

## Does cognitive perception have access to brief temporal events?

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**Abstract.** To determine whether conscious perception has access to brief temporal event, we asked subjects in an odd-man out paradigm to determine which of the four Gaussian blobs was flickering asynchronously in time. We measure synchrony thresholds as a function of the base temporal frequency for spatially scaled stimuli in foveal and peripheral vision. The results are consistent with a time delay of around 67 milliseconds (ms) for foveal vision and 91 ms for peripheral vision. We conclude that conscious perception has access to only relatively long (~ 67 ms) time events.

**Keywords:** temporal frequency, synchrony, temporal, cognition.

### 1 Introduction

The early stages of visual processing have a high degree of temporal resolution. Photoreceptors can transduce light modulations in the order of 100 hertz (Hz) (Brindley 1962), and retinal ganglion cells can transmit temporal modulations in the vicinity of 80 Hz for diffuse illumination (Frishman et al 1987). Although some regions of the visual cortex (ie, V1) have reduced temporal resolution of around 30 Hz (Foster et al 1985), other areas (ie, MT) can respond to temporal modulations in excess of 30 Hz (Priebe et al 2003). Furthermore, we are able to adjust our sensitivity to instantaneous changes in the ambient light level (ie, light adaptation) at a rate consistent with our temporal resolution of around 30–40 Hz (Robson and Powers 1988). Additionally, human temporal resolution for unpatterned stimuli is better in the periphery (Allen et al 1998; Seiple et al 1988), which is consistent with the larger size of peripheral photoreceptors (Tyler 1985). All of this argues for a visual system at the level of the visual cortex with a potential temporal resolution capability in the region of a few milliseconds.

There is a school of thought (Engle and Singer 2001; Singer and Gray 1995), though not unopposed (Kiper et al 1996; Morgan and Castet 2002), that the basis of visual perception lies in the millisecond temporal resolution with which the synchronous firing of cells responding to the same physical object, can be identified; this is the posited role of temporal synchrony, to solve the so-called binding problem (Blake and Lee 2005). Relatedly, it has been shown that textures can be identified solely on the basis of temporal and or directional asynchronies in the 5–15 milliseconds (ms) range [Alais et al (1998), Guttman et al (2005), Kandil and Fahle (2004), Lee and Blake (1999b), Lee and Blake (2001), Sekuler and Bennett (2001), Suzuki and Grabowecky (2002), and Usher and Donnelly (1998), but also see Adelson and Farid (1999), Farid (2002), and Farid and Adelson (2001)].

Notwithstanding the fact that relatively short temporal asynchronies can support texture segregation, it is still unclear whether, at the level of conscious perception, we have access to visual information at these short time scales. We address this question by asking subjects to detect a temporal asynchrony between flickering stimuli presented either in foveal or peripheral vision. The stimuli are unpatterned, and the task is designed to be a purely

temporal one. Assuming that the temporal resolution of a subset of visual cortical neurons is available to the higher levels of conscious perception, we expected to find good sensitivity for temporal synchrony judgments in the 10–15 ms range. Several researchers have used a similar temporal-asynchrony detection task in which temporal frequency thresholds were measured at a specific phase shift or at specific interstimulus distance (Aghdaee and Cavanagh 2007; Battelli et al 2003). We measured phase shift thresholds for delay detection at specific temporal frequency because we focused more on conscious judgments of temporal synchrony rather than on the temporal resolution of visual system. Furthermore, on the basis of what we know about the temporal resolution both at the level of the receptors (Seiple et al 1988) and psychophysically (Allen et al 1998) we expected our sensitivity to temporal events would be better for peripherally presented stimuli than for foveally presented stimuli. Our results show the opposite; sensitivity for the cognitive judgment of temporal synchrony is poor (ie, around 70–90 ms) and is better in the fovea. This suggests that cognitive perception has, at best, limited access to discrete temporal events.

## 2 Methods

### 2.1 Observers

GM, CN, and LGS participated in experiments. GM is one of authors.

### 2.2 Apparatus

Stimuli were generated using a Macintosh computer (MacPro 3, 1) with Psykinematix (KyberVision) and displayed on a 21-inch CRT Monitor (Sony GDM-F520). The display had a resolution of  $1024 \times 768$  with a refresh rate of 85 Hz. Observers viewed the screen at a viewing distance of 60 or 240 centimeters (cm).

### 2.3 Stimuli

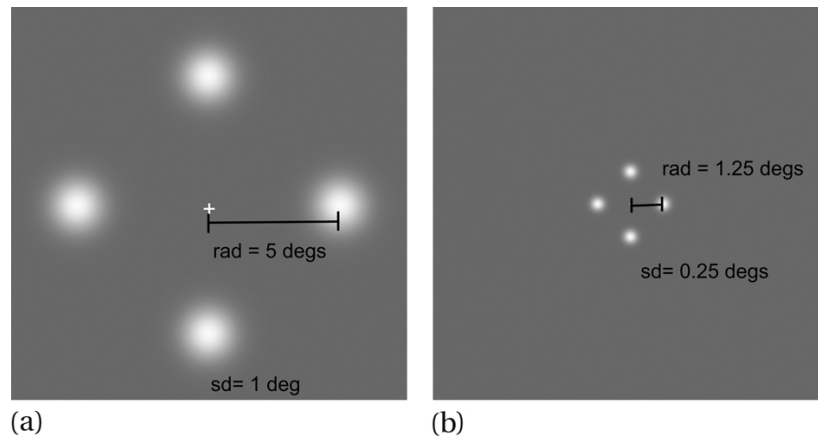
The stimuli consisted of four flickering spots presented at the top, bottom, left, and right of a presentation screen (figure 1). We have no reason to suspect that the exact arrangement of these stimuli is crucial. The eccentricity of spots were at a 5-deg visual angle for the short viewing distance (peripheral viewing) and 1.25 deg for the long viewing distance (foveal viewing). The spots had a 2D Gaussian luminance profile in space. The standard deviation (SD) of the Gaussian was 1 deg for the short viewing distance and 0.25 deg for the long viewing distance. They were limited to  $\pm 2$  SD. A maximum luminance contrast of the spots were set to be 50% in experiment 1 or randomly sampled from normal distribution with a mean of  $-10$  decibels (dB) (32%) and standard deviation of 2 dB in experiment 2. The stimuli were presented to only one eye.

The luminance contrast of spots was modulated sinusoidally in time (contrast reversal flickering). Three of four spots flickered synchronously while the other one had a delay in flickering. The delayed-flickering spot was chosen randomly for each trial. A delay was defined by a phase offset in sinusoidal temporal modulation. A movie of the trial for a 1 Hz stimulus with a near-threshold (30-deg) phase offset is provided for one of the four elements (see supplementary material). The contrast of the elements was randomly sampled from normal distribution with mean of  $-10$  dB (32%) and standard deviation of 2 dB.

## 3 Procedure

We measured delay detection thresholds at different flickering frequencies for foveal and peripheral viewing. There were four levels of flickering temporal frequency (1, 2, 3, and 4 Hz)—which makes  $2 \times 4 = 8$  experimental conditions.

On each trial, observers judged which spot had a delay (four-alternative forced choice). The spots were presented in a temporal Gaussian envelope to prevent observers from



**Figure 1.** Spatial arrangement of the foveal and peripheral stimuli used in the odd-man-out task. Fixation was always central.

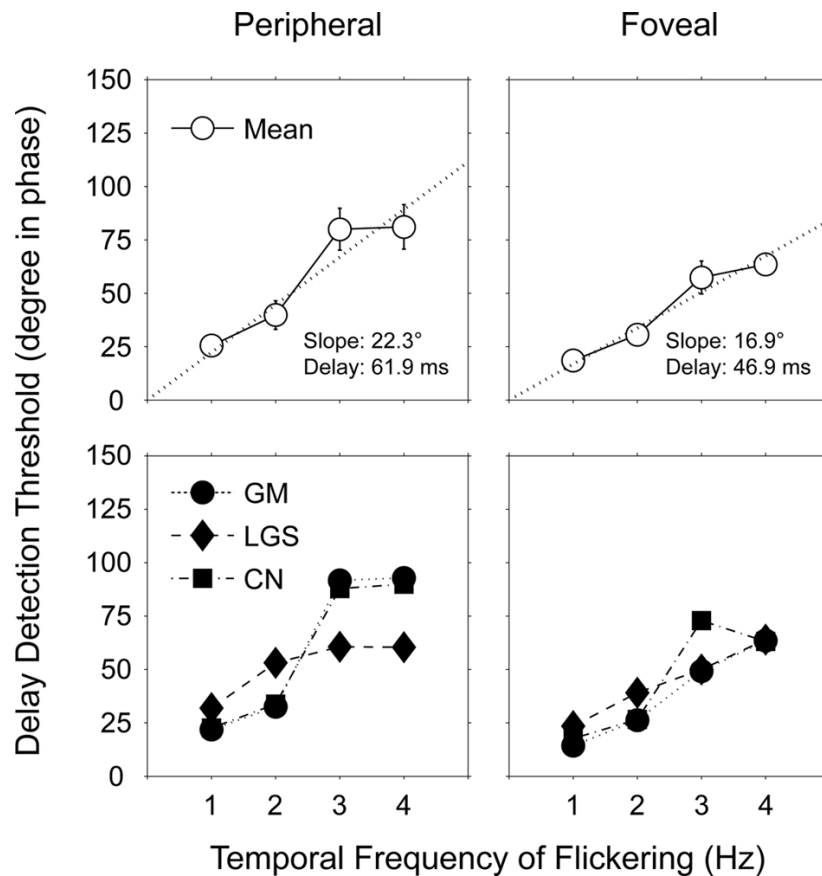
seeing an afterimage. A presentation duration, which was defined by the standard deviation of temporal Gaussian, was shorter for higher flickering frequency so that the number of temporal cycles was the same for different temporal frequencies. The standard deviations of temporal Gaussian were 1.0, 0.5, 0.33, and 0.25 seconds (s) for flickering frequencies of 1, 2, 3, and 4 Hz, respectively, in experiment 1. They were 0.8, 0.4, 0.27, and 0.2 s in experiment 2. Presentation duration was defined as 4 SD of the temporal Gaussian in experiment 1 and 6 SD in experiment 2.

A one-up–two-down staircase was used to adjust the phase offset. The starting point of the staircase was high enough to see a delay in flickering (more than 140 deg of phase). The size of the downward step of the staircase was initially set at 50% and then moved to 12.5% after the first upward reversal. The upward step size was 25%. The staircase terminated after six upward reversals. The left and right eyes were separately tested for each experimental condition. However, we pooled over the data between two eyes because there was little difference. Therefore, thresholds were calculated by taking the average of the flickering delay at twelve upward reversals.

#### 4 Results

Figure 2 shows the main result, the accuracy for temporal synchrony quantified in terms of temporal phase for a range of different temporal frequencies. Individual results and group averages are shown. A two-way ANOVA with factors of Temporal Frequency and Eccentricity revealed a significant main effect of Temporal Frequency,  $F(3, 6) = 16.6$ ,  $p = 0.003$ , indicating that as the temporal frequency increased, the accuracy for detecting temporal synchrony in terms of temporal phase increased. The linear fit to the data with a zero x intercept is consistent with a simple linear model incorporating a time delay being able to describe the results across temporal frequency. That is, delay in millisecond between peaks of sinusoidal flicker was nearly constant among different temporal frequencies. In this case the group average data are best described by a delay of 46.9 ms for foveal viewing and 61.9 ms for peripheral viewing. The main effect of eccentricity was only marginal,  $F(1, 2) = 11.9$ ,  $p = 0.075$ . This was driven by the fact that delay detection thresholds were generally higher for peripheral viewing than for foveal viewing. The interaction between the two factors was not significant ( $p > 0.05$ ).

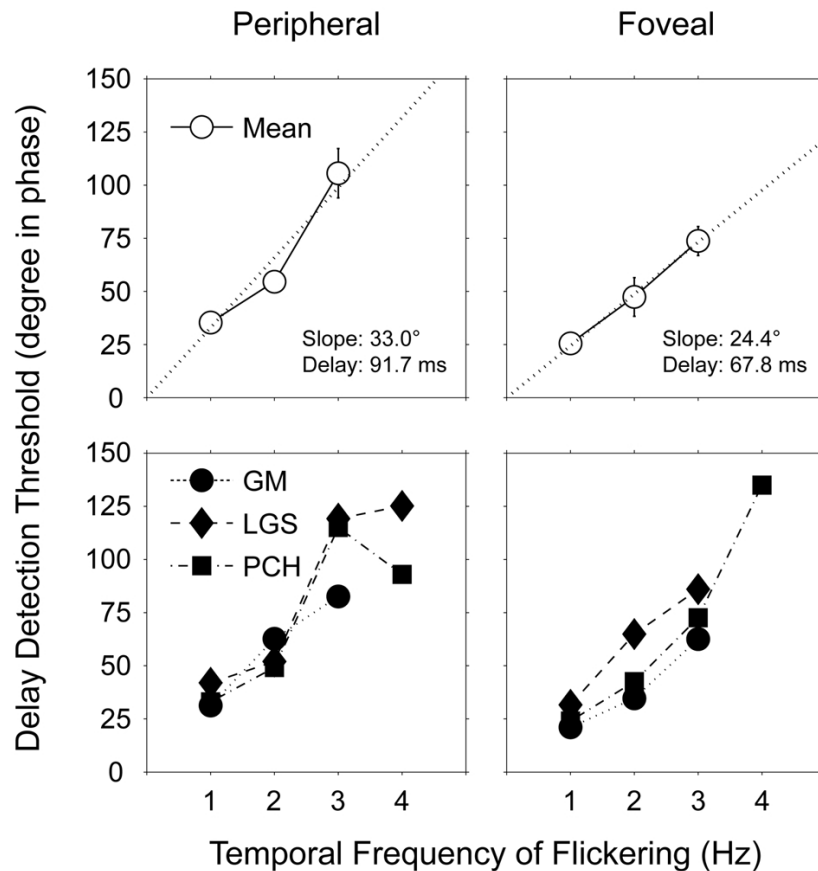
Although it is possible that this task could be accomplished based solely on maximum contrast as the contrast is covarying with temporal phase, the data in figure 2 are not consistent with a cue based on contrast alone. The finding that the phase limit covaries



**Figure 2.** Results for three subjects and averaged results for the detection of temporal synchrony measured in terms of phase in degrees as a function of temporal frequency in hertz. Results for foveal and peripheral viewing are displayed.

with temporal frequency suggests a time-dependent parameter. Still, the question arises as to how important relative contrast cues are in this task. To address this, we remeasured synchrony detection for foveal and peripheral viewing for stimuli of random contrast. The task is the same, to determine the odd man out; however, now all stimuli have different maximum contrasts. These results are plotted in [figure 3](#) in an identical fashion to that already described in [figure 2](#).

The contrast randomization procedure results in a rise in the phase shift detection threshold of around 30%–40%, which we attribute to peak contrast cues. At 4 Hz of temporal frequency, not all observers could detect a phase delay (missing data points of observers GM and LGS in [figure 3](#)). Although we subjected the data to a two-way ANOVA with factors of temporal frequency and eccentricity, data for temporal frequency of 4 Hz were excluded from this ANOVA because of the missing measurements. The main effect of temporal frequency was significant,  $F(2,4) = 54.7$ ,  $p = 0.001$ . Again, the results are well described by a simple linear function whose slope corresponds to a minimum time delay of 67.8 ms for foveal viewing and 91.7 ms for peripheral viewing. Observer GM and LGS could not perform the task under the 4 Hz condition. We attribute this to the threshold being too close to the maximum limit (180 deg). The main effect of eccentricity was significant,  $F(1,2) = 28.5$ ,  $p = 0.033$ , indicating that delay detection thresholds were higher for peripheral viewing than for foveal viewing. The interaction between the two factors was not significant ( $p > 0.05$ ).



**Figure 3.** Results for three subjects and averaged results for the detection of temporal synchrony measured in terms of phase in degrees as a function of temporal frequency in hertz for stimuli of random contrast. Results for foveal and peripheral viewing are displayed.

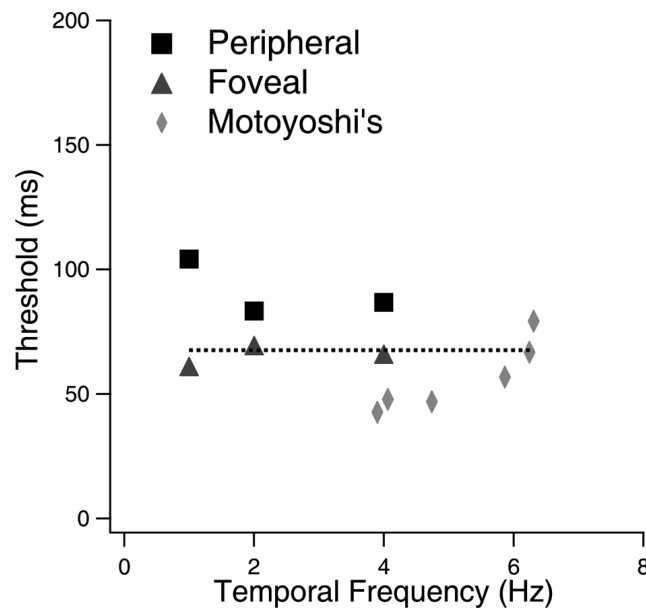
## 5 Discussion

Neurons in the lower reaches of the visual pathway have excellent temporal resolution, around 80–100 Hz (Brindley 1962; Frishman et al 1987; Priebe et al 2003). This 10–15-ms temporal resolution could provide a mechanism for object binding by virtue of the synchronous firing of cells that are spatially separate but responding to the same physical object. Psychophysically, we can segment patterns based solely on a temporal asynchrony of around 5–15 ms (Fahle 1993; Kandil and Fahle 2004; Lee and Blake 1999a, 2004; Leonards et al 1996; Sekuler and Bennett 2001), though this does depend on the spatial properties of the stimulus (Fahle 1993; Kandil and Fahle 2004; Kiper et al 1996; Lee and Blake 1999a; Lee and Blake 2004; Leonards et al 1996; Sekuler and Bennett 2001).

The question addressed here concerns the extent to which conscious perception can directly access short time scales. We make the distinction between direct conscious access and the ability to use a difference in temporal stimulation to derive a secondary measure based on contrast or motion. For example, temporal offsets as small as 5 ms can be detected (Georgeson and Georgeson 1985; Smith et al 1982), but the thresholds are very criterion dependent and are likely to be secondary to contrast cues. Previous studies have used tasks involving ‘temporal order’ detection by asking subjects to judge which of two stimuli presented at different field locations appeared first (Exner 1875; Hirsh and Sherrick 1961; Sweet 1953; Wertheimer 1912; Westheimer and McKee 1977; Yund and Efron 1974). Precision estimates range from 20 ms when the stimuli are separated by a few degrees (Hirsh and Sherrick 1961) to 2 ms when the stimuli are abutting (Sweet 1953; Westheimer and McKee

1977). It is likely that such performance is based on apparent motion rather than estimation of time per se.

A previous study by Motoyoshi (2004) used a comparable odd-man-out task where the orientation of 1D spatial frequency narrowband stimuli is flipped by 90 deg in time. He found that temporal offsets no shorter than 40 ms could be discriminated. This stimulus manipulation cannot be explained by either contrast or apparent motion and is of more relevance to the current investigation. These data are compared with those from the current study in figure 4, and the best fitting horizontal line to the combined data gives an estimate of  $67.6 \pm 5.29$  ms.



**Figure 4.** Duration measures derived from the study of Motoyoshi (2004) (triangles) compared with the foveal (triangles) and peripheral (squares) results of the current study.

We found that thresholds could not be measured for some subjects for the 4 Hz. At this temporal frequency the phase shift threshold is around 140 deg, and our measurement range extended to only 180 deg, so the thresholds were out of the measurement range (missing data points in figure 3 for GM and LGS). We found no evidence of a singularity (ie, improved function) at a phase offset of 180 deg, the special case where the target is of opposite polarity to that of the other stimuli. As temporal frequency is increased above 3 Hz, even this phase offset can no longer be detected. It is interesting to note that for patients with parietal damage, this picture is very different (Battelli et al 2003). In this case, the relationship between phase offset and temporal frequency is nonmonotonic, a result of both temporal frequency-dependence and phase-dependent deficits.

Putting aside the issue of whether synchrony is fundamental to object binding, which is not addressed in this report, and instead concentrating on the temporal limitations of conscious perception, the study suggests that for purely temporally varying stimuli conscious perception has access to time intervals no shorter than around 67 ms and that this is slightly better in the fovea. This is the opposite effect to that expected from findings on temporal resolution (Allen and Hess 1992; Seiple et al 1988). But that is not to say that temporal information concerning synchrony, among other things, is not available at a finer scale at the lower reaches of the pathway but simply to say that conscious perception does not have direct access to finer temporal periods. This poor time resolution for conscious temporal

alignment parallels the poor spatial resolution for conscious spatial alignment that has been reported previously (Hess et al 2003).

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