MEASURING SIZE CONSTANCY AND THE MOON ILLUSION

Helen E. Ross
Department of Psychology, University of Stirling,
Scotland FK9 4LA
h.e.ross@stir.ac.uk

Abstract

Improvements in measuring size constancy and the moon illusion have come with developments in apparatus and statistics, producing better agreement on the factors affecting size perception. However, there is little agreement on whether size and distance are processed in parallel or whether distance is processed before size. Recent developments include the interpretation of measures of variability in addition to mean values. It has been argued that lower variability implies fewer stages of brain processing, but experimental results are hard to interpret. Neurophysiological studies using fMRI and evoked potentials suggest that the perceived size enlargement caused by geometrical illusions is represented in the primary visual cortex. This is consistent with other evidence that observers with normal binocular vision do not have access to information about true angular size.

The moon illusion is an example of a phenomenon over which there is very little agreement. There is disagreement both about the relative contribution of different factors, and about their relation to perceived distance. The size of the illusion is typically an apparent enlargement of the diameter of the horizon moon by 30-80% compared to the high moon. Ross and Plug (2002) concluded that many factors contribute to the illusion, and gave the following figures for the approximate percentage enlargement that each factor could contribute: sight of the terrain, 40%; oculomotor and postural factors, 10%; haze and colour, 10%. These values are middle values gleaned from a wide range of values found in the literature.

This is a very poor state of affairs compared to the agreement of results across laboratories in the physical sciences. The difference lies partly in finance and equipment, which depend on government opinion as to what type of science is worth public funding. Replicability is bought by large teams working with standardised equipment and procedures. Early experiments on the moon illusion, however, were something of an amateur hobby. Two or three observers, usually including the author of the paper, would make a few observations by any method that seemed suitable. Typical observations were the ‘tube’ and the ‘sea’ tests. The tube test consisted of looking at the low moon naturally and then through a tube, and deciding whether the enlargement disappeared through a tube. The sea test asked whether the illusion was present when looking over the sea. The tube removes the sight of surrounding and intervening objects, and the sea is claimed to reduce these influences. Observers usually gave an all-or-none answer, some claiming that the illusion was removed and others that it was still present. Because several factors contribute to the illusion, the effects are not all-or-none, and some method of measuring the effect is required.

Improvements in measurement

Improvements have come with refinements of apparatus and measuring techniques and statistics. For example, Rock and Kaufman (1962) projected artificial moons low on the horizon and found that a moon with the terrain visible was judged 34 percent larger than one with the terrain obscured – thus giving a value to the effect of the terrain. Some authors claimed that there was a large effect of the angle of regard, objects appearing smaller when the eyes were raised or the head or body tilted backwards. This was disputed by others, including Kaufman and Rock (1962). When an experiment was conducted with a large number of observers, an effect of about 6 percent was found (e.g. Heuer, Wischmeyer, Brüwer & Römer, 1991). Good experiments have yet to be carried out on the contribution of colour and aerial perspective to size perception. There is every hope that improved measurement will lead to better agreement on the size of the contributing factors. There is less hope that agreement will be found on the question of whether these factors affect size and distance perception independently of each other, or whether they primarily affect distance perception, with changes in size perception as a secondary effect.

Measures of perceived size and distance

Perceived size is usually measured either by numerical estimates or by matching a variable sized disk to that of the moon. Perceived distance can be measured by numerical estimates; or (for close distances only) by matching a visual distance to the felt position of an outstretched arm, or by adjusting the distance of two objects viewed in different directions. Other methods will be discussed later. Early experiments on size and distance perception were often concerned with whether the mean values agreed with size-distance invariance (SDI) – whether perceived linear size was proportional to perceived distance for a constant angular size. Results varied greatly with the method of measuring perceived size and distance, but generally SDI was not found to hold (reviewed by Haber & Levin, 2001). McCready (1985) clarified the issue by suggesting that *perceived angular size* might differ from *true angular size*, and that perceived angular size should be combined with perceived distance to explain illusions of perceived linear size in a geometrical manner. This account is hard to test because it is difficult to obtain a clear measure of perceived angular size as distinct from perceived linear size. Usually the difference lies in the instruction to attend to one or the other, but the method of measurement (such as matching near and far sizes) remains the same. Attempts to measure all three perceptual variables (for angular size, linear size and distance) again fail to support SDI. For example, Ross and Nawaz (2003) found that observers using binocular vision at short viewing distances could not distinguish between angular and linear size. However, perceived angular size should be measured by an appropriate method involving angles, such as numerical estimates in degrees, or the proportion of the visual field an object appears to fill, or the perceived angular direction of the outer edges of the object. The latter method is impossible for very small angles, such as the half degree subtended by the sun and moon. Higashiyama (1992) used numerical angular estimates in degrees, or angular matches with a protractor, when viewing targets on a wall at distances of 3-30 m. He found that judged angular size increased with viewing distance, when true angular size was constant. This result is consistent with the idea that, when using binocular vision, we do not have access to true angular size information and normally enlarge apparent angular size with viewing distance.

It is difficult to obtain good measures of perceived distance at far distances, because numerical estimates of distance are unreliable. Kaufman and Kaufman (2000) were innovative in using a stereoscopic method to measure the binocular disparity of a fused artificial moon that was judged to be located at half the distance to an artificial moon on the horizon, and compare that with a similar half-distance judgement for an elevated moon. They found that the disparity was much greater for an elevated artificial moon, and concluded that an elevated moon appeared nearer than a horizon moon. The conclusion can be questioned because binocular disparity is not a direct measure of perceived distance, and because observers usually report that the natural high moon appears further away than the low moon. Raising the head and eyes causes accommodation-convergence micropsia, which is often accompanied by reports that objects appear further away (e.g. Heinemann, Tulving & Nachmias, 1959).

Kaufman and colleagues argue that observers say that apparently small objects look far away because of a bias towards using perceived size as a cue to reported distance.

Measuring discrimination

A fairly recent innovation is to interpret not just the mean values of responses but their variability. The latter gives a measure of discrimination, such as a jnd or Weber fraction. One can investigate whether discrimination is better for angular size or for linear size. It has been argued that better discrimination implies that there are fewer steps in the neural processing, and that an item with a smaller jnd is processed earlier than one with a higher jnd. McKee and Welch (1992) used a standard that was scaled in angular size appropriately to its stereoscopic disparity; they found that discrimination was better for angular size than for linear size for targets subtending less than 10 arcmin, but for larger targets performance was similar for both. Angular thresholds for targets presented only in the fixation plane were lower than those measured with random changes in disparity, showing that observers with normal stereopsis do not have direct access to angular size information. These results have been given various interpretations by different authors.

The discrimination of depth has also been compared with that of size. Kaufman and Kaufman *et al.* (2006) used a 2AFC procedure with stereoscopic distance to measure the precision of depth discrimination at different distances, and found that discrimination decreased with distance. They used a similar procedure to measure size discrimination (though it is unclear whether this should be described as perceived linear or angular size): observers had to detect a difference in perceived size at different perceived distances when angular size was constant. This type of size discrimination was poorer than depth discrimination, and decreased with perceived distance in parallel with depth discrimination. The authors argued that size perception was linked to distance perception and occurred after distance was processed (because of the increased 'noise'). It could also be argued that both types of perception are caused independently by stereopsis, and that the size scaling is just more difficult to detect than a change of distance. Kaufman and Vassiliades *et al.* (2007) also used a 2AFC procedure to determine whether a virtual moon at optical infinity appeared nearer or further than a virtual moon at a certain (varied) distance over a visible terrain. They calculated that the perceptual distance of the reduction moon was about 19 m, this being the point at which its distance could not be distinguished from that of a terrain moon. This distance corresponds well to other geometrical calculations of the 'registered' distance of the raised moon based on SDI (Plug, 1989). The authors also varied the sizes of the moons and measured size discrimination. At short distances the terrain moon was judged both closer and smaller than the reduction moon, but at far distances it was judged further and larger.

Neurophysiology

Knowledge of the 'outer psychophysics' of the moon illusion gives us some hints as to the 'inner psychophysics' of size perception (Ross, 2004). Measurements of neural activity in the brain allow us to investigate inner psychophysics. Murray, Boyaci and Kersten (2006) had observers view balls of equal angular size displayed in a hallway pattern giving a perspective effect, and used fMRI to show that the apparently further and larger ball generated more activity in V1 than the apparently nearer and smaller ball. This might imply that some degree of size scaling for geometrical illusions occurs at an early stage of visual processing, before distance is calculated. However, a similar recent study by Runeson, Boyaci *et al.* (2009) using evoked potentials found that there was an early and a late component at the occipital pole of the scalp, with only the late component responding to changes in perceived size. The authors suggest that 3D feedback from higher visual areas is incorporated; but it could be argued that time is needed for 2D scaling within the early visual cortex. The neurophysiological evidence remains as hard to interpet as that from conventional outer psychophysics.

Conclusions

Improvements and innovations in the measurement of size and distance perception have produced greater agreement over which factors are involved. However, there is still little agreement on whether distance perception precedes size perception or whether the two are processed independently of each other.

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