Current Biology
Dispatches

Vision and microsaccades: Time to pay attention!

Eileen Kowler
Department of Psychology, Rutgers University, Piscataway, NJ 08854, USA
Correspondence: eileen.kowler@rutgers.edu
https://doi.org/10.1016/j.cub.2024.01.032

Visual perception of exceedingly small and highly detailed spatial regions depends on coordinated patterns of small shifts of the line of sight (‘microsaccades’) aided by pre-saccadic shifts of spatial attention directed precisely to the intended target of the saccade.

Visual scenes contain objects of all kinds that continually compete for our attention as we navigate through the world or search for important objects. We rely on saccadic eye movements — rapid, voluntary jumps of the eye — to bring the fovea (the central retinal region where visual resolution is best) to selected objects, one at a time[1,2]. Although such large-scale visual inspection is essential for apprehending the content of visual scenes, it does not tell the whole story of how we use saccades. Many critical tasks — from microsurgery to delicate embroidery to grooming (in the case of non-human primates) — require that we confine our interest to a small spatial region for seconds, even minutes, on end. A new study by Guzhang, Shelchkova, Clark and Poletti[3] reported in a recent issue of *Current Biology* illuminates how the oculomotor and visual systems collaborate to use selective spatial attention to support performance of fine-scale visual and visuomotor tasks.

It is tempting to posit that visual resolution is so good in the fovea — a retinal region small enough to contain the details of a 2 cm diameter coin held at arm’s length — that there would be no need for any further shifts of the line of sight once the relevant details were safely packed within it. Indeed, for many years the prevailing view was that visual resolution within at least the central 0.5 degrees of the retina is sufficiently uniform to render small saccades (less than 0.3 degrees, termed ‘microsaccades’) visually useless: voluntary motor acts that neither harm nor help vision[4]. This view, however, was successfully challenged by studies showing that visual resolution begins to decline at retinal eccentricities as small as 0.15 degrees[5]. As a result, tasks demanding the finest levels of visual resolution will require microsaccades to bring the critical details to the very center of the fovea[5,6].

Saccadic eye movements, be they macro or micro, are not the only means of compensating for the decline in visual resolution with increasing retinal eccentricity. We can improve eccentric vision without moving the eye by allocating visual attention to a chosen location. Decades of behavioral and neural investigations have been devoted to understanding and modeling how the preferential allocation of spatial attention to eccentric retinal locations affects visual function[7,8]. Attention is particularly important in crowded visual scenes, where the improved clarity of attended features occurs at the expense of nearby or surrounding material[9,10].

It has long been appreciated that saccadic eye movements and shifts of spatial visual attention operate in close partnership, as shown by the improved visual performance at the designated target of saccadic eye movements that occurs just prior to the execution of a saccade[11–13]. Pre-saccadic shifts of attention serve as a selective spatial filter that defines the effective target of a saccade, thus ensuring that the saccade successfully lands on the chosen object without interference from irrelevant visual features[14]. Pre-saccadic shifts of attention have also been implicated in preparing the fovea for the visual details about to arrive and ensuring seamless vision despite saccadic interruptions, a process referred to as transsaccadic integration[15]. Guzhang *et al.*[3] have extended the partnership between saccades and attention to the microsaccades made to traverse distances of 0.3 degrees or less. Although previous work demonstrated presaccadic shifts of attention prior to microsaccades[16], Guzhang *et al.*[3] examined these attention shifts on a fine spatial scale and revealed several important new properties.

Their experimental task began with the line of sight positioned at the center of a small (less than 1 degree diameter) display, which was surrounded by 8 even smaller squares, each located 0.3 degrees from display center (Figure 1). One of those squares, indicated by a briefly flashed central visual cue, was to be the target for the microsaccade. Immediately following this cue, and while the microsaccade to the designated target was still in preparation, small lines tilted either to the right or to the left of vertical appeared very briefly inside each square. The direction of the tilt later had to be reported for one of the 8 lines, denoted by a ‘response’ cue, after the microsaccade was completed, and after the lines themselves had vanished. The effect of planning the microsaccade proved to be enormous, with identification of tilt direction close to

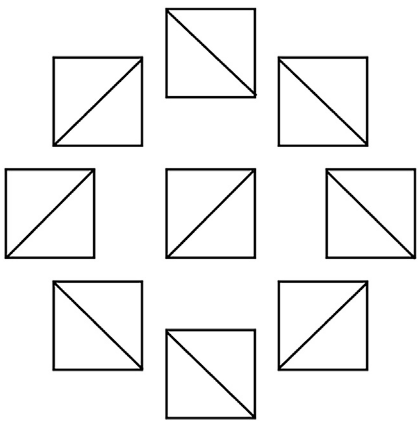

Figure 1. Visual display used to study microsaccades and attention.
Depicted is an example of a display used by Guzhang *et al.*[3] to study microsaccades and visual attention. The display subtended 1 degree visual angle. This means that the reader can approximate the experimental conditions by viewing the figure from a distance equal to about 28 times the display width (for example, a 3 cm-wide display viewed from a distance of 0.84 meters).

perfect at the microsaccadic target and barely above chance elsewhere. The superior visual performance at the target of the microsaccade is the signature indication that a shift in visual attention had taken place. Since there were no incentives to choose any one of the 8 squares as the preferred locus of attention, the superior visual performance at the target of the microsaccade can be attributed to neural events connected to the preparation of the saccade[17].

The results also revealed other characteristics that illustrate the remarkably close and spatially precise correspondence between attention and microsaccades. A follow-up experiment was done to measure the size of the spatial 'window' of attention around the microsaccade target. In this experiment the test lines could appear at one of several locations clustered around the microsaccade target. Visual performance began to decline for distances as small as only 0.2 degrees from the target, a small fraction of the size of the central fovea[18]. Another analysis took advantage of the fact that in some trials, the microsaccade did not occur (due no doubt to occasional lapses on the part of the observers). Although these omissions might seem troublesome, in fact they provided an interesting opportunity. Visual performance in trials with microsaccades exceeded that in trials in which they were mistakenly omitted, showing that saccade preparation was crucial to obtaining the full benefit of the attention shifts. The close link between microsaccades and attention was further supported by finding that the visual improvement at the target of the microsaccade was accompanied by an equivalent presaccadic loss in visual performance at the current locus of fixation, thus showing that the shifts of attention induced by the preparation of the microsaccade were strong enough to overcome the natural and hard-wired visual superiority of the very center of the fovea. It is tempting to wonder whether the relatively poor performance at fixation observed by Guzhang *et al.*[3] bears any resemblance to the phenomenon of 'foveal neglect' demonstrated in a recent study of visual search[19].

Guzhang *et al.*[3] note that their results set the stage for the next developments in understanding how microsaccades and attention work together to support the successful performance of fine-scale visual tasks. For example, in natural tasks saccades are made as part of sequences, a feature that enables spatial attention to be allocated in advance along the entire planned saccadic path[20]. It is possible that attention can be allocated along the planned path of sequences of microsaccades, a result that would confirm that attention and saccades work together in the same way on both 'macro' and 'micro' scales. In addition, we also know that the link between (large) saccades and attention is not immutable. Visual performance can be improved at locations other than the designated goal of the saccade by delaying the saccade by as little as 10 or 20 milliseconds[12]. Strategies to trade off the promptness of the saccade with the size or locus of the window of spatial attention could prove to be as or more useful when gathering information from 'micro' displays, where even a small attentionally based improvement in vision could produce a significant boost to visual performance.

Keep in mind Guzhang *et al.*'s[3] results the next time you try to recognize the details of a face from a distance of 20 meters, or read the small letters on a distant highway road sign. Human vision is remarkably accurate and precise, but it cannot achieve more than a fraction of its capabilities without fine-scale spatial and temporal coordination between attention and microsaccades.

DECLARATION OF INTERESTS

The author declares no competing interests.

REFERENCES

1. Torralba, A., Oliva, A., Castelhano, M.S., and Henderson, J.M. (2006). Contextual guidance of eye movements and attention in real-world scenes: the role of global features in object search. Psychol. Rev. *113*, 766–786.
2. Hayhoe, M.M. (2017). Vision and action. Annu. Rev. Vis. Sci. *3*, 389–413.
3. Guzhang, Y., Shelchkova, N., Clark, A.M., and Poletti, M. (2024). Ultra-fine resolution of pre-saccadic attention in the fovea. Curr. Biol. *34*, 147–155.
4. Steinman, R.M., Haddad, G.M., Skavenski, A.A., and Wyman, D. (1973). Miniature eye movement. Science *181*, 810–819.
5. Poletti, M., Listorti, C., and Rucci, M. (2013). Microscopic eye movements compensate for nonhomogeneous vision within the fovea. Curr. Biol. *23*, 1691–1695.
6. Ko, H.K., Poletti, M., and Rucci, M. (2010). Microsaccades precisely relocate gaze in a high visual acuity task. Nat. Neurosci. *13*, 1549–1553.
7. Maunsell, J.H.R. (2015). Neuronal mechanisms of visual attention. Annu. Rev. Vis. Sci. *1*, 373–391.
8. Carrasco, M. (2011). Visual attention: the past 25 years. Vision Res. *51*, 1484–1525.
9. Treue, S., and Maunsell, J.H. (1996). Attentional modulation of visual motion processing in cortical areas MT and MST. Nature *382*, 539–541.
10. Liu, S.H., Dosher, B.A., and Lu, Z.L. (2009). The role of judgment frames and task precision in object attention: Reduced template sharpness limits dual-object performance. Vision Res. *49*, 1336–1351.
11. Hoffman, J.E., and Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. Percept. Psychophys. *57*, 787–795.
12. Kowler, E., Anderson, E., Dosher, B., and Blaser, E. (1995). The role of attention in the programming of saccades. Vision Res. *35*, 1897–1916.
13. Deubel, H., and Schneider, W.X. (1996). Saccade target selection and object recognition: evidence for a common attentional mechanism. Vision Res. *36*, 1827–1837.
14. Cohen, E.H., Schnitzer, B.S., Gersch, T.M., Singh, M., and Kowler, E. (2007). The relationship between spatial pooling and attention in saccadic and perceptual tasks. Vision Res. *47*, 1907–1923.
15. Melcher, D. (2009). Selective attention and the active remapping of object features in trans-saccadic perception. Vision Res. *49*, 1249–1255.
16. Shelchkova, N., and Poletti, M. (2020). Modulations of foveal vision associated with microsaccade preparation. Proc. Natl. Acad. Sci. USA *117*, 11178–11183.
17. Moore, T., and Armstrong, K.M. (2003). Selective gating of visual signals by microstimulation of frontal cortex. Nature *421*, 370–373.
18. Poletti, M. (2023). An eye for detail: Eye movements and attention at the foveal scale. Vision Res. *211*, 108277.
19. Walshe, R.C., and Geisler, W.S. (2022). Efficient allocation of attentional sensitivity gain in visual cortex reduces foveal sensitivity in visual search. Curr. Biol. *32*, 26–36.
20. Gersch, T.M., Kowler, E., Schnitzer, B.S., and Dosher, B.A. (2009). Attention during sequences of saccades along marked and memorized paths. Vision Res. *49*, 1256–1266.