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Last but not least

A rare glimpse of the eye in motion

Our eyes move in a continual stream of very rapid saccadic rotations, punctuated by brief periods of stationary fixation that typically last for about one third of a second. We are usually unaware of these movements, and indeed we cannot observe our own saccadic eye movements however hard we try. Here we employ a familiar principle to allow us to catch a glimpse for the first time of our own eyes in motion.

Our inability to see our own eye movements was recognised by Erdmann and Dodge in 1898 thanks to a fortuitous discovery while observing, with the aid of a mirror, the eye movements of subjects reading text. The saccadic relocations of gaze were easy to spot when the experimenters observed the eyes of subjects. However, Erdmann and Dodge were intrigued when they "chanced on the observation that when the head was held perfectly still we could never catch our own eye moving in a mirror. One may watch one's eyes as closely as possible, even with the aid of a concave reflector, whether one looks from one eye to the other, or from some more distant object to one's own eyes, the eyes may be seen now in one position and now in another, but never in motion" (Dodge 1900, page 456). The readers of this article can repeat Erdmann and Dodge's demonstration themselves by looking into a mirror at their own eyes; looking from one eye to the next it is not possible to see the eyes moving—they appear always to be stationary. The reasons that we cannot see our own eye movements were not appreciated fully at the time of Erdmann and Dodge's report. However, more recently a wealth of research has uncovered details of mechanisms involved in suppressing the visual pathways during saccadic eye movements (eg Burr et al 1994; Matin 1974; Volkmann 1976). A combination of this active suppression, of motion blur, and of the motion effect (Nakayama 1981) means that we cannot perceive visual stimuli during saccades. How then can we circumvent these visual mechanisms in order to allow us to catch a glimpse of our eyes in motion?

The principle that we employ is based upon that first used by Pulfrich (1922) in his Pendulum effect, also known as the Pulfrich stereophenomenon (see Morgan and Thompson 1974). Pulfrich found that, when observing a pendulum swinging back and forth in a plane perpendicular to the observer's line of gaze, if a dark filter was used to cover one eye and the other eye was left uncovered, after a few moments the pendulum appeared to move in an elliptical arc. This effect arises from a temporal asynchrony in the visual pathways for the two eyes, introduced by the dark filter. The filter causes slight dark-adaptation in the darkened eye, which results in both retinal and cortical delays in the signalling pathways. Conversely, the other eye remains fully light-adapted and is not delayed. Because temporal synchrony is used as a signal to identify position in depth, the artificial asynchrony introduced by the filter results in a perceived mislocation in depth of the pendulum.

It is induced temporal asynchrony in the visual signalling pathways that we might be able to exploit in order to observe our own eye movements. Saccadic suppression mechanisms must be coordinated temporally with the saccadic movements, such that the suppression occurs during the movement, but does not encroach significantly into the surrounding fixations. There has been some recent debate as to the source of saccadic suppression. Many researchers support the notion that suppression is of central origin, arising from an efference copy or corollary discharge of the eye movement command (eg Burr et al 1982; Ross et al 2001). However, Castet and colleagues

(Castet and Masson 2000; Castet et al 2001) have suggested that no such central process is necessary, and that saccadic suppression can be explained merely in terms of retinal processes—namely by mechanical shearing forces on photoreceptors during movement.

If the suppression signal is generated centrally, then the introduction of a delay in the perceptual mechanisms in one eye, by the use of a dark filter, might result in a temporal mismatch between suppression and perception, allowing a glimpse of the eye in motion. Conversely, if suppression is retinal in origin, then the sudden dark-adaptation due to photoreceptor shear should itself be delayed by the introduction of a dark filter in front of one eye. Hence perceptual inflow and saccadic suppression would remain coupled in the filtered eye and so no movement of the eye would be visible. It is with these possibilities that we returned to our mirror to repeat Erdmann and Dodge's self-observation, this time equipped with a neutral density filter and a desk lamp. With careful observation and a little patience and perseverance, we found that we were able to see the final phase of saccadic movements as we looked from one eye to the next.

Figure 1 shows the arrangement of filter, mirror, and desk lamp that allowed the most obvious glimpse of the eye in motion. We found the best results were observed if the mirror was about 15 – 20 cm in front of the face. A neutral-density filter of 0.5 log units was held approximately 5 – 10 cm in front of one eye, such that neither the filter nor its reflection encroached upon the other eye. In positioning the lamp, it should be arranged such that there are no reflections of the lamp on the filter, because these make it hard to observe the eye, and so that the filtered eye is visible to both eyes in the mirror. We found that this was best achieved if the lamp was on the same side of the head as the filter, was pointed at the filtered eye, and was positioned approximately 20 cm from the side of the head, slightly further from the eye than the filter, so that the lamp was pointing toward the face.

Figure 1. The arrangement of neutral-density filter, mirror, and desk lamp that we found most effective for catching glimpses of the terminal phases of our saccades as we looked from one eye to the other in the mirror.

Different readers may find that different strengths of filters are more appropriate to themselves or the lighting conditions, and so a pair of polarising filters can be used to find approximately an appropriate strength of filter. The filter should be reasonably dark but not so dark that the iris of the eye behind it cannot be seen clearly. The reader should bear in mind that the effect is small and we were only able to catch the slightest of glimpses of the end of the movement, but compared to the situation when the filter is removed from in front of the eye, it becomes clear that it is possible to see a small amount of movement.

That we can use our simple technique to observe the terminal phase of our own saccades is consistent only with accounts in which it is proposed that saccadic suppression is generated by central mechanisms. Our straightforward demonstration argues against the recent suggestions by Castet and colleagues that suppression might be retinal in origin. Given central suppressive mechanisms, the explanation of this effect is simple and fits with what we know about the Pulfrich effect and the probable generation of saccadic suppression. Saccadic suppression is likely to be generated from an efference copy or corollary discharge of the eye-movement signal. The movements of the two eyes are synchronous and occur at the time consistent with the efference copy. In the light-adapted eye, the result is as usual: the suppression signal switches off perceptual inflow for the duration of the saccade. In the dark-adapted eye, however, the perceptual inflow is delayed and hence asynchronous with the suppression signal. In this way the suppression terminates before the end of the perceptual inflow from the movement in this dark-adapted eye, and we are thus able to catch a glimpse of this terminal phase of the saccade. As a consequence it must be that we see the movement (of both eyes) with only the dark-adapted eye. Failure to compensate for delayed perceptual inflow in the dark-adapted eye suggests that suppression is generated centrally from the efference copy or corollary discharge of the eye-movement signal and cannot compensate for the local dark-adaptation in the filtered eye. The mistiming of the suppression signal in the dark-adapted eye further suggests that, under normal circumstances, mechanisms must operate that delay the saccadic suppression signal when both eyes are dark-adapted.

While our technique is simple, it is possible to draw upon existing measures of contrast sensitivity during saccades (Diamond et al 2000) in order to make some suggestions about the magnitude of the reduction in saccadic suppression introduced by the dark filter that we used. As a result of the viewing distances suggested above, the amplitude of the saccades made between the two eyes is likely to be in the region of 15 deg. This corresponds to a saccadic duration of around 50 ms. Contrast sensitivity at the end of our saccades while looking in the mirror can be estimated by using Diamond et al's data. Ross and Hogben (1975) offer an estimate of the magnitude of the Pulfrich delay, suggesting 10 – 20 ms per log unit of filter. Our 0.5 log unit filter, therefore, should introduce a delay of 5 – 10 ms. Using this, we can return to Diamond et al's data and estimate the change in sensitivity that would be produced by a 5 – 10 ms delay. Calculations are very rough, but it would appear that the 5 – 10 ms delay introduced by our filter should result in an increase in contrast sensitivity by around 45% – 55% at the perceived end of the saccade.

Our simple demonstration uses well known techniques and principles, but to our knowledge this is the first time that such a simple method has been employed in order to defeat our usually complete saccadic blindness.

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Benjamin W Tatler
Sussex Centre for Neuroscience, School of Biological Sciences, University of Sussex, Brighton BN1 9QG, UK; e-mail: b.w.tatler@sussex.ac.uk

Tom Trościanko
School of Cognitive and Computing Sciences, University of Sussex, Brighton BN1 9QH, UK

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