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Humans Have Precise Knowledge Of Familiar Geographical Slants

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Humans have precise knowledge of familiar geographical slants

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Abstract

Whereas maps primarily represent the 2D layout of the environment, people are also aware of the 3D layout of their environment. An experiment conducted on a small college campus tested whether the remembered slants of familiar paths were precisely represented. Three measures of slant (verbal, manual and pictorial) were collected in two different between-subject conditions (perception and memory) for five familiar paths on the campus of Swarthmore College ranging in slant from 0.5° to 8.6°. Estimates from memory and from perception did not differ for any of the measures. Moreover, estimates from all measures, though different in mean value, were correlated within participants, suggesting a common underlying representation was consulted in all cases.

Humans have precise knowledge of familiar geographical slants

Whereas maps typically depict the two-dimensional layout of an environment, the vertical dimension is generally encountered only directly. The possible importance of inclines as an orienting landmark in the environment (Nardi & Bingman, 2009), as well as the energetic significance of hills (Kammann, 1967; Proffitt , Bhalla, Gossweiler & Midgett, 1995) suggests that detailed memory of this aspect of the environment might be quite useful for navigation and route planning. Geographical slant refers to surface slant relative to horizontal (Sedgwick, 1986). Previous studies of memory for geographical slant have focused primarily on newly-observed outdoor surfaces (Creem & Proffit, 1998) or on small indoor surfaces (Haun, Allen & Wedell, 2005), and each has reported biases in memory using both verbal and manual estimates. Creem and Proffitt reported evidence of additional exaggeration in memory, whereas Haun et al. reported a categorical bias toward 45° for both types of measure. What has not been investigated experimentally is whether extremely familiar locomotor surfaces (e.g., paths frequently taken in daily life) are subject to similar memory distortions.

We sought to assess the precision of the information in memory about the geographical slant of a familiar environment (a small college campus). Our principal question is not one of representational accuracy. It is well documented that geographical slant is overestimated (Kammann, 1967; Li & Durgin, 2010; Proffitt, Bhalla, Gossweiller & Midgett, 1995; Ross, 1974). Rather, our question is of representational precision. The distinction between accuracy and precision is fundamental to measurement. Precision is usually measured in terms of variability, or uncertainty, whereas accuracy is measured in terms of signed error or bias. If one's perception of a hill is consistent, but highly biased, accuracy could be poor even while precision is good. In fact, precise coding is more crucial than accurate coding for controlling action because, so long as actions and perceptions are coded in the same scale, actions themselves can be accurate (i.e., effective) without the representations that guide them being veridical. This allows action control to be able to adapt to distorted visual input, such as adaptation to wedge prisms that offset the perceived location of a target to the left. When wearing such prisms, skilled reaching to grasp an object quickly adapts so that although the object still appears to be displaced (e.g., to the left of one's midline) ballistic reaching becomes successful because one's proprioception of hand position comes to be shifted as well (Harris, 1980). So long as there is opportunity for calibration of action to visual experience, the success of action control depends on the precision rather than the accuracy of the perception. A recent theoretical account of the exaggeration of geographical slant argues that angular perceptual variables are systematically biased (coded on an expanded scale) in order to retain greater coding precision (Durgin & Li, 2011).

For similar reasons, memory representations of surface layout ought to be most informative if they are scaled similarly to perception. Moreover, the precision of such memory representations is of particular interest. One would expect that estimates from newly-formed memories would be more variable (less precise) than those from perception and thus more open to categorical bias. That is, judgmental biases have greater impact on estimates when estimate uncertainty is high (precision is low). But memory variability might decline to something quite close to the limits available in perception for familiar hills. Indeed, given that a familiar slope might have been observed from many different perspectives, it is possible that a memory representation of a familiar surface could be even richer than that obtained by perceptual experience from a single vantage point. On a small campus with a single dining hall, students may become experts not only at 2D route knowledge, but also at knowing the apparent 3D shape of the terrain they are frequently traversing.

Haun et al. (2005) proposed that memory errors in slant judgments might be due to categorical distortions and biases. For example, memory for position is biased toward categorical locations (e.g., Engbretson & Huttenlocher, 1996; Huttenlocher, Hedges & Duncan, 1991) and memory for angles (Fisher, 1968), graphs and figures also show systematic distortion (Tversky & Schiano, 1989) so that errors in slant memory may be quite general. But one might nonetheless expect that highly familiar surfaces would be remembered as they actually appear to us.

There have been many investigations of spatial memory biases for the 2D layout of real environments and maps (e.g., Bahrick, 1979; Byrne, 1979; Tversky, 1981). However, most of these studies address novel layouts or long periods of storage. The one study conducted by Creem and Proffitt (1998) for familiar hills (Experiment 3) was non-experimental in that all participants were tested only in the memory condition and were then compared to perceptual estimates previously collected by Proffitt et al. (1995) under different circumstances. We therefore sought to conduct a full experimental comparison of memory and perception for familiar slants.

We used a small liberal arts college campus as the stimulus for our study. Swarthmore College is situated in a variably inclined environment that provides a shared locomotor experience for its students. There is a single dining hall, for example, that is commonly exited by ascending a somewhat steep extended path to the main academic area of the campus. The campus is relatively small, so students are familiar with most of its paths. But, how familiar are they with their slopes? That is, how precise are their memory representations and how similar are they to their perceptual experience?

We compared slant estimates obtained when students directly observed each of several paths with estimates obtained when other students recalled the same paths from memory. To anticipate the results, students differentiated the various slopes of the tested paths equally well both in perception and in memory and there were no salient differences between estimates made from memory and from perception. This suggests that incidental memory representations of the vertical dimension of a familiar locomotor environment can be quite rich.

Perception and memory for familiar paths

The front of the campus of Swarthmore College features an extended broad hillside, of variable slope, at the center of which extends a tree-lined path (Magill Walk) leading up to the central college building (Parrish Hall) from the train station and town center. We selected for study five well-travelled campus paths in this region of campus ranging from nearly flat (0.5°) to the steepest extended section of path (8.6°) in this part of campus. Images of the steeper paths, and the locations of all the tested paths are illustrated in Figure 1.

Method

Participants. Sixty students (balanced for sex, which is known to affect slant estimates) were recruited from lounge areas in academic buildings and paid to participate. Half made estimates of the five paths from memory and half made estimates from perception while standing at the base of the path.

Non-verbal measures. Two non-numerical measures were used (each individual participant used only one or the other of the non-verbal measures). The *pictorial* measure was a white anti-aliased line, 10 cm in length, on a circular black background inside a gray outer background presented on a computer screen. The line's orientation was adjusted from horizontal by slow (±3°/s) or fast (±30°/s) rotations controlled by holding down one of four keys or by (unlabeled) ±2° steps by key taps. Key taps tended to be preferred by participants (2/3 of non-zero pictorial estimates were even numbers, suggesting key taps were employed exclusively on about 1/3 of trials). The *manual* measure required attempting to hold up one's hand (unseen behind a vertical barrier) parallel to the surface orientation of the path (Durgin, Hajnal, Li, Tonge & Stigliani, 2010; Durgin, Li & Hajnal, 2010; Li & Durgin, 2011, 2012). These manual gestures were measured by a custom lightweight inclinometer (Li & Durgin, 2011) that continuously registered the orientation of the hand to the nearest 0.1°. The inclinometer was zeroed with the hand resting on a horizontal surface and the output was recorded by the experimenter when the participant was satisfied with the setting.

Paths. The five path orientations were measured by inclinometer over a stretch of several meters and an average slant computed (0.5°, 1.2°, 5.7°, 6.1°, and

8.6°). The two shallow paths were at the ends of the central campus building (Parrish Hall) and are identified as *Parrish East (PE 0.5°)* and *Parrish West (PW 1.2°)* respectively. *Upper Magill Walk* (*UM* 5.7°) is part of the central path. *Sharples* (*SH* 6.1°) leads up from the Sharples dining hall, and *Willets* (*WI* 8.6°) leads up from Willets dormitory. The three steep paths are pictured in Figure 1.

Design. All participants made estimates of all five paths in varying order. Half of the participants in each condition used the pictorial measure and half used the free-hand manual measure. All participants then made a numerical estimate (in degrees relative to horizontal).

Procedure. After being instructed and consenting to participate, participants made estimates for each of the five paths while standing outdoors. Presentation order followed one of five orders in both conditions also depicted in Figure 1.

In the memory condition, participants stood in a level courtyard (none of the paths were visible from this location). Path locations were described verbally, depicted on a standard campus map, and shown on satellite images of the campus to disambiguate the exact intended location. While slant estimates were collected, familiarity ratings were additionally collected for each path on a nine-point scale from 1 ("not familiar at all") to 9 ("very familiar") in order to ensure that each participant was at least somewhat familiar with each path (all were). All paths had average familiarity ratings greater than 5, ranging from 5.7 for Willets, to 7.4 for Sharples. Familiarity data was not collected in the perception condition because no memory was required to perform the task. Because participants were randomly assigned to condition (unlike prior studies that compared memory and perception for slant across different populations) we can assume that the memory and perception groups probably did not differ along dimensions that might be relevant to slant estimation. In the perception condition, participants were led to the lower end of each path according to one of five pre-selected orders and looked at the path while making their estimates.

In both conditions the non-verbal estimate was made for each path followed by the verbal estimate before moving on to the next path. Participants were simply told to represent the overall slant of the indicated hill first with the non-verbal measures (e.g., *Hold your hand so that it is/would-be parallel to the extended surface of the path*, or *Adjust the line on the circle until its orientation matches the overall orientation of the path*.) and then to indicate the hill slant verbally in degrees relative to horizontal. Half the participants used only the manual estimate and then gave the verbal estimate; half used only the pictorial line estimate and then gave the verbal estimate.

Results

Our principal question was whether slant estimates made from memory would differ either in mean value or in variability from those made while directly looking at the path in question. To this end, Figure 2 shows the mean estimate (± 1 standard error) for each path from memory plotted against the mean estimate for each path based on direct perceptual experience separated by measure used. It is evident from the size of the error bars (vertical for memory; horizontal for perception) that variability was not increased in memory. Moreover, verbal estimates given from memory did not differ significantly from those based on direct perception of the path: The data were first analyzed by comparing a mixed-effects model including Source (memory or perception), Path Slant, Sex, and Measure (and all 2-way interactions) with a similar model that excluded Source (intercepts and slopes by subjects were included for each factor in the error term). This method allows us to consider whether a model that includes Source (and its 2-way interactions with other factors) provides a better fit than a model that left Source entirely out of consideration. The statistic reported by the comparison of models is a Chi-Square. Including Source (and its 2-way interactions) did not reliably improve the fit of the model, $X^2(11) = 7.6$, $p = .743$. We secondarily conducted fifteen two-sample t-tests, representing the comparison of memory and perception for the combination of each path and measure. These tests revealed only two instances with an uncorrected p-value of less than 0.15. Both of these were for low slants (< 2°), and neither was reliable when even the most liberal correction for multiple tests was applied (i.e., both uncorrected p-values > .04).

Naturally, it was the case that excluding either Path Slant, $X^2(9) = 707.7$, $p < .0001$, or Measure, $X^2(15) = 202.2$, $p < .0001$, decreased the fit of the mixed-effects model highly reliably. This shows that participants were quite sensitive to differences in slant and that the outputs of the various measures were scaled quite differently, as illustrated in Figure 3. Note that the difference between measures does not imply that participants' representations of the slopes of the paths were imprecise. Instead, differential scaling of estimates across measures suggests that each measure is subject to different scaling constraints or measurement artifacts.

Measurement artifacts. Whereas most studies report that verbal and pictorial estimates are quite similar in magnitude, our pictorial measure provided much lower estimates than our verbal measure, as shown in Figure 3. It is likely that this was due to the fact that the pictorial measure was anchored at zero and required many key-taps to elevate it. Shaffer, McManama, Swank, Williams and Durgin (2013) have found that palm board estimates, for example, show strong anchoring effects such that when started from an initial horizontal position, palm board matches to a hill were 30° lower than when started from vertical. For the purpose of our present analysis, the critical issue is not the relative gains between the various measures employed, but whether these particular measures of slant, including the pictorial measure as implemented here, showed substantial agreement between memory and perception.

Free-hand manual estimates, such as used here, tend to be closer to verbal estimates than to actual hill orientation for large hills (e.g., Bridgeman & Hoover, 2008; Durgin, Klein, Spiegel, Strawser & Williams, 2012). The present data are thus consistent with the idea that even manual estimates show that the slants of hills are grossly overestimated in perception. Farther surfaces (like hills) appear steeper than near surfaces (Bridgman & Hoover, 2008; Li & Durgin, 2010), and Li and Durgin (2011) have proposed that free-hand manual estimates, which have been shown to be excellently calibrated for surfaces within reach (Durgin et al., 2010a, 2010b, Li & Durgin, 2011, 2012), may be understood as representing the perceptual "near-surface equivalent" of a distant hill.

Inter-measure correlations. When judgments were made from memory, we would expect a strong correlation among the various measures if a common memory representation were consulted. Moreover, because participants who adjusted the pictorial measure could, of course, see the orientation of the resulting line, it would not be surprising if their pictorial and verbal reports were strongly correlated in both conditions as a result of contamination from one measure to the other. Manual judgments made in the presence of the hill might be based off of a fresh comparison of felt hand orientation and perceived hill slant. Nonetheless, prior studies have reported reliable correlations between manual free-hand estimates (occluded from vision, as here) and verbal estimates (Durgin et al., 2012; Shaffer et al., 2013). Imperfect correlations are to be expected when sensory production (via proprioception) adds measurement noise that is independent of the visual or spatial memory representation of the hill.

To assess such correlations in the present case, we calculated the correlation coefficient between the non-verbal estimates and the verbal estimates given for each slant and measuring type. A 2 (Source) x 2 (Measure) ANOVA conducted on the correlation coefficients showed that the effect of Source differed as a function of Measure, $F(1, 12) = 5.94$, $p = .0313$. The average correlations across the five slants are plotted in Figure 4. Note that even in the perceptual case, the manual measure was positively correlated (mean $r = 0.16$) with the verbal measure across the five slants, one-sample $t(4) = 3.33$, $p = .0292$, though the correlations were reliably less in this case than when the manual matches were made from memory (mean $r = 0.41$), paired $t(4) = 3.78$, $p = .0194$. That the mean manual estimates from memory are so similar to those from perception is all the more impressive given the reduced correlation with verbal estimates in the perception condition.

Despite fairly strong correlations between pictorial and verbal estimates and the much lower means of the pictorial estimates relative to the manual and verbal estimates, verbal estimates did not differ as function of whether a manual or a pictorial estimate preceded them. That is, verbal estimates were not lower for participants who had been tested using a pictorial measure rather than the manual measure. This was established both using overall mixed-effects modeling, in which a model of verbal estimates which took non-verbal measure type into account (along with Sex, Path Slant, Source, and all two-way interactions) explained no more variance than a model that did not, $X^2(9) = 0.65$, $p = .99$, and by ten paired t-tests comparing verbal estimates as a function of non-verbal measure for each path in each of the memory and perception conditions (all $p > .20$, without correction for multiple tests). This suggests that, when present, the correlations between measures more likely reflect a common underlying representation than a contamination from one measure to another – else verbal estimates should have been lower following the use of the pictorial measure. That is, given the low pictorial settings, if the pictorial measure had affected the verbal estimates, we should have expected to see lower verbal settings for participants who had used the pictorial measure than for those who instead used the free hand measure, but we did not find any evidence that this was the case.

Finally, it must be noted that despite the objective similarity between the average slants of the 5.7° path and the 6.1° path, the two paths are judged to be very different in overall slant both in perception and in memory. Although similar in average slant, the shallower of these paths (depicted in the middle panels of Figure 1) is convex, textured by flag stones, and relatively wide whereas the steeper one (depicted in the left images in Figure 1) is somewhat concave in the region tested, relatively devoid of texture, and is also narrower. These details (and perhaps others, such as the termination of the shallower path at the base of a building) may affect apparent slant.

Discussion

We sought to assess the precision of memory representations of the slants of highly familiar campus paths. We tested separate groups of Swarthmore students for their memory or their perception of 5 commonly-used Swarthmore campus paths using three different measures including verbal estimation (all participants), and either manual estimation or pictorial (line orientation) matching. Estimates differed as a function of path orientation and as a function of type of measure used, but mean estimates made from memory did not differ in systematic ways from those made from perception on any of the measures. This suggests that Swarthmore students have a fairly precise memory representation of the slants of common paths on the campus that does not differ in magnitude from their perceptual experience of those slants.

Were there any differences between memory and perception? Like Creem and Proffitt (1998), we observed some indication that manual estimates made from memory were more closely tied to explicit verbal estimates. That is, in our study, the correlation between manual and verbal estimates was reasonably high when both were made from memory (0.41), but was substantially less when both were made from perception (0.16). Nonetheless, both sets of estimates precisely differentiated the different paths even when made from memory, and both sets of estimates remained correlated across measures even when made based on perception. The correlation between pictorial and verbal estimates, on the other hand, was comparable in perception and memory suggesting that pictorial slant matching may be based on explicit verbal estimates or on a third, common representational format. (As noted above, influence on the verbal measure by the pictorial estimates seems to be contraindicated by the lack of effect of having used the pictorial measure on the mean of the verbal estimates, though we cannot rule it out entirely.)

Creem and Proffitt (1998) reported evidence of increased exaggeration of hill slant in memory, but their results were mixed for familiar hills. We did not observe increased exaggeration in the present investigation. However, a number of factors differed between the present experiment and their study including our decision to use locomotor paths exclusively and our decision not to use imagery instructions in the memory task. We did show people a map and satellite image of each path and represented to them that they should estimate the uphill direction, but we did not specifically encourage them to visualize or imagine being in front of the hill. It is possible that our participants could have appealed to their memories even when asked to use perception. However, we believe this is unlikely because the decoupling (reduced correlation) between manual measures and verbal measures in the perception condition suggests that participants in the perception condition were responding afresh to available perceptual information yet gave essentially the same mean estimates manually as others did from memory.

Our data may contribute to the debate over whether exaggerated slant perception is based on effort coding (Bhalla & Proffitt, 1999; Durgin et al., 2009, 2012; Proffitt et al., 1995; Shaffer & Flint, 2011) or on the efficient angular coding of locomotor space (Durgin & Li, 2011; Durgin et al., 2010a; Hajnal, Abdul-Malak & Durgin ,2011; Li & Durgin, 2009, 2010). The relatively strong correlations between differently scaled measures in the memory condition suggest that a common representation may underlie all three. Whereas effort coding assumes that action is controlled by a different representation than conscious perception, the angular expansion theory of slant perception assumes that exaggerated angular scaling might be useful for both perception and action because actions are calibrated to perceptual experience (Li & Durgin, 2012). The correlations observed here are consistent with the idea that manual, pictorial and verbal estimates of slant can all tap into the same underlying representation, but that each measure may have its own output gain, resulting in different mean estimates, but reasonably high correlations between measures. Although each measure may be susceptible to different additional sources of noise and bias, all three seemed to tap a common underlying representation of path slant in memory. Estimates from perception did not differ from those from memory.

In conclusion, the present data show that people internalize the apparent 3D shape of a highly familiar locomotor environment and that slant judgments made from this internalized representation are nearly as rich in information as those obtained from perception. Memory for slant is not particularly accurate with respect to the true geometry of the physical environment, but it precisely captures the perceived geometry (i.e., the perceived geographical slant) of the environment. As we pointed out in the introduction it is representational precision rather than accuracy that typically matters to adaptive biological systems for the control and planning of action. In this sense, memory for the slant of a familiar environment is excellent.

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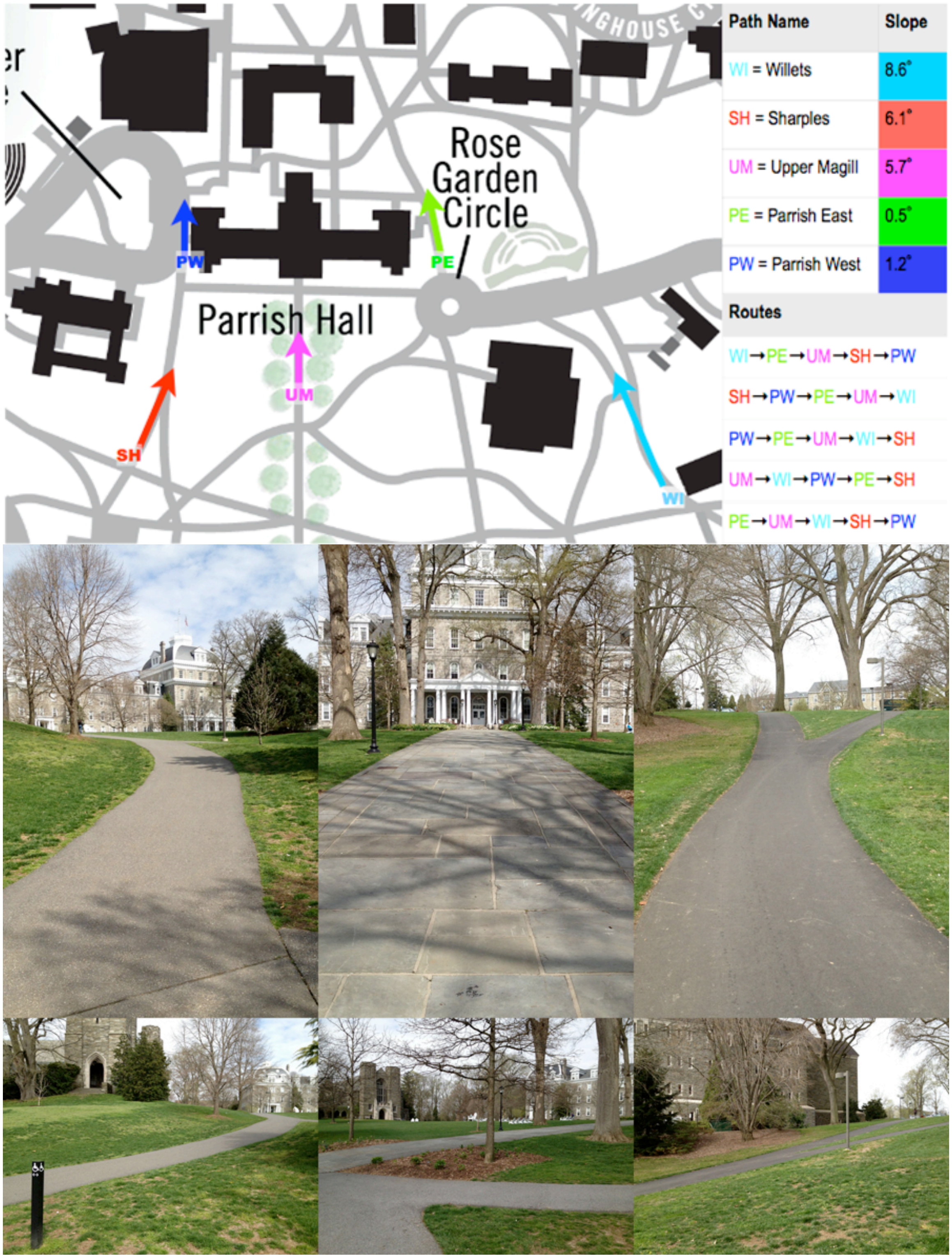
Figure captions

Figure 1. The locations of the five slanted paths used in the study on a campus map. “Routes” refers to the 5 different orders used in both the perception condition and in the memory condition. Below, the three steeper paths are shown in frontal and 3/4 view. Left to right these are Sharples (SH), Upper Magill (UM) and Willets (WI).

Figure 2. Mean path slant estimates from memory as a function of perceived path slant for each of the three measures used. Lying close to the (dashed) unit line is an indication of the similarity of estimates from memory by one group of participants to estimates made by another group while directly observing the path. Error bars represent standard errors of the means for the respective measures.

Figure 3. Mean estimates (averaged across perception and memory) as a function of measure for each path. Standard error bars are shown.

Figure 4. Mean correlations (averaged across correlation coefficients computed for each of the five paths) between verbal and non-verbal measures in the memory condition and in the perception condition. Standard error bars are shown.



Path Name	Slope
WI = Willets	8.6°
SH = Sharples	6.1°
UM = Upper Magill	5.7°
PE = Parrish East	0.5°
PW = Parrish West	1.2°

Routes

WI→PE→UM→SH→PW
SH→PW→PE→UM→WI
PW→PE→UM→WI→SH
UM→WI→PW→PE→SH
PE→UM→WI→SH→PW

Figure 1

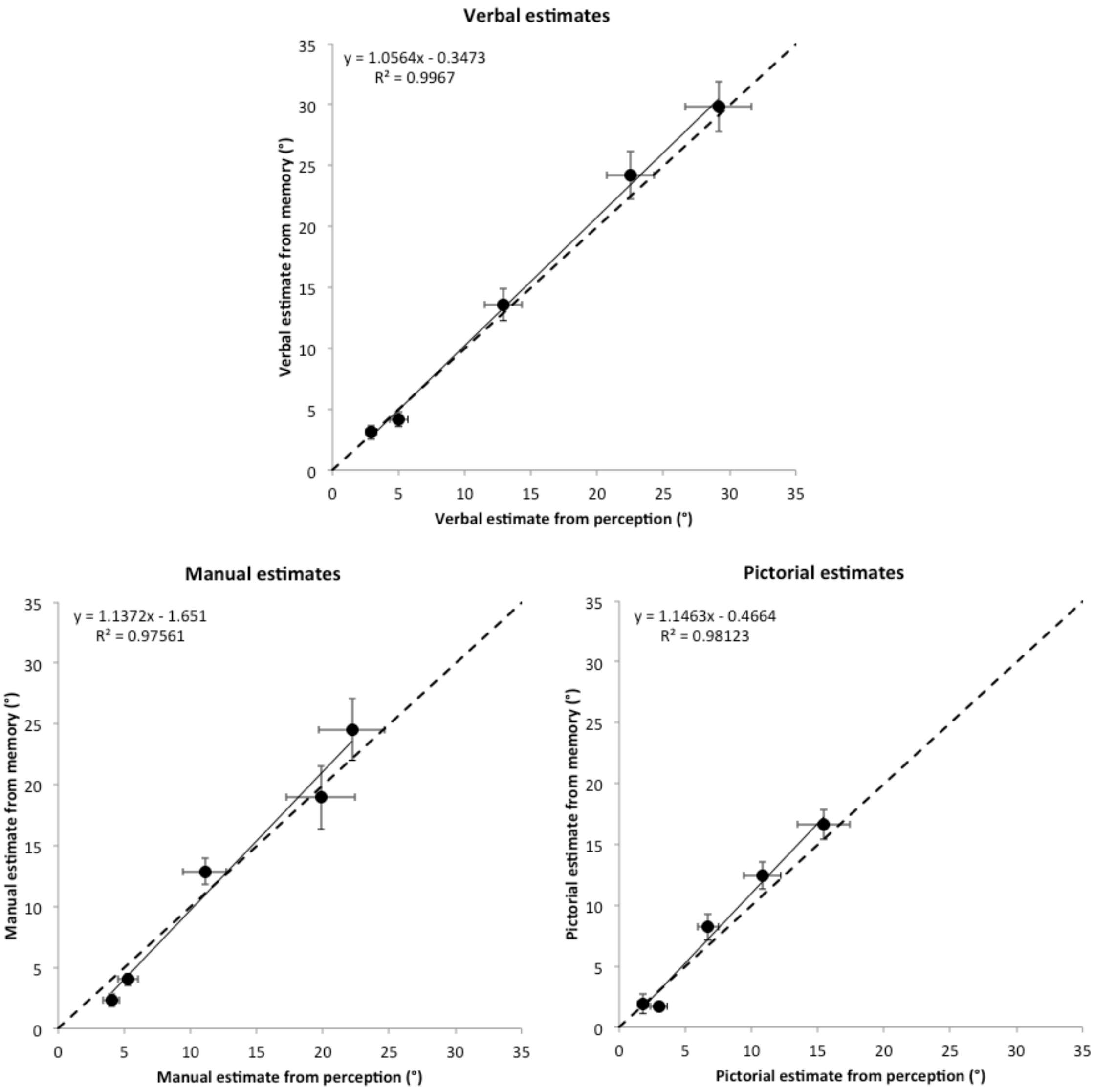

Verbal estimates
y = 1.0564x - 0.3473
R² = 0.9967
Verbal estimate from memory (°)
Verbal estimate from perception (°)
0
5
10
15
20
25
30
35
Manual estimates
y = 1.1372x - 1.651
R² = 0.97561
Manual estimate from memory (°)
Manual estimate from perception (°)
Pictorial estimates
y = 1.1463x - 0.4664
R² = 0.98123
Pictorial estimate from memory (°)
Pictorial estimate from perception (°)

Figure 2

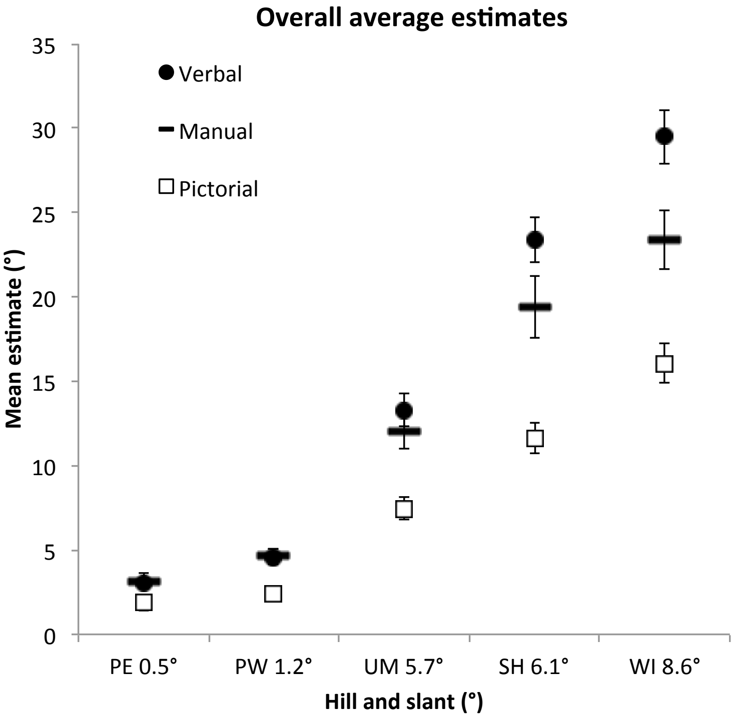

Overall average estimates
Verbal
Manual
Pictorial
Mean estimate (°)
35
30
25
20
15
10
5
0
PE 0.5°
PW 1.2°
UM 5.7°
SH 6.1°
WI 8.6°
Hill and slant (°)

Figure 3

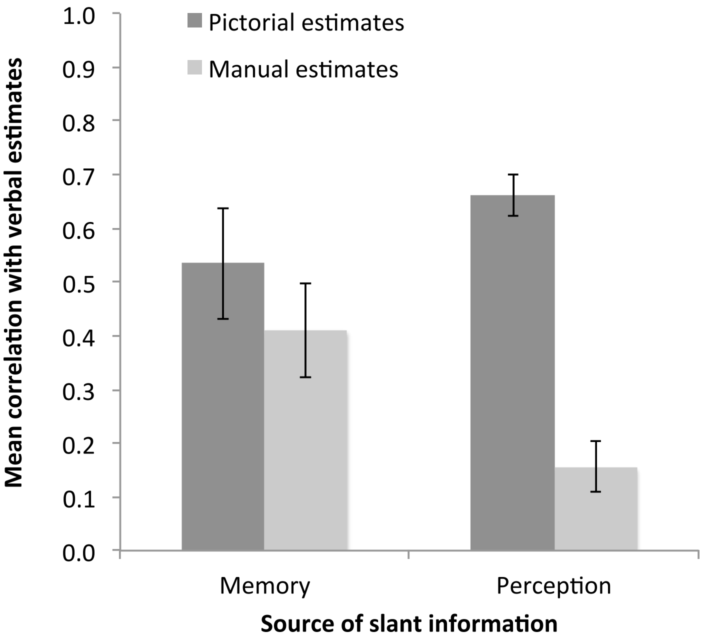

1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Pictorial estimates
Manual estimates
Mean correlation with verbal estimates
Memory
Perception
Source of slant information

Figure 4