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Speed of visual processing across the visual field

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Despite the phenomenological experience of vision being stable and uniform in both space and time, our visual system constructs this representation from markedly inhomogeneous spatial and temporal structures. While considerable progress has been made in understanding the inhomogeneities in spatial vision, much less attention has been given to the inhomogeneities in the temporal dynamics of vision. Specifically, little is known about how speed of processing varies across the visual field. In this non-systematic review, we focus primarily on psychophysical and neurophysiological studies of low-level photopic vision to elucidate how the speed of visual processing changes with eccentricity. Specifically, we examine key findings from major investigations on this topic, highlighting areas of convergence, points of divergence, and aspects that remain unresolved.

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Introduction

The visual percept is normally experienced as spatially and temporally homogeneous across the entire visual field. However, this phenomenological homogeneity is paradoxical for two main reasons. The first reason concerns the very nature of visual signals. Local properties of a scene — such as illumination, contrast, and spatial and temporal frequencies — can vary substantially across space and time. These variations in low-level features are known to modulate processing speed [1–3]. For instance, high-contrast stimuli are processed faster than low-contrast ones [3], suggesting that information from stimulus regions with different contrast gradients is encoded at different temporal rates [4]. The picture becomes even more complex when one considers a second factor: the visual system itself is highly non-uniform, with anatomical and physiological properties that vary systematically with eccentricity [5–7].

The human visual system comprises various classes of neurons that can be distinguished based on their function and morphology. A coarse division already emerges at the level of the retinal ganglion cell layer: large parasol ganglion cells project to the magnocellular layers of the lateral geniculate nucleus (LGN), whereas smaller midget cells project to its parvocellular layers. These two classes exhibit distinct tuning properties — magnocells are preferentially sensitive to high temporal and low spatial frequencies, while parvocells are tuned to low temporal and high spatial frequencies [8]. In other words, magnocells respond best to fast, spatially coarse inputs, whereas parvocells favor slow, spatially fine details. Importantly, the parvo-to-magno cell ratio decreases with retinal eccentricity, meaning that, as we move from the center of the visual field (fovea) toward the periphery, the number of parvocells decreases sharply, whereas the number of magnocells increases [6,9,10]. Such spatio-temporal specialization introduces pronounced inhomogeneities in image encoding. Peripheral vision for instance, is characterized by lower spatial resolution [11], stronger crowding effects [12], but also higher temporal resolution compared to central vision [11,13] (for a comprehensive review see: Strasburger et al. [14]). Beyond these perceptual differences, important disparities also emerge in the temporal dynamics of neural responses. Magnocells, for example, conduct signals and integrate information $\approx$ 20 ms faster than parvocells [15]. Furthermore, even within the same neuronal class, temporal response properties vary substantially with eccentricity, with responses being approximately half as fast in the fovea as in the periphery [16,17].

While many aspects of spatial vision are known to vary with eccentricity, far less is understood about how the temporal dynamics of vision change across the visual field, and how these different temporal measures relate to one another [18–20]. In this non-systematic

review we summarize key findings from major studies investigating visual processing speed at different eccentricities, aiming to highlight both converging and diverging evidence, as well as unresolved questions. Our focus is primarily on psychophysical and neurophysiological investigations of low-level photopic vision.

Eccentricity-dependent effects at the retinal level

Neuronal temporal sensitivity and response latencies

In a seminal study, Schmolesky et al. [15] recorded single−cell activity across various regions of the macaque brain. The authors analyzed responses of neurons with receptive fields at eccentricities between 3° and 10°. Although in this study response latencies were not directly compared across different eccentricities, it was reported that magnocellular responses in the LGN were ≈ 17 ms faster than those of parvocells [15]. Even if magnocellular cells respond faster than parvocellular cells, and the parvo-to-magno ratio decreases with eccentricity — so that magnocellular neurons become relatively more prevalent in the periphery [6,9,10] — this does not necessarily imply systematic changes in processing speed across the visual field. Even with large differences in class densities, response latencies could remain stable if each pathway preserves eccentricity-invariant temporal dynamics. Thus, stimuli that predominantly engage the magnocellular pathway could elicit similar latencies and temporal profiles across eccentricities, indicating that shifts in the parvo/magno ratio do not automatically translate into slower or faster processing.

Later, Solomon et al. [21] (see Table 1) measured the temporal contrast sensitivities of both magnocellular and parvocellular neurons in the macaque retina across a wide range of eccentricities (≈ 1° to 50°). Besides reporting that magnocells excel at high-frequency luminance flicker, while parvocells are more selective for low-frequency chromatic flicker, they found that the temporal response threshold — quantified as critical fusion frequency (CFF), the highest temporal frequency at which a flickering stimulus is perceived as flicker rather than as a steady, continuous light — increased with eccentricity. Importantly, the increase in temporal resolution, *i.e.*, sensitivity to fast changing stimuli, was evident in both parvo- and magno-cells [21], indicating that the properties of retinal ganglion cells (RGCs) change with eccentricity and that peripheral retinal neurons are generally more sensitive to fast changes than foveal ones.

Still, the finding that temporal resolution is higher in the periphery than in the fovea does not necessarily translate to shorter peripheral response latencies. It is possible that peripheral neurons integrate over shorter time windows — consistent with higher temporal thresholds (*i.e.*, higher temporal resolution) — without exhibiting earlier responses. This distinction between *temporal sensitivity* (integration time) and *response latency* (processing speed) remains critical for understanding how the visual system maintains temporal coherence across eccentricities [4,13,22].

More recently, Sinha et al. [16] (see Table 1) provided compelling evidence that peripheral response latencies are indeed shorter than central ones. Recording midget ganglion cell responses in the macaque retina across different eccentricities, they showed that response latency decreased progressively from the fovea to the periphery, with time-to-peak values of ≈ 65 ms at 0−4°, ≈ 55 ms at 8−16°, and ≈ 35 ms beyond 24° eccentricity (Figure 1b). Importantly, these differences in retinal output were not attributable to variations in synaptic inhibition between the fovea and the periphery. The authors further investigated whether these effects might originate at the level of photoreceptors. Although cones are traditionally considered functionally homogeneous across the retina, this assumption had not been directly tested. By recording the response dynamics of foveal and peripheral cones, they revealed that foveal cones responded more slowly than peripheral cones, unexpectedly linking cone kinetics to perceptual sensitivity [16] (Figure 1a). This study provided the first direct evidence that differences in neuronal temporal sensitivity across eccentricities arise, at least in part, from the intrinsic response dynamics of cone photoreceptors.

In a more recent study, the same group [23] (see Table 1) further demonstrated that these inhomogeneities are not limited to differences in baseline response speed. Foveal cones exhibited slower response kinetics than peripheral cones across a broad range of background luminance levels and showed a smaller modulation of kinetics with increasing luminance. This reduced luminance-dependent speeding of responses leads to weaker adaptation of foveal cone dynamics compared with peripheral cones, reinforcing the idea that intrinsic photoreceptor properties contribute critically to eccentricity-dependent differences in temporal processing.

Signal transmission times: From photoreceptors to the optic disk

Notably, the shorter response latencies of peripheral photoreceptors and RGCs do not necessarily imply that visually evoked activity originating in the retinal

Table 1

Summary of the main studies discussed in the review.

Study	Level/measure	Paradigm and stimulus	Matching/ scaling	Eccentricity	Main result
Solomon et al. [21]	Temporal modulation sensitivity; macaque M- and P-pathway RGCs	Responses to luminance temporal modulation.	No M-scaling	Approx. 1–50° retinal eccentricity	Peripheral advantage. Modulation sensitivity extended to higher temporal frequencies with increasing eccentricity in both M- and P-cell classes; this indexes temporal resolution, not response-onset latency.
Sinha et al. [16]	Cone and midget-RGC response kinetics; macaque retina	Gaussian noise and flash/light-modulation responses	No M-scaling	0-4, 8–16, and >24°	Peripheral advantage. Response time-to-peak decreased from about 65 ms near the fovea to about 35 ms beyond 24°; foveal cone responses were also slower.
Saha et al. [23]	Cone luminance-adaptation kinetics; macaque retina	Responses across background luminance	No M-scaling	Foveal vs. peripheral retina	Peripheral advantage. Foveal cones adapted more weakly and slowly than peripheral cones, supporting a retinal contribution to eccentricity-dependent temporal sensitivity.
Bucci et al. [17]	RGC axonal propagation speed; human and macaque retina	Spontaneous and light-evoked RGC responses; AOSLO foveal RT measurements.	Not applicable	Foveola to peripheral retina	Mechanistic/ compensation. Axonal propagation speed increased with axon length and eccentricity, reducing arrival-time dispersion at the optic disc; compensation was substantial but not complete.
Osaka & Yamamoto [25]	Flash-VEP P1 latency and manual RT	Speeded detection of a constant-size 1° flash	No M-scaling	0°, 20°, and 40°	Peripheral cost. P1 latency increased from about 83 ms at fixation to about 105–106 ms peripherally; RT changed in the same direction. Higher luminance shortened both measures.
Kremláček et al. [40]	Motion-onset VEP P1 and N1 latency	Motion-onset stimulation at multiple visual-field locations	M-scaling	Up to 42°	Peripheral advantage/ MIXED. P1 depended mainly on visual-field quadrant; N1 became earlier with eccentricity except at the most extreme locations.
Benedetto et al. [20]	VEP N1; manual discrimination RT	Orientation discrimination of brief letters; high-precision eye tracking	Sensitivity matched; M-scaling	Foveola (approx. 0.33°) vs. perifovea (6.5°)	Peripheral advantage. Perifoveal discrimination was about 15 ms faster behaviorally, and the VEP N1 peaked about 15 ms earlier; neural and behavioral effects were weakly correlated.

(*continued on next page*)

Table 1 (*continued*)

Study	Level/measure	Paradigm and stimulus	Matching/ scaling	Eccentricity	Main result
Poggel & Strasburger [18]	Simple visual RT and double-pulse resolution thresholds	Topographic mapping of temporal performance parameters	No M-scaling	Multiple visual-field locations	Peripheral cost. RT and double-pulse thresholds generally worsened with eccentricity but were only weakly associated.
Poggel et al. [19]	RT, double-pulse resolution, detection, and contrast thresholds	Normative visual-field mapping	No M-scaling	Multiple visual-field locations	Peripheral cost. RT and double-pulse resolution varied with eccentricity, but their topographies remained partly dissociable.
Carrasco et al. [45]	Information-accrual rate from speed-accuracy trade-off functions	Orientation discrimination with Gabor targets alone or among distractors	M-scaled and unscaled conditions	4° vs. 9°	Peripheral advantage. Information accrued faster at 9° than at 4° with same-size stimuli; magnifying the 9° stimulus attenuated but did not eliminate the difference.
Jovanovic & Mamassian [47]	Perceived event time	Report of when a visual event occurred within a learned temporal interval	M-scaled and unscaled conditions	Central to approx. 18°	Peripheral advantage. Events were reported progressively earlier with eccentricity, with a peripheral-central bias of roughly 100 ms.

RGC, retinal ganglion cell; RT, reaction time; VEP, visual evoked potential.

periphery reaches downstream stages earlier than activity originating in the fovea. The visual system may partially compensate for physiological differences in order to reduce temporal dispersion in signal arrival. Bucci et al. [17] (see Table 1) tested this directly, showing that action potentials of foveal RGCs temporal to the umbo (*i.e.*, farther from the optic disc and thus requiring longer axonal trajectories) propagated over 40% faster than those nasally located (closer to the optic disc, with shorter axonal paths).

Extending beyond the fovea, Bucci et al. showed that conduction velocity is not uniform across the retina; it is lowest in the fovea and increases progressively with eccentricity, in both midget and parasol cells (Figure 1c). This increase, largely due to axonal thickness, likely serves to compensate for the longer axonal trajectories of peripheral cells, reducing temporal dispersion at the optic disc. However, this compensation was only partial for cells in the foveal region and for peripheral midget cells, whereas peripheral parasol cells were more in line with the equal-travel-time hypothesis [17]. Together with eccentricity-dependent differences in retinal response latency, these results suggest that peripheral action potentials following a retina-wide flash stimulation may reach the optic disc before foveal ones [17].

In summary, converging neurophysiological evidence suggests that action potentials evoked by more eccentric stimuli may reach the optic disc earlier than those generated by foveal stimuli, providing evidence for faster signal propagation in the periphery compared with the center of the visual field. An open question remains as to whether this asynchronous input is also processed asynchronously in the visual cortex, or whether compensatory mechanisms exist at the cortical level to achieve a more uniform temporal processing across eccentricities.

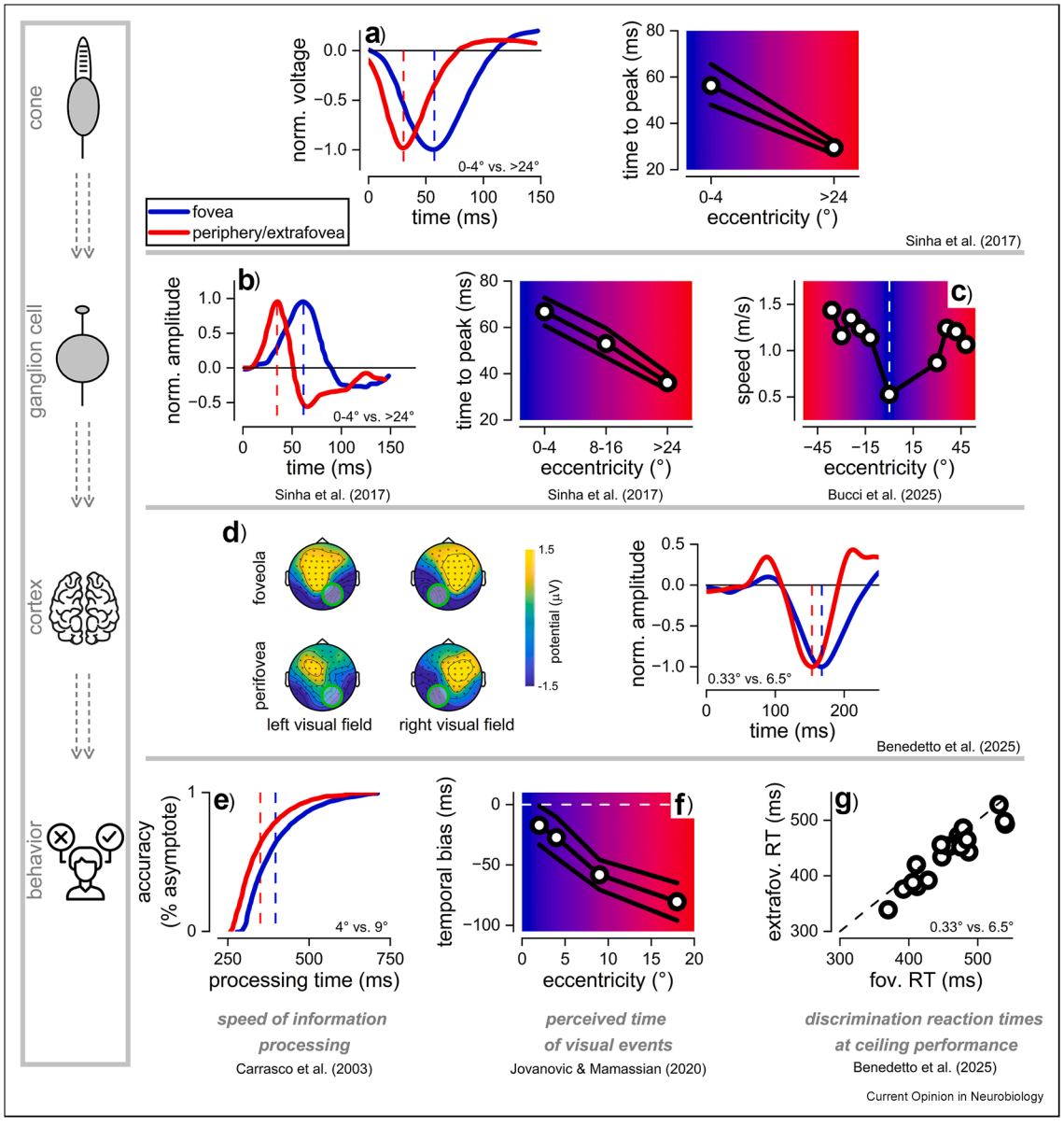
From cortical response time to perception

Measuring speed of visual processing

Once visual signals leave the retina, they follow multiple pathways. The primary route projects from the LGN to the primary visual cortex (V1), where visual information undergoes its first stage of cortical processing. At this stage, we can pose questions similar to those discussed for the retinal processing stage: (*i*) do visual responses in V1 exhibit dynamics that vary with eccentricity, and (*ii*) if so, do these differences translate into temporal disparities at the perceptual level?

There are several ways to estimate the cortical processing times in the visual system. A common approach relies on measuring the brain's electrical or magnetic responses to visual stimuli using electroencephalography (EEG) or magnetoencephalography (MEG). Visual evoked potentials (VEPs) represent the

Figure 1



Differences in the speed of signal processing across the visual field, from photoreceptors to behavior. This figure illustrates some of the key findings from studies reviewed here, highlighting systematically slower processing for foveal stimuli and faster processing for extrafoveal/peripheral stimuli across different stages of the visual pathway and at the behavioral level. **A**, from Sinha et al. [16], *left*, time-reversed linear filters for foveal and peripheral M-cone voltage responses. *Right*, quantification of the time to peak for foveal and peripheral M-cone voltage responses. The central curve represents the mean, while the upper and lower curves indicate ± 1 standard deviation. **B**, from Sinha et al. [16], *left*, time-reversed linear filters for excitatory synaptic currents of Midget Retinal Ganglion Cells (mRGCs) measured in response to white noise stimuli, not M-scaled. *Right*, quantification of the time to peak for foveal, central and peripheral mRGCs for not M-scaled stimulation. The central curve represents the mean, while the upper and lower curves indicate ± 1 standard deviation. **C**, from Bucci et al. [17], mean axonal propagation speed for not M-scaled stimulation of RGCs in human retinal explants along the naso-temporal axis. Approximate eccentricity values in degrees of visual angle. **D**, from Benedetto et al. [20], *right*, grand-average VEP for foveal and perifoveal M-scaled stimuli. Dashed lines mark the N1 peak latency for the two eccentricities. *Left*, VEP amplitude topographic distribution around the average N1 peak latency for stimuli presented to the left and right visual field. The marked locations on the topoplots indicate the electrodes used to assess the VEP on the right graph. **E**, from Carrasco et al. [45], temporal dynamics of feature searches. Accuracy normalized by asymptote isolates the differences in processing speed for feature searches with M-scaled stimuli at 4° and 9°. Differences in processing speed are illustrated by plotting the time at which each condition reaches a given proportion of its asymptote. **F**, from Jovanovic and Mamassian [47], average temporal bias in reporting the perceived time of events as a function of stimuli (M-scaled) eccentricity. Events presented further in the periphery are reported earlier. The central curve represents the mean, while the upper and lower curves indicate ± 1 standard error of the mean. **G** from Benedetto et al. [20], scatter plot showing individual median visual discrimination reaction times for M-scaled foveal and peripheral stimuli. Each dot represents a single participant.

summed activity of large populations of cortical neurons responding synchronously to visual input. These signals primarily arise from postsynaptic potentials in cortical pyramidal cells. Different components of the VEP appear at characteristic latencies following stimulus onset, enabling the temporal segregation of potentially distinct visual processes.

One of the earliest visual evoked responses — driven mainly by the physical characteristics of the visual stimulus — emerges ≈ 90–100 ms after stimulus onset. Known as P1, it is thought to reflect visual processing in extrastriate areas such as V3/V3a [24]. A natural question, then, is whether the latency of this component varies with stimulus eccentricity. One of the first studies to address this question was conducted by Osaka and Yamamoto [25] (see Table 1), who measured the latency of the early EEG P1 component evoked by a brief flash of constant size (1°) presented at 0°, 20°, or 40° of eccentricity. Their results showed that P1 latency increased with retinal eccentricity, rising from ≈ 83 ms at the fovea to 105 ms and 106 ms at 20° and 40°, respectively. The authors focused on P1 because it showed the strongest association with reaction times (RTs), and did not examine whether eccentricity similarly affected later components such as N1, which has been linked to discrimination processes. At first glance, this suggests that the visual system's effective time constant — which likely reflects retinal ganglion cell latency and conduction velocity — slows with eccentricity.

Notably, the study also recorded RTs to stimulus detection, allowing a direct link between neural and perceptual timing. Like P1 latencies, RTs increased with stimulus eccentricity and closely tracked the neurophysiological measures [25] — contrasting sharply with the faster peripheral conduction observed in retinal ganglion cells.

Areal summation and speed of visual processing

At first glance, the findings from Osaka and Yamamoto [25] seem to conflict with eccentricity-dependent effects observed in macaque retinal ganglion cells [16] and with the conduction velocity variations reported across the human retina [17]. Yet, consistent with Osaka and Yamamoto's results, several studies have shown that when neural response latencies — as well as multiple behavioral time-related measures — are compared across eccentricities using stimuli with the same size (*i.e.*, not scaled for cortical magnification, not M-scaled), foveal responses are indeed faster than peripheral ones [18,19,26–29]. In particular, Poggel and Strasburger [18] and Poggel et al. [19] (see Table 1) examined several time-related behavioral measures as a function of retinal eccentricity, including simple RTs and double-pulse resolution (DPR) thresholds. Using stimuli that were not M-scaled, they reported that both simple RTs and DPR thresholds increased with eccentricity. However, the two measures showed little correlation with one another. This weak association suggests that RTs and DPR thresholds involve partly distinct aspects of temporal processing.

The apparent discrepancy between retinal and cortical latencies may be explained — at least in part — by mechanisms of areal summation and cortical magnification. In fact, in the primary visual cortex, the cortical area devoted to a given portion of the visual field decreases systematically with eccentricity, following a magnification function [7,30]. Classical studies suggested that a disproportionately large fraction of V1 is devoted to the central few degrees of the visual field [31,32]. This disproportionate representation reflects both the high foveal RGC density [33], and additional amplification mechanisms at the cortical level [34–36]. However, more recent analyses have emphasized that quantitative estimates of foveal cortical magnification vary substantially across studies [37]. What remains clear is that the foveal representation is strongly magnified relative to the periphery, so that the same visual stimulus (*i.e.*, with the same size, irrespective of eccentricity) can recruit a much larger cortical area when presented near the center of gaze than at more eccentric locations, allowing foveal responses to reach population-level activation thresholds sooner and thereby producing shorter effective response latencies.

Following the same principle, stronger stimuli are expected to yield shorter processing times: they recruit larger or more strongly driven neural populations, producing earlier detectable cortical responses. This aligns with Osaka and Yamamoto [25], who found that both P1 latencies and RTs decreased with increasing stimulus luminance, independently of its eccentricity.

In short, cortical processing times depend not only on retinal input but also on many other factors, including the number of neurons recruited and the strength of their activation. One way to reduce these confounds and measure neural response latencies more accurately is to use stimuli that engage comparable neural populations with similar intensities across eccentricities.

Importantly, the use of cortical magnification factors (CMFs) to equate neural engagement across eccentricities is not as straightforward as it is often presented. Although stimulus scaling based on cortical magnification has long been used to compensate for the decreasing cortical representation of peripheral stimuli [38], the precise value of the CMF remains debated. Estimates of the CMF vary substantially across studies depending on the measurement technique, the stimulus characteristics, and the visual area considered [37].

Further, commonly used magnification functions can differ substantially from other estimates of cortical magnification [37]. Moreover, psychophysical scaling that equalizes perceptual performance across eccentricities does not always correspond to the anatomical CMF [39]. More recent analyses have further emphasized that commonly used magnification functions, including the widely adopted formulation of Rovamo and Virsu [38], can differ substantially from other estimates of cortical magnification and may not provide a unique solution for equating neural processing across eccentricities [37]. Consequently, whether peripheral stimuli appear to be processed faster or slower than foveal stimuli may depend on the specific scaling rule used. This methodological variability should be kept in mind when interpreting eccentricity-related differences in processing speed.

Speed of visual processing across the visual pathways

The mixed pattern of eccentricity effects reviewed above suggests that retinal position does not exert a uniform influence on visual processing speed, but rather that its impact likely depends on stimulus scaling, the behavioral task, and the processing stage under consideration. In this respect, Kremláček et al. [40] (see Table 1) provided an important bridge to the previous literature. Using M-scaled motion stimuli [38], they found that P1 latency was determined primarily by the stimulated visual quadrant, with little evidence for a systematic effect of eccentricity; by contrast, eccentricity modulated the latency of the later N1 component: for all but the most extreme peripheral locations (i.e., $> 28°$), N1 latencies became progressively shorter with increasing eccentricity [40].

In a recent study, Benedetto et al. [20] (see Table 1) extended this line of research by investigating how cortical processing times vary with stimulus eccentricity when both stimulus size was M-scaled [38] and visual sensitivity was controlled. The authors analyzed VEPs elicited by simple visual stimuli briefly presented for discrimination either at the foveola (0.3°) or at the perifovea (6.5°). Much like Kremláček et al. [40], the study was especially informative with respect to the N1 component, as the experimental paradigm and stimuli were optimized to elicit a robust discrimination-related response at this later processing stage. By contrast, the data did not allow for a reliable analysis of the P1 component, because in a substantial number of participants the signal was not sufficiently well defined to permit a robust latency estimate.

Benedetto et al. [20] showed that discrimination reaction times for peripheral stimuli were significantly shorter than for foveal ones (Figure 1g), with a robust difference of $\approx$ 15 ms that persisted across manipulations of spatial attention and task complexity. This perceptual advantage was mirrored neurophysiologically: the latency of the N1 component was also $\approx$ 15 ms shorter in the perifovea than in the fovea (Figure1d). Crucially, however, despite the parallel effects of eccentricity on behavior and N1 latency, the two measures were largely uncorrelated, highlighting a dissociation between perceptual performance and this early neurophysiological marker [20]. This pattern is reminiscent of the findings of Poggel and Strasburger [18] and Poggel et al. [19], who likewise showed that different time-related measures may display similar eccentricity-dependent trends while remaining only weakly associated once retinal position is taken into account.

Taken together, these findings support the view proposed by Kremláček et al. [40] that eccentricity effects become more pronounced at later stages of processing, particularly along the dorsal stream, where the N1 may reflect the combined activity of multiple generators distributed from early visual cortex to the frontal eye fields. Consistent with this hypothesis, Stephen et al. [41] showed that, within the dorsal pathway, central and peripheral inputs follow distinct temporal dynamics, with peripheral signals traveling along faster routes, resulting in earlier response onset in dorsal regions [41]. This view is further supported by Hagler [42], who reported marked latency differences in visual responses across V1, V2, and V3a, pointing to a pronounced eccentricity effect along the dorsal stream [42]. By contrast, Himmelberg and Wade [43] found that neurons in ventral area hV4 — and likely other higher-order ventral regions — exhibit relative invariance to the eccentricity-dependent temporal sensitivity biases observed in earlier and dorsal areas. They proposed that this invariance reflects a hierarchical integration mechanism along the ventral pathway, progressively compensating for temporal differences between foveal and peripheral inputs and promoting temporal stability at later stages of visual processing [43].

'When' we see it depends on 'where' it is: Does perception come earlier in the periphery?

Evidence suggests that temporal visual processing is not uniform across the visual field [14]. When stimuli are scaled to approximately match cortical representation, many studies report faster processing for peripheral stimuli than for foveal stimuli [20,40,41], an effect that grows along the visual hierarchy, particularly in the dorsal stream [42], a pathway specialized for spatial localization, motion processing, and action guidance. Some behavioral measures support this pattern: both manual and oculomotor reaction times to peripheral (M-scaled) stimuli are generally faster than those to foveal stimuli [20,36,44]. However, the relationships among these measures appear to be weak,

and likely depend on stimulus scaling and task conditions. This suggests that they may reflect partly distinct processing stages rather than a single common mechanism [18–20].

Carrasco et al. [45] (see Table 1) developed an elegant paradigm to characterize the temporal dynamics of visual information processing using combined measures of discriminability and processing speed. Consistent with other studies [20,46], they showed that, when stimuli were M-scaled [38], they were processed ≈ 50 ms faster at 9° than at 4° of eccentricity (Figure 1e). However, this peripheral advantage increased rather than decreased with same-size stimuli, reaching approximately ≈ 90 ms. This pattern indicates that the effect of M-scaling is not straightforward, and temporal inhomogeneity cannot be reduced simply to the relative cortical extent of the stimulated area.

Directly probing perceived time, Jovanovic and Mamassian [47] (see Table 1) found that participants reported peripheral events ≈ 100 ms earlier than central ones, showing that faster peripheral processing can translate into earlier perceived time (Figure1f). Further evidence comes from studies of perceived duration. Brief peripheral stimuli are consistently perceived as shorter than foveal stimuli, even when cortical magnification or stimulus visibility is controlled [48–50]. This suggests a compression of subjective duration in the periphery, consistent with models proposing spatially localized temporal mechanisms and multiple spatially dependent timing processes [51]. Importantly, consistent with Carrasco et al. [45] (2003), Jovanovic and Mamassian [47] (2020) also observed a peripheral advantage with non-scaled stimuli, further indicating that eccentricity effects on perceived timing cannot be reduced to stimulus size alone. More generally, the effects of M-scaling may depend on how scaling is implemented, as well as on the task, the stimulus properties, and the processing stage under consideration.

Complementing these findings, Hirano et al. [52] (2023) [52] investigated eccentricity effects on motion prediction using a time-to-contact task with moving targets at 4° to 12° eccentricity. They found that peripheral stimuli were predicted earlier, indicating faster processing in the periphery. Motion RT, however, increased with eccentricity, possibly due to fixed stimulus size (which was not corrected for cortical magnification) and constant velocity, which may confound the relationship between RT and processing speed (but see [52] for a different interpretation). These findings are consistent with the idea that, while peripheral vision can support faster prediction of event timing, simple reaction time measures (vs. discrimination reaction time measures) may not always provide a straightforward readout of perceptual processing speed.

Notably, the longer processing times observed centrally than peripherally may be interpreted within the Central-Peripheral Dichotomy (CPD) framework. The CPD specifically proposes that feedback supporting visual recognition is more strongly directed to representations of the central than of the peripheral visual field [53]. Functionally, the CPD framework proposes that peripheral vision is primarily specialized for 'looking,' namely the rapid selection of locations toward which attention and gaze should be directed, whereas central vision is primarily specialized for 'seeing,' namely recognition and discrimination [53,54]. Peripheral selection may therefore rely more heavily on relatively rapid feedforward signals, while central recognition may additionally recruit iterative top-down feedback to resolve ambiguity and recover information constrained by the visual-processing bottleneck. Accordingly, the central–peripheral difference in processing time observed here could partly reflect these distinct functional specializations and the greater involvement of feedback-dependent operations in central vision, although our findings do not directly establish this neural mechanism.

Conclusions

Neurophysiological and behavioral evidence indicates that temporal dynamics vary with eccentricity; however, several key questions remain open: (1) whether the visual system simply disregards these temporal differences or instead engages compensatory mechanisms to offset them, (2) how neurophysiological delays relate to behaviorally measured delays, and (3) whether—and how—these eccentricity-dependent differences in perceived time and processing speed are accounted for during visually guided action, potentially through mechanisms that counterbalance delays across the visual field. Addressing these questions will be an important goal for future research.

Declaration of competing interest

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Data availability

No data was used for the research described in the article.

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- • of special interest
- •• of outstanding interest

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