Looking down is looking up

Jack M. Loomis

How do we perceive distance using only one eye? A neat variation on existing methods of measuring visually perceived distance highlights the importance of 'angular declination', a cue long thought to be involved.

Distance perception relies on two binocular cues and many monocular cues, several of which make up the so-called pictorial cues (linear perspective and texture gradient, for instance)[1]. Binocular vision has received the lion's share of research attention[2], in part because of its more apparent physiological basis and its many fascinating phenomena, such as the depth seen in stereoscopic photographs and random-dot posters. But the importance of monocular vision should not be underestimated: the appearance of most natural scenes varies little as one alternates between one and two eyes, and many one-eyed people lead normal lives, including participating in sports.

On page 197 of this issue[3], Ooi *et al.* describe a set of beautiful experiments that provide the best evidence yet that one particular monocular cue, angular declination, is indeed a strong determinant of perceived distance. This general topic is not only of intrinsic interest. It also helps us to understand how we move and act in three-dimensional space, and is central to developing realistic computer graphics, including virtual-reality displays.

Angular declination (also known as 'height in the field') is the angle between a visual target, typically one situated on the ground, and an observer's eye level, which generally coincides with the visible horizon (Fig. 1). As an object on the ground moves closer to an observer, its angular declination increases. Ooi and her colleagues show that manipulations of angular declination do indeed cause a change in perceived distance.

To measure perceived distance, the authors extended an established methodology known as visually directed action, which 'opens the loop' between vision and action[4]. In blindfolded walking, for example, an observer views a target and then proceeds blind to the estimated location of the target. Walked distance is taken as the estimate of initially perceived distance. Because of concern that such a simple response might be mediated by reasoning-like processes, and so might not provide a pure measure of perception, other variants of the method have been developed[5,6]. In these variants, more complex spatial behaviours are used to 'triangulate' the perceived location (such as walking blind along an indirect path to the initially perceived target), thus allowing a purer measurement of perceived distance, one aspect of perceived location. However, these triangulation methods require several responses to a single target.

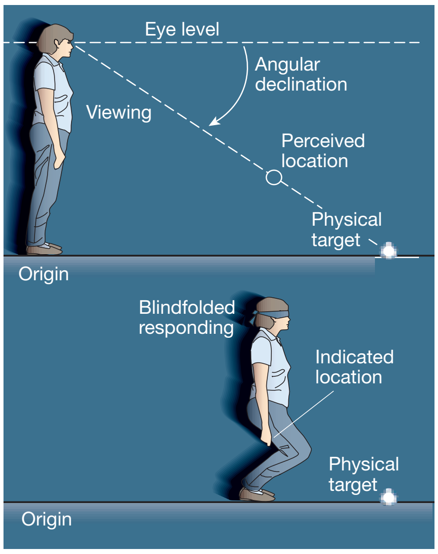

Figure 1 **An eye on distance — one of the experiments carried out by Ooi *et al.*[3]. Top, an observer in darkness views a glowing target on the ground. Typically, a target more than several metres away is perceived to be closer than it is, and appears slightly elevated. After viewing the target, the observer puts on a blindfold and walks forwards to the target's perceived location. Bottom, the observer crouches and uses her hand to indicate the perceived location of the target. Despite the neuromuscular complexity of such a response, the indicated direction is very nearly equal to the angle of declination — this is strong evidence that the response does indeed measure the perceived location, and hence its distance.**

Ooi *et al.* have developed a new variant of visually directed action that, with just a single response to a target stimulus, allows the precise determination of the target's perceived three-dimensional location (as specified by distance and two parameters of direction). In this variant, the blindfolded observer walks out to the distance of the initially perceived, and mentally updated, location of the target (Fig. 1). On stopping, the observer then provides a precise indication of the three-dimensional location with his or her hand. Although this single response might seem an obvious way of measuring perceived location, no researcher had actually used it before, perhaps out of the belief that a response of such neuromuscular complexity cannot provide a direct measurement of perception.

A striking result obtained by the authors confirms that their method does indeed measure the perceived location of a target, and so its perceived distance. Other methods of measuring perceived distance have suggested that when a visible target more than a few metres away is viewed in an otherwise dark environment, it tends to be perceived as closer than it actually is. In one of their experiments, Ooi *et al.* used their method to measure the perceived locations of single glowing targets on the ground viewed in darkness. They found that the locations indicated by the observer for more distant targets were closer than their physical locations, as well as being elevated above the ground (Fig. 1). What is remarkable, however, is that this indicated three-dimensional location, following blindfolded walk and hand positioning, is very nearly in the same direction as the initially viewed target. Given the neuromuscular complexity of the response and the fact that the indicated location is not coincident with the physical target, the close agreement between the indicated direction and the initially viewed angular declination is strong evidence that the indicated location coincides with the perceived location.

This result means that visual direction (angular declination) is correctly perceived, a notable outcome in its own right. However, of much greater interest here is perceived distance, for which the method also provides a measure. The more distant targets viewed in darkness tend to be perceived as closer than they are. But Ooi *et al.* also provide evidence that near targets viewed in darkness, and targets as far away as 7.5 metres viewed normally within a rich visual scene, tend to be perceived quite accurately.

So far, so good: the method measures perception. But the results described so far tell us nothing about angular declination as a distance cue, because other cues were available in Ooi and colleagues' experiments even when glowing targets were viewed in darkness. There have been previous indications that angular declination acts a distance cue[7], but what was needed was a demonstration that manipulating angular declination alone causes a change in perceived distance.

Ooi *et al.* provide such a demonstration, by showing that manipulations of angular declination, which have no influence on other distance cues, cause variations in perceived distance. In one experiment, using visible targets viewed against darkness, observers wore prisms that deviated the light from the targets, causing them to have larger angular declinations (signalling closer targets) than in the initial experiments described above. The walking and pointing procedure revealed a systematic increase in the perceived visual direction as well as a corresponding reduction in perceived distance.

In the same experiment, observers were allowed to adapt to the prisms beforehand by walking around a lighted room while avoiding obstacles, after which they performed blindfolded walking and pointing to targets. Adaptation to the prisms produced shifts in perceived direction towards the horizon, with corresponding increases in perceived distance. A separate experiment, in which the adaptation procedure involved throwing beanbags at a target instead of avoiding obstacles, produced similar results. This confirms that the shifts were real shifts in perceived angular declination, not some after-effect specific to the coupling between vision and walking.

The question still remained as to the exact meaning of eye-level used by the nervous system in evaluating angular declination. Visually perceived eye level (VPEL) — the direction in space that appears level with the eyes — is determined both by the visual scene and by non-visual signals, such as those from the inner ear, which indicate the gravitationally specified horizontal plane[8]. In an additional experiment, Ooi *et al.* asked observers to position a visible spot viewed in darkness so that it appeared at eye level. Observers carried out this procedure under the same sets of conditions used in the other experiments: with and without prisms, and while experiencing the after-effects of prism adaptation. The shifts in VPEL matched those observed with the walking and pointing procedure, indicating that angular declination is indeed measured with respect to VPEL, at least under these conditions of darkness. Another experiment, in which observers viewed a well-illuminated scene, showed that viewing through prisms both before and after adaptation produced shifts in perceived distance in the expected directions. So it seems that VPEL might also serve as the reference direction for angular declination in well-illuminated scenes.

Apart from showing the effectiveness of angular declination as a distance cue and revealing one aspect of its processing by the visual system, this research also has great methodological significance. Until now there has been no sure and simple way of measuring the perceived three-dimensional location of a viewed target, at least one beyond arm's reach. With Ooi and colleagues' unambiguous demonstration that their refinement of visually directed action does indeed measure perceived location using just a single response, the approach can be used much more widely to measure the effectiveness of different distance cues and their integration within the visual system. ■

Jack M. Loomis is in the Department of Psychology, University of California, Santa Barbara, California 93106, USA.
e-mail: loomis@psych.ucsb.edu

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Biophysics

Water at the nanoscale

Mark S. P. Sansom and Philip C. Biggin

You would not expect water to enter a hydrophobic carbon nanotube. But computer simulations show that it can, and studying the process should provide clues about the behaviour of biological pores.

Water continues to surprise us. Intuitively, one would not expect water to enter a narrow hydrophobic pore, such as that formed by a carbon nanotube, because of both the tube's narrowness and its 'oily', water-repellent properties. Such chemical common sense stems from our experience of the macroscopic world, however, and may not apply at the nanometre scale.

On page 188 of this issue[1], Hummer and colleagues report molecular-dynamics simulations that examine the behaviour of water within carbon nanotubes, the internal diameter of which is sufficient to accommodate a single-file column of water molecules. Using standard parameters for the strength of the weak attractive force — the van der Waals' interaction — between water molecules and the carbon atoms of the nanotube, the authors show that water molecules enter the pore, forming a column five molecules in length. But if the carbon–water interaction is made a little less favourable, by reducing the depth of the interaction's energy well (the strength of the interaction) from 10.114 kcal mol^{11} to 10.065 kcal mol^{11}, there is a dramatic change in water behaviour, and the pore remains empty of water molecules for most of the time.

The simulations are long by current standards (50 nanoseconds or more), thereby allowing the flow of water molecules through the pore to be monitored. This work extends our understanding of how liquids behave on the nanoscale. Several studies have examined the behaviour of liquids squeezed into thin films, but comparable data on nanoscale pores are harder to come by, hence the value of simulations.

Many fluids behave abnormally when confined in a space of nanometre dimensions[2]. For example, simple organic liquids become solid-like when squeezed between two smooth surfaces into a film that is less than about five molecular layers thick[3]. In contrast, if water is squeezed between two mica surfaces, only small changes in viscosity occur[4]. The nature of the surfaces between which the water is confined may also have an effect. There have also been simulations[5] to examine the 'nano-ice' formed by water in nanotubes of different dimensions, revealing phases of ice that are not found under bulk conditions. This line of research is relevant not only to the science of carbon nanotubes. Water-filled pores of similar dimensions to nanotubes, for instance aquaporins and ion channels, are present in many membrane-spanning transport proteins (Fig. 1). Aquaporins form water-permeable pores in many cell membranes, and ion channels form ion-permeable pores that govern the electrical properties of nerve cells.

Hummer *et al.*[1] describe simulations of a narrow — (6,6), in trade notation — carbon nanotube in a 'box' of 1,000 water molecules. A crucial feature of the simulations is that water molecules are allowed to enter and leave the tube freely, rather than simply being confined within it. Perhaps the most interesting aspect of the simulations is how the wet–dry transition (that is, the entry and exit of water to and from the pore) can be manipulated, and the consequences of such manipulation. In the simulations, the transition could be induced by a minute change in the strength of the water–carbon interaction potential, implying that small changes in the polarity (electrostatic state) and/or geometry of a pore might drive transitions between full and empty states.

How is water able to enter a hydrophobic channel? The key lies in the energetics of hydrogen bonding. If water molecules enter the nanotube, they each lose on average two out of their four hydrogen bonds. This would be expected to be too high an energetic cost to allow the water to enter. However, fluctuations in the number of hydrogen bonds per water molecule in the bulk aqueous phase mean that a significant fraction of water molecules are incompletely hydrogen-