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Visual Perception: Monovision Can Bias the Apparent Depth of Moving Objects

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'Monovision' — using one eye for near work and one for distance — is a common alternative to reading glasses. New work shows that monovision can cause the distance of moving objects to be misestimated, with potentially serious consequences.

As we grow old, our eyes lose the ability to adjust their focus. We may be able to read road signs many metres away but not decipher the text on our phone. One solution which works surprisingly for many people is *monovision* — correcting one eye for distance viewing, and the other one for near work (Figure 1). Some people are bothered by the blurry image in the 'wrong' eye, but others successfully learn to ignore this and find that their perception is dominated by the sharp image. Unsurprisingly, monovision tends to reduce stereoacuity — the ability to detect small depth discontinuities using binocular depth perception — but that seems like a small price to pay. Now, reporting in this issue of *Current Biology*, Burge *et al.* [1] show a much more worrying side effect. Monovision can not only make your depth perception less precise, it can also cause systematic biases in the perceived depth of moving objects. The authors show that these biases could theoretically be large enough to matter in high-stakes situations like driving.

Burge *et al.* [1] relate these biases to the Pulfrich effect, a similar misestimate of the depth of moving objects, named after the German physicist Carl Pulfrich. A century ago, Pulfrich and his team at optical company Carl Zeiss were trying to understand some troubling depth distortions reported by astronomers who were using the firm's stereoscopic devices [2,3]. Stereoscopic depth perception arises from a disparity in the position of an object as seen in the left eye compared to the right (compare red and green lines of sight in Figure 2A). The Zeiss team realised that these distortions, which only affected moving objects, were ultimately due to a difference in the time at which signals from the two eyes were received by the brain [4]. If there is a difference Δ*t* in the time taken for each eye to transmit its signal, then when one eye is reporting the object at position *x*, the slower eye will still be reporting the object at its earlier location *x* – *v*Δt. In other words, for moving objects a temporal delay is translated into a spatial disparity between the eyes [5] (Figure 2). You can sometimes see this effect when watching three-dimensional TV or cinema. On displays which work by rapidly alternating between left and right eye images, a soccer ball kicked from left to right can appear to curve out of the screen, while one kicked from right to left curves into it [6].

It turns out that brighter images reach the brain faster, so one way of achieving such a time difference is simply to dim one eye's image. The Pulfrich effect can be a troubling side-effect of many medical conditions which alter the time taken for visual input to reach the brain, for example a cataract that dims one eye's image, or a neuritis which slows transmission along one optic nerve. The

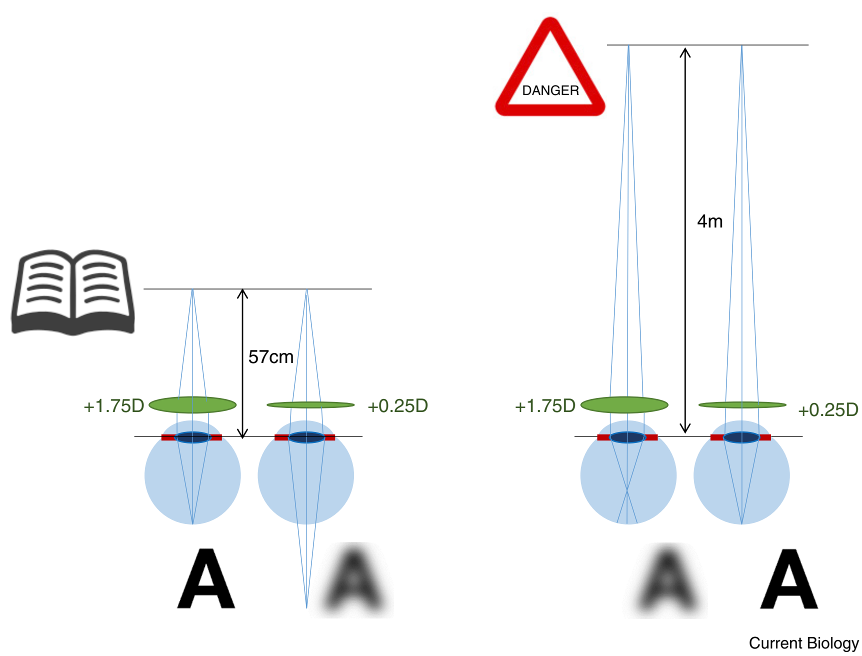

Figure 1. The idea behind monovision.
One solution for ageing eyes is artificial lenses (green) with different optical powers for each eye. Here, I've assumed that the eyes alone are focused at infinity. The left eye's lens has power +1.75D (dioptres), focusing at 57 cm (=1/1.75 m). The right eye's is +0.25D, focusing at 4 m. The artificial lenses are shown in front of the eyes, though clinical monovision usually uses contact lenses, intraocular lenses following cataract surgery, or surgical modification of the cornea. Monovision spectacles tend to cause (non-motion dependent) distortions due to differential magnification.

resulting depth distortions can be ameliorated by putting a tinted lens in front of the good eye: this helps reduce the timing difference and thus the distortions [7].

Now, Burge *et al.* [1] show that monovision also produces a Pulfrich-like effect. They set up a computer monitor at 'optical infinity', so it appeared in sharp focus with the eye's lens at its minimum power. They then placed a 'plus lens' in front of just one eye. Plus lenses add in extra optical power (Figure 1), so to keep the image sharp, the eye would have to reduce its own power to compensate. As it was already at minimum power, it couldn't do this, so that eye's image appeared blurred. The authors found that this monovision caused systematic distortions in the perceived depth of moving objects. Just like the soccer ball on the three-dimensional TV, objects moving across the screen seemed to curve in or out depending on their direction of motion. The authors quantified the effect by introducing a physical delay in the time at which stimuli were presented to the left and right eye, and measuring how long a delay was required to cancel out the depth distortion and make the stimulus seem to move within the screen plane. These delays could be as long as four milliseconds.

Why would monovision have this effect? Monovision makes one eye's image blurrier, but it doesn't make it dimmer, so why would it affect the timing? A clue is provided by the direction of the distortions. In Pulfrich's classic effect, objects moving towards the dimmed or delayed eye appear closer: that is, if the right eye is dimmed, objects moving rightward seem to be closer than objects moving to the left. Yet in monovision, objects moving *away from* the blurred eye appear closer. To null out the distortions, Burge *et al.* [1] had to present stimuli earlier in the sharp eye, as if signals from the blurred eye were reaching the brain faster.

Burge *et al.* [1] point out that luminance and contrast are not the only things that affect how rapidly signals are processed. Spatial scale also matters. The brain first receives visual information at relatively coarse scales — the broad-brush overall distribution of light and dark in a scene — and only later receives the pattern of fine details. Neuro-imaging suggests that the delay can be substantial — some tens of milliseconds [8]. Intriguingly, the brain must take this delay into account when constructing our perception. Otherwise, moving objects would appear to split apart, with their fine spatial scales lagging behind their coarse scales (Figure 3A). We don't know much about this process, but as fine details are most precise, it would make sense if our perceived location of a moving object were based on the fine details. This is indicated by the black arrow labelled 'perceived trajectory' in Figure 3A. At each time, the object is perceived at the location indicated by the finest scales, with this information being merged with the coarse information which arrived at a time T earlier.

We can now see why blurring an object might effectively bring it forward in time (Figure 3B). Blurring removes the finest details present in an image, so the brain does not have to wait so long for all the details to arrive. This could shift the perceived location of the object towards earlier times. Where one eye's image is sharp and the other blurry, this difference in time would produce an illusory stereoscopic depth change for a moving object, with the same sign as found by Burge *et al.* [1].

Remarkably, although monovision has been used for decades, scientists and optometrists had never realised it could produce this kind of depth error. Studies have quantified monovision's effect on visual acuity, stereoacuity, perceived direction and more [9], but none seem to have used moving stimuli. It is concerning to think that a well-intentioned optometric correction could produce the sort of depth distortion usually encountered as a side-effect of serious pathology. And this monovision Pulfrich effect can't be corrected so easily by putting a tinted lens in front of one eye, since which eye is blurred depends on what distance you are looking at.

So should monovision be abandoned in favour of other solutions such as multifocals? That would be premature. Several studies have compared monovision with other solutions, specifically looking at critical situations like driving, and have found no evidence that performance is particularly impaired with monovision [10,11]. Burge *et al.* [1] found considerable variation between their three observers, with delays ranging from 1.4 to 3.7 milliseconds for a 1.5D difference in lens power. It is well known clinically that many people will not tolerate monovision, so it is used only in a self-selecting group of patients. It is very possible that the people who succeed with monovision are precisely those in whom the temporal delay is small, and/or who suppress the blurred image so much

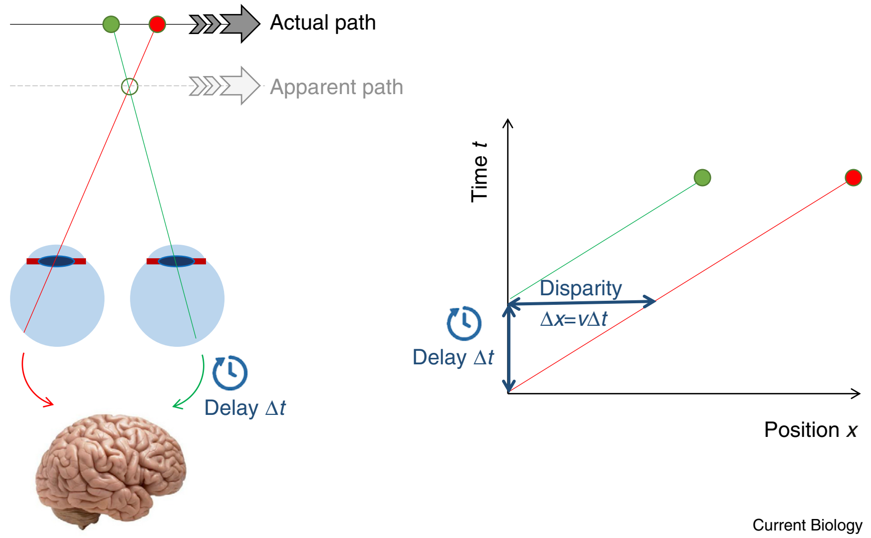

Figure 2. The Pulfrich effect.
The signal reaching the brain from the right eye is delayed by a time Δ*t*, as we view an object moving at speed *v*. When the left eye sees the object at position *x*, the right eye sees it at its earlier position (*x* – *v*Δt). Stereoscopically, this disparity implies that the moving object must be closer than it really is.

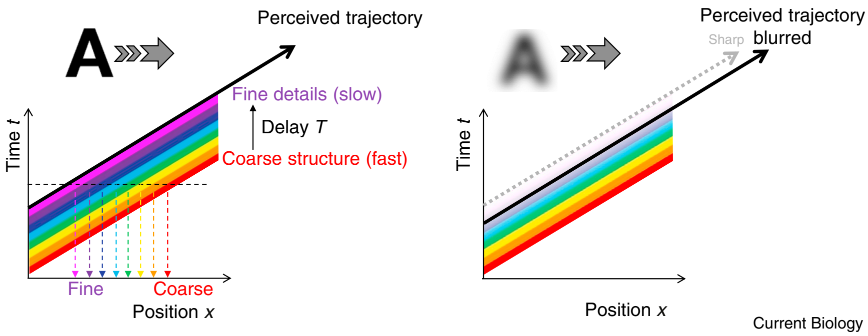

Figure 3. Faster perception of blurred objects.
(A) Visual information about coarse structure (red) reaches the brain faster than information about fine details (violet). If we simply perceived each spatial scale at the location reported when it arrives in the brain, moving objects would split apart by scale (arrows). Since this doesn't happen, presumably our visual system knows to match up fine information with coarse information which arrived earlier.
(B) Blurring an image selectively removes information at fine scales, shifting the trajectory towards earlier times.

that it cannot influence their perception of depth. Thus, the relevance of this effect for real-world monovision users is unclear. Clinicians should, however, now be aware that a monovision patient who reports "with my reading eye open [while driving], my vision is distracted by white lines appearing to bend" [12] may be experiencing a Pulfrich-like effect. Experiments like those reported here [1] could measure an individual's susceptibility to these distortions, potentially enabling more nuanced treatment.

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Plant Cell Biology: UVA on Guard

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Stomata are pores on the surfaces of leaves that function to regulate loss of water for cooling while at the same time facilitating the uptake of carbon dioxide for photosynthesis. A new study shows how stomatal guard cells can sense ultraviolet-A radiation via cGMP signalling to inhibit the opening of these pores in order to reduce transpirational water loss in the short-term.

Solar radiation is made up of a complex spectrum of light, ranging from ultraviolet (UV) and visible light to infrared radiation [1], that can exert a myriad of effects on plant growth and development, as well as modulating a host of biochemical and physiological processes in the plant. Solar radiation is required for photosynthesis, but the consequence to the sessile plant is exposure to UV radiation, which can be divided into UV-C (200 to 280 nm),

