that the temporal resolution of attention shows no significant effect of visual field, while spatial resolution of attention shows a noticeable advantage for the lower field presentation (between 17% and 50% advantage for the lower field; Intriligator & Cavanagh, 2001). In addition, even though both spatial and temporal resolution of attention are better near the fovea than in the periphery, the magnitude of the change is very different: the resolution in spatial attention increases by 288%, from 0.50 targets/ $^\circ$

at 15° eccentricity to 1.94 targets/ $^\circ$ at 3.5° eccentricity (tangential stepping task, computed as 75% threshold for single selection step, average of upper and lower fields, Intriligator & Cavanagh, 2001) whereas, the temporal resolution of attention improves by only 28%, from 8.9 to 11.4 Hz, between 14° and 4° .

We should emphasize that the task we used in our study is as much as possible, the temporal equivalent to that used for studying spatial resolution of attention (Intriligator & Cavanagh, 2001) and thus comparison of spatial and temporal limits of attention from the two tasks are meaningful. For studying the spatial limitations of attention (Intriligator & Cavanagh, 2001), an array of dots was presented in the periphery and one dot was cued. Following computer commands, subjects stepped mentally back and forth from dot to dot only using attention (keeping fixation) until a probe was presented and subjects reported whether the probe was on the dot they had stepped to. The task could be performed only if attention could (spatially) individuate the items, allowing attention to move from one dot to the next. For item-to-item spacings closer than the resolution of spatial attention, targets could not be spatially individuated and tracking was not possible. For studying the

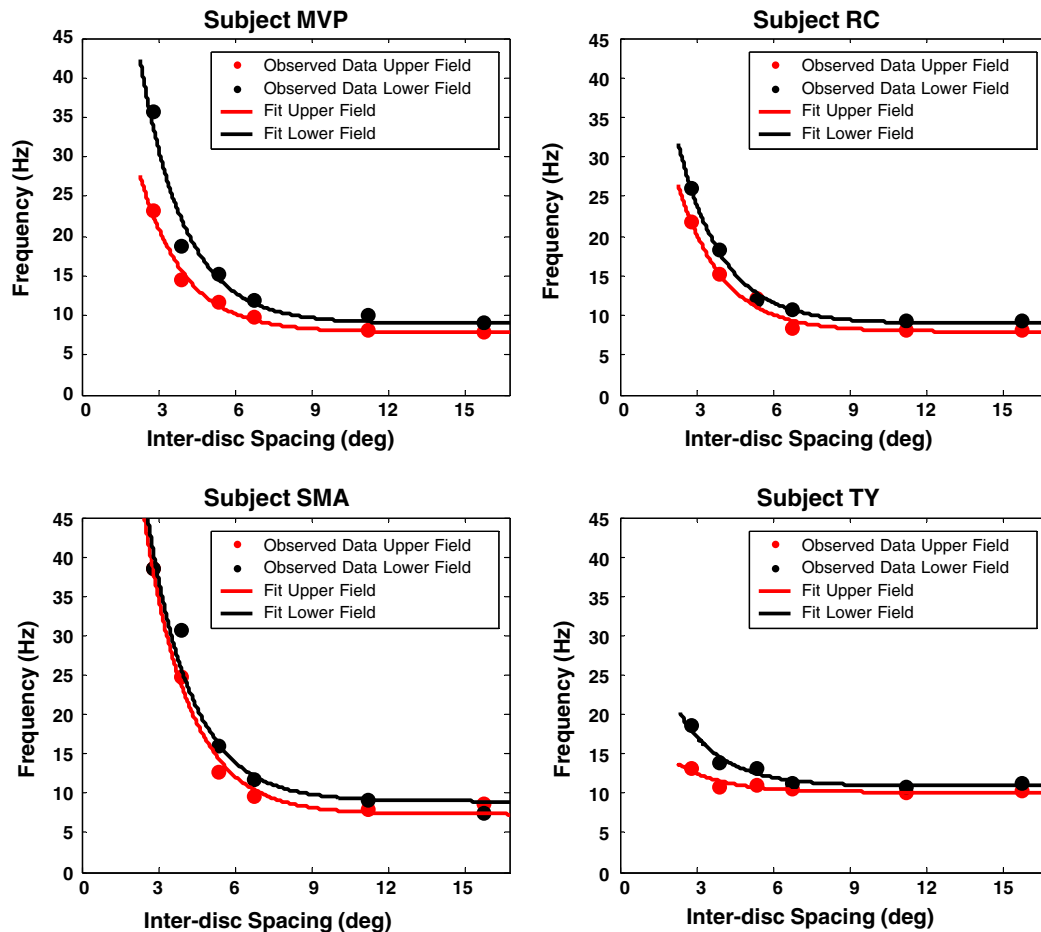


Fig. 4. Temporal frequency thresholds for phase judgments as a function of inter-disc separation at 14° eccentricity. Data for each subject are shown separately. The curves show the exponential fits to the data. Red and black lines correspond to upper and lower visual field data, respectively. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

resolution of temporal attention, the equivalent question is posed for spacing of items in time rather than space. If items were presented too closely spaced in time to be individuated, tasks that require access to the individual dot appearances would fail. To test temporal resolution at different eccentricities, we chose the phase judgment task where two dots flickered either in- or out-of-phase. Discriminating the relative phase of the flickering stimuli is possible only if each light and dark phase of a flickering dot can be accessed individually. If not, the two dot locations are both seen as undifferentiated flicker, the relative timing between the dots is lost, and no cross-location pairing can be made that supports the phase judgment. We believe this approach is equivalent to the spatial tests. In the spatial case, the question asked was whether the closely spaced adjacent dots could be individuated and thus allowed stepping from one to the other. In the temporal case, we asked whether dot flashes, closely spaced in time, were sufficiently individuated from the following flashes at the same location to support a comparison of phase between the two locations. In either the spatial or temporal cases, if the locations or moments were not individuated, the stepping or phase comparison failed.

The temporal threshold levels obtained in our study are in the same range of those reported previously. Gestalt flicker fusion, the temporal rate at which observers can individuate successive states of light, is around 7–10 Hz (Grüsser & Landis, 1991; Van de Grind et al., 1973). Above this rate, there is no access to the individual state of each “on” and “off” event. As a result, the percept changes: the spot of light seems to be flickering continuously with no discrete appearances and disappearances. In a study where subjects had to discriminate between apparent motion and synchronous presentation of stimuli, similar thresholds were obtained (Battelli et al., 2001). Verstraten et al. showed that above the rate of 4–8 Hz, observers could not attentively track a bi-stable moving display, neither could they report the direction of unambiguous apparent motion nor track a continuously moving target (Verstraten et al., 2000). Phase judgments for widely spaced items (Forte et al., 1999; Victor & Conte, 2002) and discrimination of flickering lights (He & McLeod, 1993; He et al., 1998; Rogers-Ramachandran & Ramachandran, 1998), and direction discrimination of cyclopean motion (Patterson et al., 1992) all show the similar 7–10 Hz limitation on temporal selection. It has been suggested that this

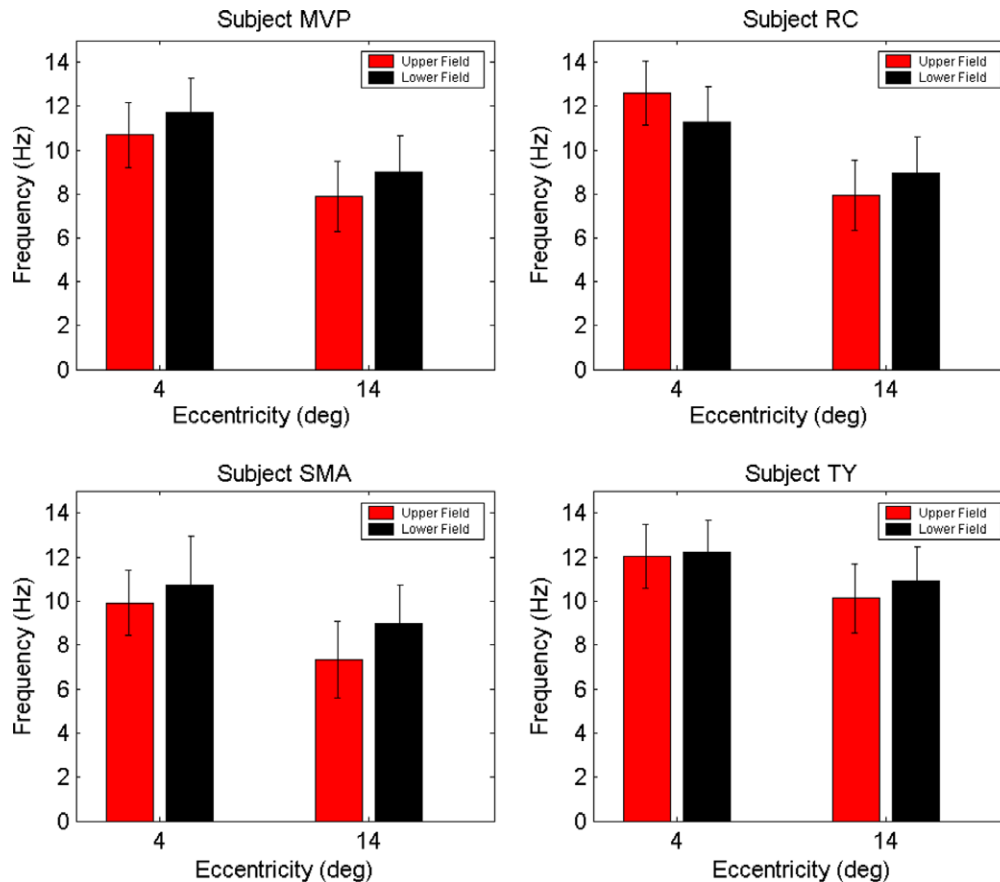


Fig. 5. Long-range phase discrimination thresholds at 4° and 14° eccentricities. Data for each subject are shown separately. Each threshold is the asymptote value (c) of the exponential fit to each threshold vs. frequency function (Figs. 3 and 4). Error bars represent ± 1 standard error of the fit parameter c . Red and black colors show data corresponding to upper and lower visual fields, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

temporal limitation is imposed by attentional mechanisms (Forte et al., 1999; Verstraten et al., 2000).

As predicted (see Section 1), when we increased the inter-dot spacing, phase judgments deteriorated up to a particular spacing (representing the limit of low-level motion) and stay relatively constant beyond that point. The inter-disc separation at which low-level motion drops away and performance relies on high-level signal is similar to the D_{\max} measure (Braddick, 1974), the maximum displacement of random dot pattern that supports low-level motion perception. D_{\max} gives a good measure of the spatial range of low-level motion because the random dot patterns do not offer any obvious large-scale shape to track over distances beyond the limit of low-level motion. In our display, however, only single dots are presented, so that once the limit of low-level contribution is exceeded, motion of the dot can still be seen based on high-level object tracking (Braddick, 1980; Cavanagh, 1992). We use performance at separations beyond this asymptote to estimate the properties of high-level mechanisms. Over some range, high-level motion may mediate the phase judgment decision, but at larger spacings, motion may not be seen and phase judgments will be based on perception of simultaneity vs. non-simultaneity. In either case, we assume

that the performance reflects the underlying individuation of the “on” and “off” phases of each dot and reveals the temporal limits of visual attention.

As it can be seen in both Figs. 3 and 4, at each eccentricity the threshold rates are highest for the closest spacing between the discs. When discs are close enough, observers can perform the simultaneity judgments based on low-level motion signals between the dots. As the spacing between the discs increases, the contribution of low-level motion signals diminishes, leading to a drop-off in the thresholds. At each eccentricity we also compared the inter-disc spacing beyond which the low-level motion signal between out-of-phase discs is dominated by the high-level signal. We chose the rate that produced a drop to $1/e$ of the maximum value as our measure of this cut-off point (given by the inverse of the exponential decay rate, b , in the function that we fit to the data). This $1/e$ inter-disc spacing ($1/b$) is 0.91° at 4° eccentricity vs. 1.75° at 14° eccentricity. Thus, with increased eccentricity, the inter-disc spacing at which high-level motion signals dominate low-level motion signals increases. This is in accord with studies which report an increase in D_{\max} , the limit of the low-level motion system, with eccentricity (Baker & Braddick, 1985), where they found an increase in D_{\max} from 0.83° at 4° eccentricity to 1.66° at 10° eccentricity.

The parietal cortex has been the candidate cortical region for visual spatial selection (Corbetta, Shulman, Miezin, & Petersen, 1995; Driver & Mattingley, 1998; Posner et al., 1987). Patients' deficits are not restricted to spatial tasks and they also exhibit problems in the time domain. Husain and colleagues showed that parietal patients suffer from timing deficits, as their attentional blink period is three times longer than controls (Husain, Shapiro, Martin, & Kennard, 1997). However, neuropsychological data suggest that there are differences in terms of cortical regions for spatial and temporal selection. In contrast to neglect syndrome, where the spatial deficits in attention only affect the contra-lateral visual hemifield, patients with right parietal damage have slower temporal selection rates in both left and right visual fields (Battelli et al., 2001).

In conclusion, we found that temporal resolution of attention as measured by long-range phase judgments, shows a small decrease with eccentricity, and no upper vs. lower visual field difference. In contrast, the spatial resolution of attention shows both a foveal and lower visual field advantage. These results suggest that the advantages seen for foveal and lower field presentation cannot be attributed to general attentional factors; they are specific to spatial attention. This also suggests that spatial and temporal properties of visual attention are mediated by different cortical networks.

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