**JUDGEMENTS OF FRONTAL SLOPE IN NEARBY OUTDOOR SCENES**

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**Abstract**

*The appearance of distant slopes is affected by distance foreshortening, so that uphill slopes appear too steep and downhill slopes too shallow. Other factors affect the judgement of nearby slopes on which the observer is standing. Groups of 20 observers at each site were asked to estimate the angular slope in degrees for uphill or downhill views of slopes of 0, 2, 5, 7 and 23 deg. Slope angles were greatly overestimated, with no significant difference between uphill and downhill views. Distance foreshortening is thus unimportant for nearby slopes. Women overestimated more than men. The cause may be their lower ability at spatial tasks and mental rotation.*

The judgement of slope in natural outdoor scenes is notoriously difficult. Golfers, skiers and hill-walkers all suffer from their mistakes. Several factors may contribute to slope judgements. Slope may be judged in a geometrical manner, by estimating the distance to the top and bottom of the slope, and the angle between these two lines of sight. Additionally, slope may be judged from the texture and contour gradients contained in the two-dimensional image. The observer's viewing angle must also be taken into account. Surrounding slopes also produce effects of contrast or assimilation. Expectations of danger and effort lead to steeper judgements, while experience of slopes leads to more accurate judgements.

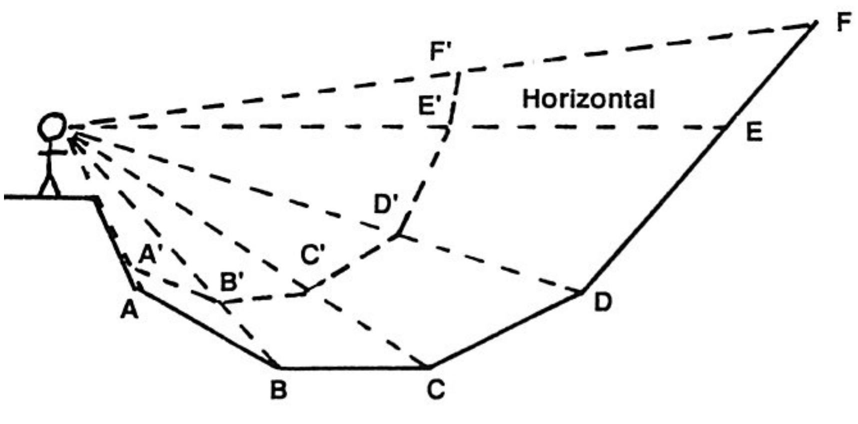


Figure 1. Distance foreshortening makes uphill slopes appear too steep (EF to E′F′) and downhill slopes too shallow (AB to A′B′). (Reprinted from Ross, 1994, with permission.)

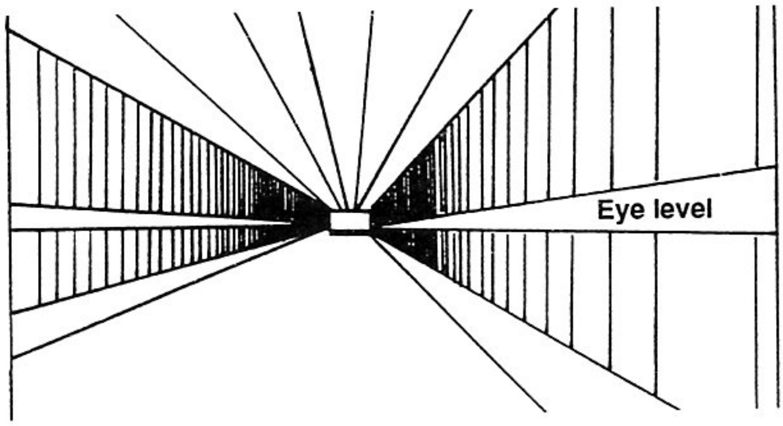


Figure 2. Perspective sketch of a corridor. The floor slopes up and the ceiling slopes down to the centre, which is at eye level. (Reprinted from Ross, 1994, with permission.)

*Viewing distant slopes*

Far distances are underestimated, causing predictable distortions of apparent slope (Figure 1). Distant hills appear very steep, because the difference in distance between the top and bottom of the slope cannot be detected – a point made by Alhazen in the 11$^{th}$ century (Sabra, 1989, pp.164-165). The misperception of distance can also explain slope errors when viewing from a height. Foreshortening will make a downhill slope appear too shallow, a flat valley appear to slope upwards, and a facing hill appear too steep. Errors of this type are frequently reported by skiers, who see other skiers below them apparently skiing uphill. For the same reason the earth appears concave from a great height, curving up to the horizon in all directions (Minnaert, 1954, p. 159).

Ground level views can also be misleading, with the ground appearing to rise gently to a distant horizon (Zehender, 1900). An observer at ground level with an eye height of 1.5 m sees the horizon at a distance of about 4.5 km, giving a perspective slope of about 0.02 deg for a level geographical slope. The effect can be seen in a flat and featureless desert (Thesinger, 1964, p.176), and also confounds hill-walkers when attempting to find the highest point on a wide plateau. This again is due to the effects of perspective, when not counteracted by accurate distance perception. The situation was clearly stated by Euclid in about 300 BC. He wrote in Theorems 10 and 11 of his Optics: "In the case of flat surfaces lying below the level of the eye, the more remote parts appear higher..... In the case of flat surfaces located above the level of the eye, the parts further away appear lower" (Burton, 1945, p. 359). The effects can be seen in a photograph of a corridor (sketched in Figure 2). Two extremes of perception can be distinguished. If distance perception is perfect, the floor and ceiling will appear horizontal and parallel to each other. If distance perception is totally lacking, the scene will appear to be like the vertical picture in Figure 2 with its centre at eye level, and the ceiling sloping down and the floor sloping up. Euclid was concerned with this latter case, but in natural settings the perception of ground level represents some compromise between these extremes.

*Observations and experiments on nearby slopes*

Slope estimation has been studied, both outdoors and in the laboratory. When observers judge the slope on which they are standing, the effects of foreshortened distance are much less than for distant slopes. Downhill slopes are never mistaken for uphill slopes, and overestimation is normally found for both uphill and downhill views. Ross (1974) found that a 24 deg uphill slope was estimated numerically as 37 deg by one group of skiers, and as 47 deg by another group from a greater viewing distance. Experienced skiers or hillwalkers gave more accurate estimates than novices, and men than women. Kammann (1967) found a similar sex difference for downhill views in a city: a 34 deg hill was estimated as 48 deg by men and 55 deg by women. Slope angles may be overestimated because inexperience of sloping terrain makes the terrain seem arduous (i.e. too steep); or because inexperience of numerical angular estimation leads to an overestimation bias. Small angles are also overestimated for other types of angles, such as two-dimensional line drawings (Fisher, 1968), and the visual angle subtended at the eye (Higashiyama, 1992). The apparent angular height of objects in the sky is also grossly exaggerated - a factor thought by some authors to explain the apparent enlargement of the sun or moon near the horizon (Ross and Plug, 2002). Ross (1998) found less severe overestimation of slope when using a non-numerical test method: observers adjusted the angle of a frontally-viewed rod to match the perceived slope of stereoscopic photographs of slopes of 0, 2, 6 and 20 deg. Adults judged the horizontal view as 0.4 deg, and uphill views as 8, 12 and 27 deg respectively, and downhill views as –6, -11 and –24 deg. Children gave very variable results, and overestimated more than adults.

Other studies of slope have been conducted by Proffitt and colleagues (Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Proffitt, Bhalla, Gossweiler, & Midgett, 1995). Proffitt et al. (1995) showed that slope is always overestimated, but more by women than men, and more for downhill than uphill slopes, and more when the observer is fatigued or carrying a load. They argued that the overestimation was related to the supposed effort in traversing the hill. They also found that the overestimation was reduced when observers used a motor rather than a numerical response: they matched the slope of their unseen hand to the slope of the hill.

There are conflicting trends for distant and nearby views of downhill slopes. Perspective predicts that downhill slopes should appear less steep than uphill slopes, but the literature for nearby slopes suggests the opposite of this. Further investigations of nearby slopes were therefore undertaken.

## Method

*Observers*

The observers were drawn from students, staff and visitors who were passing by at the observation spots on the University of Stirling campus. Twenty observers (10 men and 10 women) were found at each of 10 locations who were willing to participate in a short experiment. The mean age was 30 years (range 19-71 years). The mean eye height of the men was 170 cm, and that of the women 159 cm.

*Visual scenes*

Two horizontal scenes were chosen: a footpath heading west with trees on one side and trees blocking the view at a distance of 37.3.m; and a playing field looking south, with a hedge and trees blocking the view at a distance of 131 m. The playing field appeared to have a just detectable downhill tilt, probably caused by a slight downhill slope on the left side of the playing field at right angles to the field of view. Other scenes were chosen with frontal slopes of 2, 5, 7 and 23 deg. Two viewpoints were used for each slope, so as to cover the same ground with uphill and downhill views. The 2 deg slope was a footpath with trees blocking the view at about 50 m in both viewing directions. The 5 deg slope was a road with more extended views. The 7 deg slope was a footpath looking up to the brow of the hill at about 20 m, or down to trees at about 60 m. The 23 deg slope was a grassy bank above a footpath and loch. The uphill view from the footpath rose to the brow at a distance of about 15 m, and the downhill view looked over the bank to the loch and some steep woodland and buildings.

*Procedure*

The observers first took part in an experiment on eye level, as described in O'Shea and Ross (submitted). They were then asked to estimate the slope of the ground in degrees, giving it a value of zero if it appeared horizontal, and using negative values for downhill slopes. They were shown a photocopy of a protractor to assist in the numerical estimation of degrees.

**Results**

The mean slope estimates for all of the scenes are shown in Figure 3, for both men and women. Negative values for downhill views are treated as positive in this graph.

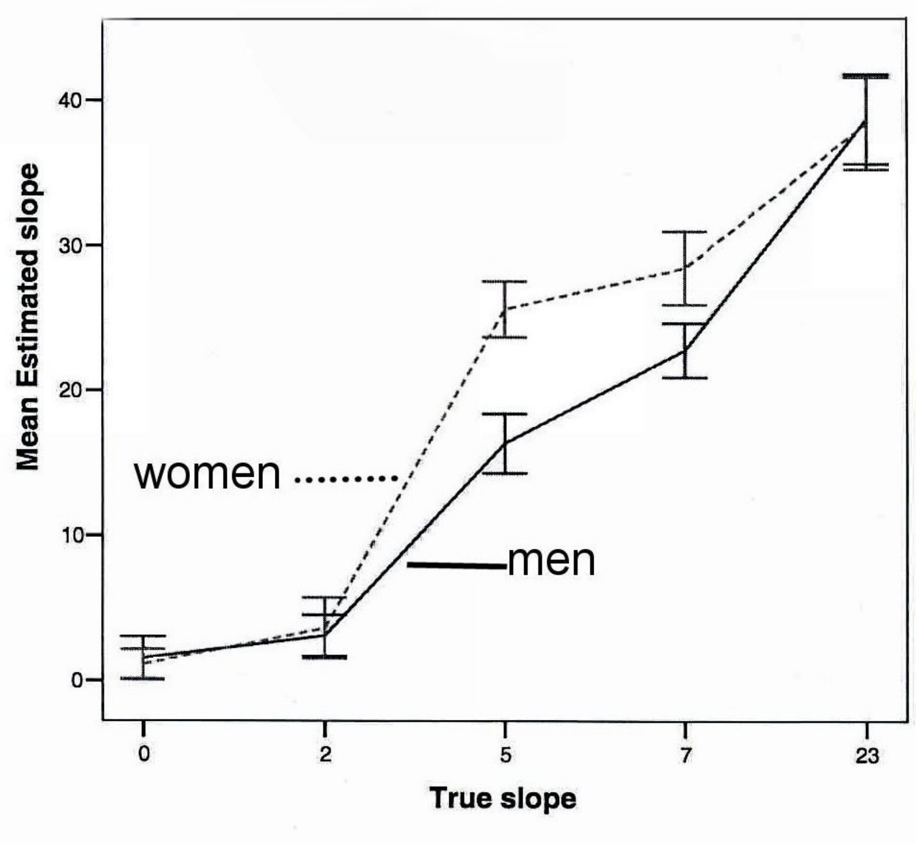


Figure 3. The mean estimated slope (degrees) for men and women as a function of true slope.

The data for the two horizontal scenes were analysed separately, since it is not clear that they should be treated as uphill and downhill views. The mean estimate for the horizontal footpath was 0.93 deg (men 0.55 deg, women 1.30 deg), and that for the playing field -1.80 deg (men -2.60 deg, women -1.00 deg). A two factor ANOVA gave no significant differences or interactions between the visual scenes or sexes. Slope estimates were not significantly different from zero for either scene.

The data for the four sloping scenes were analysed by a three factor ANOVA, with negative downhill estimates treated as positive. This gave a significant main effect of slope angle, $F(3, 144) = 77.49$, $p < 0.0001$; and of sex, $F(1,144) = 5.28$, $p = 0.023$. The slope effect was that estimates increased with true slope angle. The sex effect was that women overestimated slope angles more than men, the mean estimates for a true mean slope of 9.25 deg being 24.08 deg for women and 20.27 deg for men. The difference between the sexes was greater for downhill viewing (women 24.43 deg, men 17.64 deg) than for uphill viewing (women 23.73 deg, men 22.90 deg), leading to a nearly significant interaction between sex and viewing direction, $F(1,144) = 3.24$, $p = 0.074$. There was no significant main effect of viewing direction, $F(1,144) = 1.90$, $p = 0.171$, though the uphill mean (23.31 deg) was slightly greater than the downhill mean (21.03 deg).

## Discussion

The data confirm the common finding that slopes on which an observer is standing are greatly overestimated, whether the view is uphill or downhill. This situation is clearly different from the observation of distant slopes, where downhill slopes are underestimated. The current experiment showed no significant difference between uphill and downhill views, though the mean estimates were slightly lower for downhill views. There was also no significant positive bias for the horizontal footpath. Thus these results show that perspective has little effect on slope perception at the short viewing distances used in this experiment. Equally, the results give no support to the idea that there is greater overestimation of downhill than uphill slopes, as had been found by other authors. .

The sex difference is consistent with the literature, but is hard to explain. Women overestimated slope more than men, particularly downhill slopes. This may because they truly perceive slopes as steeper – perhaps because of inexperience of walking on steep slopes, or perhaps because their lesser strength invokes the idea of extra effort. However, the sex difference was mainly apparent at intermediate slopes, and not at the 23 deg slope. The perceived effort should surely be greater for the steeper slopes, leading to greater overestimation. Body height was not a factor, despite the fact that men were an average of 11 cm taller than women: there was no correlation between eye height and slope estimates. A more likely explanation is that women are less experienced at making angular estimates, and thus more liable to numerical biases. However, these biases have ground and ceiling effects. The 5 and 7 deg slopes were estimated as 21.0 and 25.7 deg, an overestimation by a factor of about 4. On that ratio a 2 deg slope should be estimated as 8 deg, and a 23 deg slope as 92 deg (vertical!). The former is implausible, and the latter quite absurd. The question remains as to why women should be worse at angular estimation. Perhaps they are less likely to have studied geometry or technical drawing in school. It is more likely that they have difficulty with mental rotation and spatial tasks, a finding well documented in the literature (e.g. Dabbs et al., 1998; Collins & Kimura, 1997). This particular task involves the mental rotation of frontal slope to fit the sideways view shown in a protractor – a difficult task even if the frontal slope is correctly perceived.

## References


Bhalla, M., & Proffitt, D. R. (1999). Visual-motor recalibration in geographical slant perception. *Journal of Experimental Psychology: Human Perception & Performance*, 25, 1076-1096.

Burton, H. E. (1945). The optics of Euclid. *Journal of the Optical Society of America*, 35, 357-372.

Collins, D.W. & Kimura, D. (1997) A large sex difference on a two-dimensional mental rotation task. *Behavioral Neuroscience*, 111 (4), 845-849.

Creem, S. H., & Proffitt, D. R. (1998). Two memories for geographical slant: Separation and interdependence of action and awareness. *Psychonomic Bulletin & Review*, 5, 22-36.

Dabbs, J.M.J., Chang, E.-L., Strong, R.A., & Milun, R. (1998). Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution and Human Behavior*. 19 (2), 89-98.

Fisher, G.H. (1968) *The frameworks for perceptual localization*. Report on MoD Research Project 70/GEN/9617. Department of Psychology, University of Newcastle upon Tyne.

Higashiyama, A. (1992) Anisotropic perception of visual angle: Implications for the horizontal-vertical illusion, over constancy of size, and the moon illusion. *Perception and Psychophysics*, 51, 218-230.

Kammann, R. (1967). The overestimation of vertical distance and slope and its role in the moon illusion. *Perception & Psychophysics*, 2, 585-589.

Minnaert, M. G. J. (1954*). The nature of light and colour in the open air* (H. M. Kremer-Priest, revision by K. E. Brian Jay, Trans.). New York: Dover.

O'Shea, R.P., & Ross, H.E. (Submitted). Judgements of visually perceived eye level (VPEL) in outdoor scenes: Effects of slope and elevation. *Perception*.

Proffitt, D. R., Bhalla, M., Gossweiler, R., & Midgett, J. (1995). Perceiving geographical slant. *Psychonomic Bulletin & Review*, 2, 409-428.

Ross, H. E. (1974*). Behaviour and perception in strange environments*. London: George Allen & Unwin.

Ross, H. E. (1994). Scaling the heights. *Scottish Mountaineering Club Journal*, 25(185), 402-410.

Ross, H.E. (1998) Environment, age and frontal slope perception. In: Grondin, S. & Lacouture, Y. (Eds.) *Fechner Day 98* (pp. 332-337). Proc. 14th Annual Meeting of the International Society for Psychophysics.Quebec, Canada: The International Society for Psychophysics.

Ross, H.E. & Plug, C. (2002*). The mystery of the moon illusion: Exploring size perception*. Oxford: Oxford University Press.

Sabra A. I. (1989) *The Optics of Ibn Al-Haytham: Books I-III On direct vision. I Translation.* London: The Warburg Institute, University of London

Thesiger, W. (1964) *Arabian Sands*. London:Penguin Books.

Zehender, W. v. (1900). Die Form des Himmelsgewölbes und das Grösser-Erscheinen der Gestirne am Horizont. *Zeitschrift für Psychologie*, 24, 218-284.