PERSPECTIVE EFFECTS IN FRONTAL SLOPE PERCEPTION

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

Abstract

Observers usually judge slopes to be steeper than they are. However, according to perspective theory, distance foreshortening should make distant uphill slopes appear steeper and distant downhill slopes flatter. Experiments have shown that distant uphill slopes appear steeper than near slopes. Downhill slopes are also overestimated, but they are judged flatter when viewed from a height and greater distance than when viewed from ground level. When viewed from a height of 100 m, flat ground was estimated as sloping 6 deg uphill. These results support the distance foreshortening account, but contravene the changes in optical angle of the scenes - which should make distant uphill views appear flatter and distant downhill views steeper.

Judging the steepness of a frontal slope is a difficult task. The angle of the slope could be judged in a geometrical manner from knowledge of some of the distances and angles involved. Some accounts emphasise the distance information, and others the slope information present in the 2D image. A common account is that the observer takes the distances to the bottom and top of the slope, and knows the angle of regard to these points (deviation of gaze from the horizontal) and the angular size subtended by the slope, and uses these variables to calculate the geographical slope angle. Far distances are normally underestimated (e.g. Teghtsoonian and Teghtsoonian, 1970) and this should have the effect of flattening distant downhill slopes, giving an apparent uphill slope to level ground, and steepening distant uphill slopes (Fig.1).

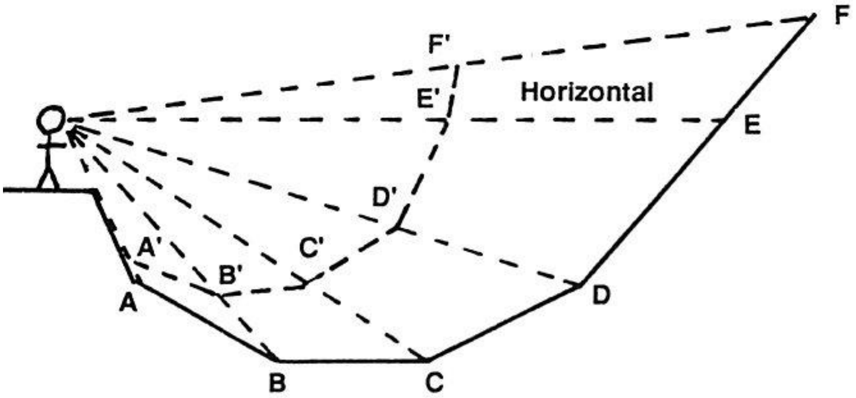

Figure 1. Effects of foreshortened distance on slope perception

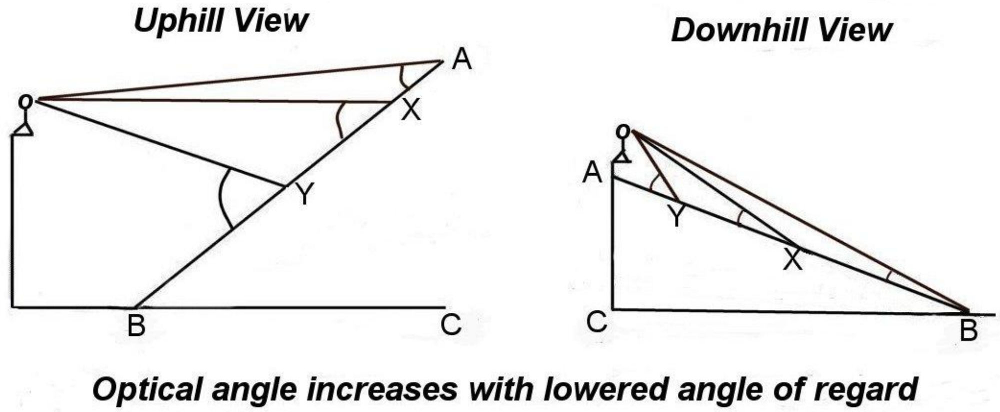

Figure 2. Effect of angle of regard on optical angle.

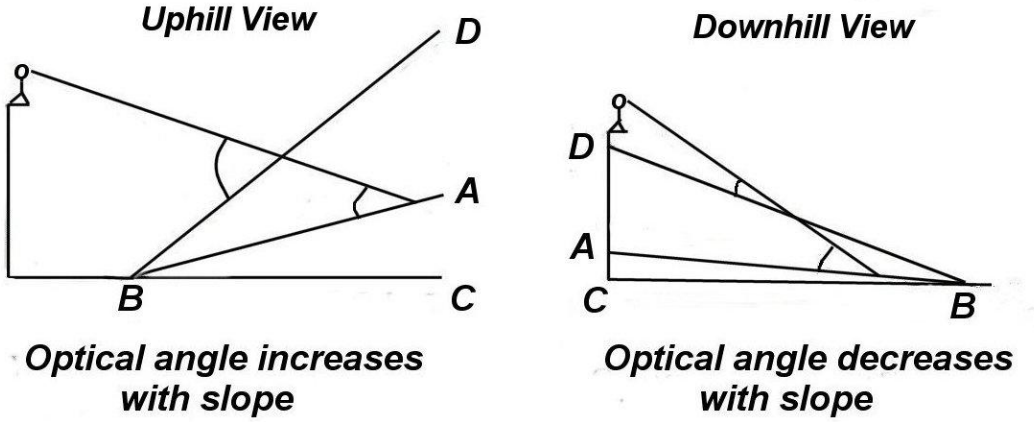

Figure 3. Effect of geographical slope on optical angle

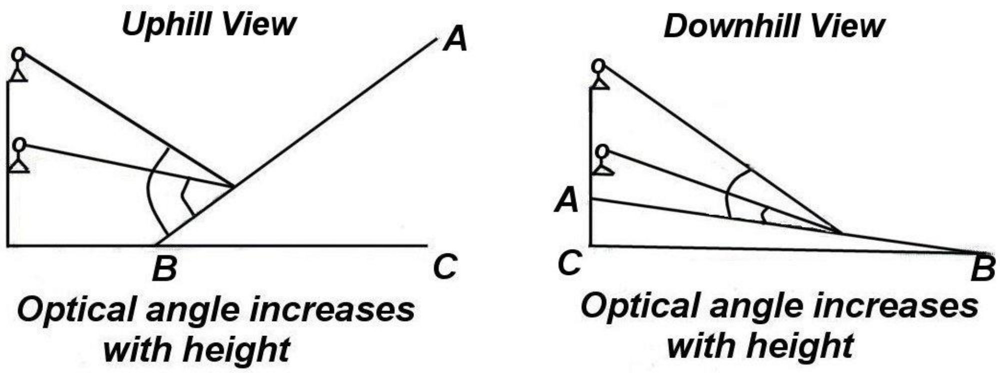

Figure 4. Effect of viewing height on optical angle.

According to Gibsonians (e.g. Sedgwick, 1986), slope could be judged without knowledge of distance, from knowledge of the optical angle which the line of sight makes with the slope, and knowledge of the angle of regard. The optical angle is assumed to be given by slope information within the 2D image, mainly from the texture gradients. The relation between angle of regard, viewing distance and optical angle is illustrated in Fig. 2 , with the optical angles marked. The optical angle in the uphill view (∠OXB) is equal to the geographical slope angle (∠ABC) when the angle of regard is horizontal (the line OX). The optical angle increases with downward gaze and decreases with upward gaze. An increase in geographical slope increases the optical angle for uphill viewing, but decreases it for downhill viewing (Fig. 3). An increase in viewing height increases the optical angle for both uphill and downhill views (Fig. 4).

It should be possible to distinguish between the two accounts if observers fail to compensate for the angle of regard and for viewing height. On the Gibsonian account, an uphill slope should appear flatter when the eyes are raised than when they are lowered, because the optical angle is smaller; but on the distance foreshortening account the higher part of the slope should appear steeper because it is more distant and suffers more foreshortening. Conversely when looking down, the more distant part of the slope presents a smaller optical angle and should appear steeper on the Gibsonian account; but on the distance foreshortening account it should appear flatter. Li and Durgin (2009) found that a reduced optical angle made downhill slopes appear steeper when viewed further back from the edge of the drop.

There is anecdotal evidence from hill walkers and skiers consistent with the foreshortening account. Skiers at the top of a hill see skiers in the valley below skiing uphill, and climbers report that distant uphill slopes look impossibly steep. There is also experimental evidence that increased viewing distance produces steeper slope judgements for uphill slopes (Ross, 1974, p.73; Bridgeman & Hoover, 2008). Experimental studies of slope estimation have usually been conducted at close viewing distances, and do not show the effects of foreshortening. Slope angles are usually overestimated, both uphill and downhill. Proffitt *et al.* (1995) found downhill slopes to be overestimated more than uphill slopes, while Ross (2006) found no difference. In the current experiments varied viewing distances and heights were used to investigate the effects of distance and optical angle.

Experiment 1. Flat and uphill slopes from a high distant view

Method

20 observers (10 men and 10 women) were drawn from volunteers (mean age 40 years) visiting the Wallace Monument. The viewpoint was 100 m above the flat plain of the River Forth. Observers were shown two photographs: one of the view looking north west across the plain (2 km) to the distant hills including Ben Ledi (29 km), and one looking north to the hill of Drumbrae (2 km). They were also shown a page of figures illustrating the angles 0, 5, 10, 30, 45 and 90 deg. They were then asked to estimate the slope in degrees of the flat plain (0 deg), Ben Ledi (9 deg) and Drumbrae (5 deg). The slopes to be estimated were indicated by lines added to the photographs.

Results and discussion

The mean estimate for the flat plain was 6.45 deg (SD 7.24), which was significantly different from 0 ($t = 3.98$, d.f. 19, $p = 0.001$), and also from 0.93 ($t = 2.90$, d.f. 38, $p = 0.006$) which was the estimate for the horizontal footpath in the experiment by Ross (2006). The estimate of 34.05 deg (SD 13.56) for Drumbrae was significantly different from 23.8 deg ($t = 2.90$, d.f.38, $p = 0.006$) which was the estimate for a 5 deg uphill slope in the former experiment. The estimate for Ben Ledi at 58.5 deg (SD 22.37) was significantly different from 30 deg ($t = 5.70$, d.f. 19, $p < 0.000$), which is the extrapolated value for a 9 deg slope in the former experiment. Thus horizontal ground appears slightly uphill, and uphill slopes appear steeper, when viewed from a height or distance. It is unlikely that angle of regard was important for this experiment, as eye level deviated little from the horizontal at these viewing distances.

Experiment 2. Uphill slope from low and high views and varied distance

Method

The observers were drawn from volunteers (mean age 24 years) who were passing by at the three observation spots at the University of Stirling: high window, A; far ground, B; near ground, C (Fig.5). Thirty observers (15 men and 15 women) participated at each location. The chosen slope was a road running uphill at 3.2 deg from a central roundabout to a pedestrian crossing. For the high window scene the observers stood on a link bridge, with an average eye height of 4.34 m above the ground, and a calculated viewing distance of 119 m from the crossing. For the far ground scene the observers stood below the link bridge, 119 m from the crossing. For the near ground scene the observers stood on a footpath, 14.8 m below the crossing. The observers had an average eye height of 1.64 m.The test procedure was the same as in the previous experiment. The observers were asked to estimate the slope leading up to the pedestrian crossing.

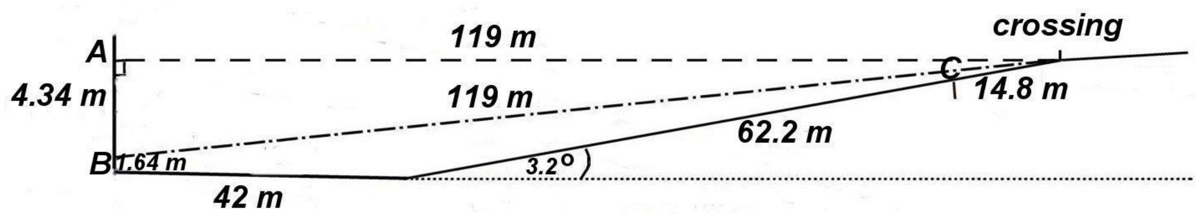

Figure 5. Viewing distances and layout for the uphill scene.

Results and discussion

The data were analysed by a two factor ANOVA, which showed a significant effect of viewing location $F(2, 84) = 5.02$, $p = 0.009$, and sex $F(1, 84) = 5.61$, $p = 0.02$. There was no interaction between sex and location. The mean estimated slope angle was 15.1 deg from the near ground, 18.8 deg from the far ground and 21.8 deg from the high window. The high window estimate was significantly steeper than the near ground estimate (p=0.002), but the far ground estimate did not differ significantly from either of the other locations. The mean estimate for men was 16.5 deg, and that for women 20.6 deg, showing the usual direction for the sex difference (e.g. Ross, 2006).

TABLE 1 Viewing variables and slope estimates for the 3.2 deg uphill slope.

Location	Distance	Regard angle	Optical angle	Estimate
Near ground	14.8 m	-3.2 ^{0}	6.4 ^{0}	15.1 ^{0}
Far ground	119 m	1.3 ^{0}	1.9 ^{0}	18.8 ^{0}
High window	119 m	0 ^{0}	3.2 ^{0}	21.8 ^{0}

The angle of regard to the slope at the crossing point, and the optical angle, is listed in Table 1 for the three viewpoints. In this experiment the increase in viewing distance at the far locations was combined with a large decrease in the optical angle. The significant difference between the near view and the high window view confirms the prediction that greater viewing distance increases the apparent steepness of uphill slopes, but the role of optical angle is unclear. The estimate of 15.1 deg at the near viewing distance, with a fairly large optical angle, is similar to the extrapolated value for a 3 deg uphill slope in Ross (2006). The small difference in optical angle between the high window and the far ground, with the same viewing distance, did not yield a significantly higher slope estimate from the high window. Perhaps a larger increase in optical angle is needed to show an effect.

Experiment 3. Downhill slope from low and high views and varied distance

Method

The observers were drawn from passers-by, or from student volunteers, at three observation spots at the University of Stirling: high window, A; mid window, B; ground, C (Fig. 6). Thirty observers (15 men and 15 women) were tested at each location. Their mean age was 35 years.

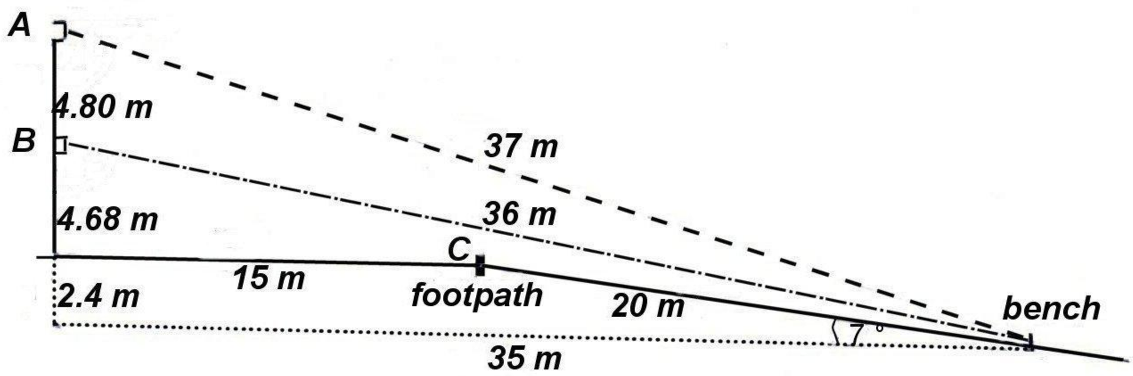

Figure 6. Viewing distances and layout for the downhill scene.

The chosen slope was a grassy bank below a footpath, sloping at 7 deg down to a bench 20 m from the footpath. For the ground scene the observers stood on the footpath. For the mid window scene the observers looked down to the bank from a window. The base of the window was 4.2 m above ground level, and the base of the building was a horizontal distance of 15 m from the footpath. The viewing distance from the window to the bench was calculated as 36 m, for an observer with an eye height 0.48 m above the window base. The base of the high window was 9 m above ground level, and the viewing distance to the bench was calculated as 37 m. The test procedure was the same as in the previous experiments. The observers were asked to estimate the slope angle of the ground at the bench.

Results and discussion

The data were analysed by a two factor ANOVA, which showed a significant effect of viewing location $F(2, 84) = 26.3$, $p < 0.001$, and sex $F(1, 84) = 9.84$, $p = 0.002$. The mean estimated slope angle was 23.1 deg from the ground, 9.6 deg from the mid window and 16.30 deg from the high window. This shows the predicted flattening of downhill slope when viewed from a height or from a distance. The mean estimate for men was 14.0 deg, and that for women 18.7 deg, showing the usual sex difference.

For downhill views, viewing distance can be increased by increasing the viewing height above the ground, or by increasing the viewing distance along the slope, or both. When height alone is increased, the angle of regard is increased; but when distance alone is increased, the angle of regard is reduced. In this experiment, observers standing on the ground with an average eye height of 1.64 m lower their gaze 11.6 deg below horizontal when viewing the ground beside the bench at a distance of 20 m. When looking from the mid window, observers have an average eye height of 4.68 m above ground level, and lower their gaze 11.5 deg when looking to the bench at a distance of 36 m. When looking from the high window, observers have an average eye height of 9.48 m above ground level, and lower their gaze 18.9 deg when looking to the bench at a distance of 37 m. The relevant variables are summarised in Table 2.

TABLE 2 Viewing variables and slope estimates for the downhill slope.

Location	Distance	Regard angle	Optical angle	Estimate
Footpath	20 m	-11.6^0	4.6^0	-23.1^0
Mid window	36 m	-11.5^0	4.5^0	-9.6^0
High window	37 m	-18.9^0	11.9^0	-16.3^0

The results suggest that viewing distance affects slope estimation. The effect of viewing distance, with similar optical angle, can be seen in the difference between the footpath and mid window estimates: increased distance made the slope appear significantly flatter. The viewing distance was similar for the high and mid windows, but the increase in optical angle from the high window did not have the predicted effect of making the slope appear flatter. Instead it appeared steeper. This might be caused by the increased image size of the relevant piece of ground, which would give greater opportunity to detect texture gradients, or to detect differences in apparent distance to the boundaries of the slope.

The current results suggest that observers cannot compensate for loss of relative distance information. Increased viewing distance, and perhaps a reduction in image size, makes distant uphill slopes appear more vertical and distant downhill slopes more horizontal. Changes in the optical angle seem unimportant in this experiment.

References

Bridgeman, B. & Hoover, M. (2008) Processing spatial layout by perception and sensorimotor interaction. *Quart. J. Experimental Psychology*, **61**, 851-859.

Li, Z. & Durgin, F.H (2009) Downhill slopes look shallower from the edge. *Journal of Vision,* 9 (11): 6, 1-15, http://journalofvision.org/9/11/6,doi:10.1167/9.11.6

Proffitt, D.R., Bhalla, M., Gossweiler, R. & Midgett, J. (1995) Perceiving geographical slant. *Psychonomic Bulletin & Review*, 2 (4), 409-428.

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

Ross, H.E. (2006) Judgements of frontal slope in nearby outdoor scenes. In: Kornbrot, D.E., Msetfi, R.M. & MacRae, A.W. (Eds.) *Fechner Day 2006* (pp. 257-262). St Albans, UK: International Society for Psychophysics.

Sedgwick, H.A. (1986). Space perception. In K.R.Boff, L.Kaufman & J.P.Thomas (eds). *Handbook of perception and human performance, Vol.1: Sensory processes and perception,* pp. 21.1-21.57. New York: Wiley.

Teghtsoonian, R. & Teghtsoonian, M. (1970) Scaling apparent distance in natural outdoor settings. *Psychonomic Science*, 21, 212-216.