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BRIEF REPORT

Manual anchoring biases in slant estimation affect matches even for near surfaces

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Abstract People verbally overestimate hill slant by ~15°–25°, whereas manual estimates (e.g., palm board measures) are thought to be more accurate. The relative accuracy of palm boards has contributed to the widely cited theoretical claim that they tap into an accurate, but unconscious, motor representation of locomotor space. Recently, it was shown that a bias that stems from anchoring the hand at horizontal prior to the estimate can quantitatively account for the difference between manual and verbal estimates of hill slant. The present work extends this observation to manual estimates of near-surface slant, to test whether the bias derives from manual or visual uncertainty. As with far surfaces, strong manual anchoring effects were obtained for a large range of near-surface slants, including 45°. Moreover, correlations between participants' manual and verbal estimates further support the conclusion that both measures are based on the same visual representation.

Keywords Geographical slant · Action measures · Anchoring · Two systems

For 20 years, people's estimates of slant have frequently been measured both verbally and manually (Bhalla & Proffitt, 1999; Bridgeman & Hoover, 2008; Durgin, Hajnal, Li, Tonge, & Stigliani, 2010; Durgin, Li, & Hajnal, 2010; Hajnal, Abdul-Malak, & Durgin, 2011; Li & Durgin, 2011; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Shaffer, McManama, Swank, & Durgin, 2013; Stigliani, Li, & Durgin, 2013). Verbal estimates of hill slant have typically been quite exaggerated and are almost always much higher than estimates made by manual matching. It has sometimes been argued that manual measures tap into a more accurate motor representation (e.g., Proffitt et al., 1995) or are simply quite accurate (Feresin & Agostini, 2007; Taylor-Covill & Eves, 2013). An alternative view is that the standard procedures used for manual measures have inadvertently been selected because they produce the theoretically desired accuracy (Durgin, Hajnal, et al., 2010; Durgin & Li, 2011; Shaffer, McManama, Swank, Williams, & Durgin, 2014). For example, egocentric biases in the haptic perception of orientation (Coleman & Durgin, 2014; Kappers, 2004) guarantee that palm boards set at waist level will produce lower estimates than those set higher (e.g., shoulder height). The standard procedure calls for setting the palm board at waist level. Moreover, we have recently shown that when palm boards are adjusted from horizontal, they give much lower hill matches (by 15° to 30°) than when they are adjusted starting from vertical (Shaffer et al., 2014). Again, the standard procedure used in essentially every article on perceived slant has been to have participants start manual adjustment from horizontal. In the present study, we further investigated this anchoring effect.

Anchoring effects, including those found both with palm board adjustments and with free-hand matching, are expected under conditions of uncertainty (Tversky & Kahneman, 1974). That is, biases like anchoring are not expected when an exact answer can be produced with certainty. For example, if asked "What is half of 90?," the answer "45" is not likely to be affected by first mentioning "0." When one is asked to match one's hand orientation to the slant of a visible surface, there are two possible sources of uncertainty (or variance): (possibly unconscious) perceptual uncertainty about the slant of the surface to be matched, and (possibly unconscious) uncertainty about the orientation of one's own hand. Both of

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these forms of perceptual uncertainty can be thought of as the basis for making matching tasks susceptible to anchoring.

This dual source of variance in perceptual-matching tasks raises the question of whether, in the act of manually matching the orientation of visually perceived hills, the primary source of uncertainty is manual or visual. In the present investigation, we tested for manual anchoring effects when matching near surfaces, because less visual error variance is expected in near space, whereas proprioceptive error variance should remain similar. It has been shown that near surfaces appear to be less exaggerated in slant than do farther surfaces (Bridgeman & Hoover, 2008; Hecht, Shaffer, Keshavarz, & Flint, 2014; Li & Durgin, 2010). Li and Durgin (2010; Li et al., 2013) argued that this effect of viewing distance could be explained by increasing stereoscopic depth compression at farther distances, combined with the systematically exaggerated perceptual coding of slant (Durgin, Li, & Hajnal, 2010). An alternative view is that visual uncertainty is greater at far viewing distances, leading to greater bias. If the latter view were correct, and anchoring in manual matching tasks are due primarily to visual uncertainty, we might expect that manual anchoring effects would be greatly reduced for near surfaces. But if manual anchoring effects are due primarily to perceptual uncertainty in the haptic/proprioceptive system, then large anchoring effects (i.e., of about 20°) would be expected even for manual matches to near surfaces.

Manual slant underestimation found for near surfaces (e.g., Durgin, Hajnal, et al., 2010) can be predicted by the shallower verbal estimates that are found for near than for far surfaces (Durgin, 2013; Li & Durgin, 2011). Distance-related changes in perceived slant have been established using both explicit estimates and shape constancy tasks (Li & Durgin, 2010). Moreover, studies that have examined correlations between manual and verbal estimates for a single hill have reported that these correlations (ranging from about .2 to .5) are relatively high, considering the different sources of measurement variance that each type of measure contributes (Shaffer et al., 2014; Stigliani et al., 2013). These observations suggest that anchoring effects on manual estimates concerning near-surface slant would likely continue to be quite large. This is of some importance to establish empirically, however, because it would help to clarify that manual estimates may be exceedingly noisy measures even in near space (Durgin 2013; Durgin, Hajnal, et al., 2010). This is of theoretical importance because palm board measures have often been used to report null effects as one part of a dissociation with verbal measures, whereas these null effects might simply be due to measurement noise.

Method

We performed an anchoring experiment using an adjustable ramp in near space as the visual stimulus. Observers made six manual matches (with either a free hand or a palm board), and then gave a verbal estimate of the slant of the ramp. Half of the participants in each condition made manual estimates starting from a horizontal hand position, whereas the other half made manual estimates starting from a vertical hand position. Our primary hypothesis was that manual anchoring effects when matching visual surfaces in near space would be as large (about 20°) as those found for hills. In addition, we expected that the manual estimates would continue to be correlated with verbal estimates within each group, even though verbal estimates are not typically affected by manual anchoring (Shaffer et al., 2014).

Design

There were four between-subjects conditions, representing the 2×2 crossing of initial hand orientation (vertical or horizontal) and type of manual measure (palm board or free hand). Six ramp orientations (6°, 18°, 30°, 42°, 45°, and 54°) were tested in randomized order. For each ramp orientation, the manual estimate of slant was collected first, followed by the verbal estimate. This fixed order was intended to minimize the likelihood that the manual estimate would be based on the verbal estimate given.

Participants

A total of 80 participants were divided equally among the four conditions. All participants were undergraduates (43 male, 37 female) from Ohio State University at Mansfield who participated in fulfillment of an Introductory Psychology requirement.

Materials

We created a wooden ramp by attaching two pieces of wood (1×1 m) with a hinge. Six pairs of precut rods were used to hold the slanted portion of the ramp at the six different angles of inclination.

The same palm board used in Shaffer et al. (2014) was used here. It was situated at mid-torso level in order to afford vertical positioning and was set to either a vertical or a horizontal anchoring position in advance of each trial. For the free-hand measure, a calibrated lightweight (0.084-kg) inclinometer (Digi-Pas DWL80e) was attached to the back of the hand of the observer with adhesive tape and was held securely by elastic straps (see Shaffer et al., 2014). A vertical screen blocking the participant's view of his or her hand was adjusted to shoulder height so that the participants could not see their hands when making settings.

Procedure

Each participant stood 1 m from the base of the ramp. In the free-hand conditions, the participants were asked to set their hands to the appropriate anchor orientation (i.e., horizontal or vertical) at the beginning of each trial. Prior studies have shown that participants can manually represent horizontal and vertical with no reliable bias (e.g., Shaffer et al., 2014). Participants were then told to adjust the orientation of either their hand or the palm board to make it parallel with the slope of the ramp. After a digital reading was taken of the indicated orientation, participants were told to lower their hand to their side and were then asked to estimate the slope of the ramp in degrees from horizontal. Participants turned their backs to the ramp between each of the six different ramp orientation settings.

Analysis

Digital inclination recordings from the back of the hand for free-hand estimates were adjusted by half of the average angular hand width (i.e., 6.5°), as per the method of Durgin, Li, and Hajnal (2010). Using mixed-effects modeling, we expected to find an interaction between measure (manual or verbal) and manual anchoring (horizontal or vertical), because no effect of manual anchoring was expected for the verbal measure, whereas a large anchoring effect was expected in the manual measures.

At far distances, manual estimation data are typically found to be noisier (more variable) than verbal estimations when variance is scaled relative to the gain of the measure (e.g., Durgin, 2013). By dividing the standard deviations (*SD*s) of estimates for each slant within each condition by the gain of the measure (change in estimated slant relative to changes in actual slant) within that condition, we could compute mean scaled *SD*s for the manual and for the verbal measures and compare their normalized variances (squared *SD*s) statistically.

Correlations between the measures (with the physical stimulus held constant) might imply a common underlying perceptual representation. To test for the expected correlation between verbal and manual estimates of any particular slant, we calculated correlations at each physical slant value within each condition. We then fit a linear mixed-effects regression model to the correlation coefficients to see whether they differed by measure type or anchor.

Finally, to compare the amounts of anchoring in the present experiment with those reported by Shaffer et al. (2014) for hills, we sought to use the slant values that produced verbal estimates most similar to those measured in that previous study.

Results

Analysis of anchoring effects in the present data

Two linear mixed-effects regression models with measure (manual or verbal) and anchor (horizontal or vertical) as fixed effects and subject and slant as random effects were computed. The model that included the interaction term between the two fixed effects was compared with the model that did not. This comparison produced a highly reliable chi-square statistic indicating a reliable interaction, given that the model with the interaction term included provided a substantially better fit to the data, $\chi^2(1) = 66.1$, $p < .0001$.

As expected, we found a large effect of anchoring on the manual measures (see Fig. 1). A linear mixed-effects regression on the manual estimates with anchor (horizontal or vertical) as a fixed effect and subject and slant as random effects estimated a substantial effect of manual anchoring on the manual slant estimates (19.3°). Linear modeling indicated that the average palm board estimates were 7.5° lower than the free-hand estimates [reliably lower: $t(75) = 5.0$, $p < .0001$]. However, anchoring did not differ reliably between the palm board and free-hand measures: A mixed-effects linear model that included the interaction between anchoring and measure type fit the data no better than did a model that did not include the interaction, $\chi^2(1) = 0.8$, $p = .37$.

In contrast, and as expected, there was little evidence of anchoring affecting the verbal measures (see Fig. 2). A linear mixed-effects regression on the verbal estimates with anchor (horizontal or vertical) as a fixed effect and subject and slant as random effects estimated only a small (2.6°) effect of manual anchoring on the verbal estimates. Applying the standard tools of null-hypothesis testing, the null hypothesis that no effect of anchoring was present in the verbal estimations could not be reliably rejected, $t(72) = 1.8$, $p = .075$. In combination with the reliable interaction between anchoring and measure type, this

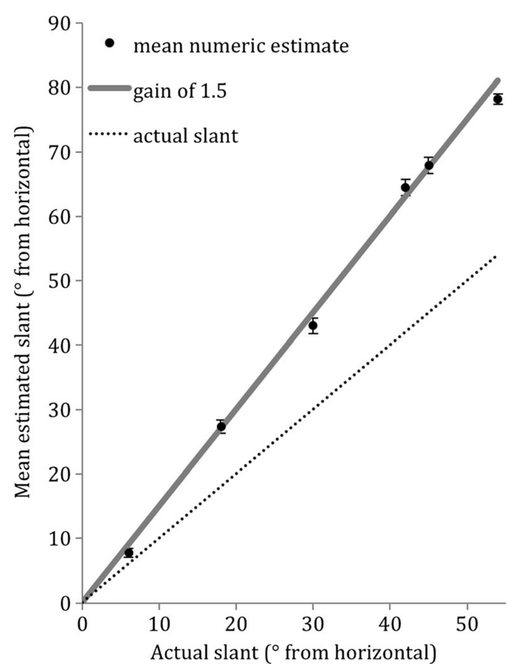

Fig. 1 Manual estimates of slant for near surfaces. Standard errors of the means are shown

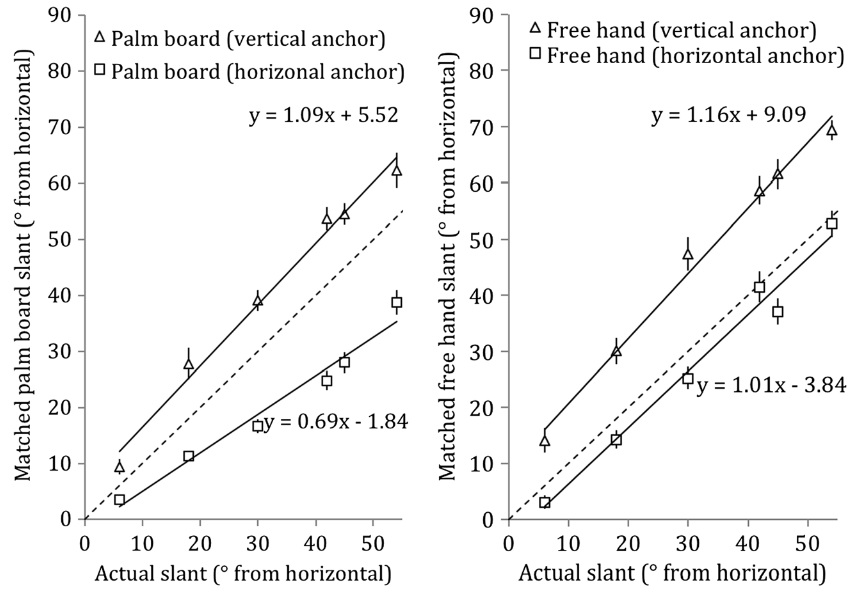

Fig. 2 Verbal estimates of slant for near surfaces. Standard errors of the means are shown

indicates that anchoring had a much larger impact on the manual measures than on the verbal estimates.

Analysis of normalized measure variances in the present data

For each slant, a mean manual scaled *SD* was computed by dividing the *SD* of the estimates by the gain of the estimates (i.e., the slope of the estimates shown in Fig. 1) in each condition and averaging across conditions. Squaring this value produced a normalized variance score for the manual measure (variances did not differ consistently by manual measure type) at each slant. A similar normalized variance was computed for verbal estimates at each slant value. For each of the six slant values tested, the normalized variance for the manual measure was reliably greater than the normalized variance for the verbal estimates (all $ps<.003$, except for the 30° slant, $p=.0128$). Thus, as expected, the normalized variances of the manual measures were higher than the normalized variances of the verbal estimates.

Analysis of correlations between the manual and verbal estimates

For each slant, each participant gave both a manual and a verbal estimate. Because the manual estimate was given first, and because there was a large anchoring effect on the manual estimates but practically no anchoring effect on the verbal estimates, it is clear that the manual estimates did not directly affect the verbal estimates. Table 1 shows the correlation coefficients between the manual and verbal slant estimates for each slant in each of the four conditions. Note that these are correlations between two measures given by the same participants with physical slant held constant. Each measure had its own sources of measure variance (e.g., numeric rounding for verbal estimates). If the two measures reflected two different underlying perceptual representations, they should show no correlation. The presence of correlation shows that part of the variance in the two measures was held in common. Presumably the common variance is that due to intersubject variability in the underlying perceptual representations of the same physical slant.

A mixed-effects linear model of the correlation values with measure type (palm board or free hand) and anchor (horizontal or vertical) as fixed effects and slant as a random effect showed no significant effect of measure or anchor on the correlations (both ts <1). However, the average correlation in the data (.38) was highly reliable according to the model, $t(21)=10.7$, $p<.0001$.

Comparisons to prior data

The verbal estimates of slant in the present experiment replicate the patterns observed by Durgin and Li (2011; Durgin, Li, & Hajnal, 2010; Li & Durgin, 2010), in that verbal estimates

Table 1 Correlations between manual and verbal slant estimates, by actual slant and condition

Measure	Anchor	Slant (deg)						Mean
		6	18	30	42	45	54	
Palm board	Horizontal	.50	.60	.42	.71	.45	.21	.48
Palm board	Vertical	.37	.46	.21	.13	.32	.35	.31
Free hand	Horizontal	.40	.14	.39	.20	.12	.10	.22
Free hand	Vertical	.50	.35	.62	.45	.59	.58	.52

of near surfaces appear to have a gain of about 1.5 relative to actual slant, as is shown in Fig. 2. This somewhat simplifies the task of quantitatively comparing anchoring in the present experiment to anchoring in the data of Shaffer et al. (2014), however.

For the steeper (21.7°) of the two hills tested by Shaffer et al. (2014), the mean verbal slant estimate was 53.5°. On the basis of the 1.5-gain model, this corresponds to a near slant of about 36°. This falls halfway between the 30° and 42° ramps in the present experiment. For their palm board, Shaffer et al. (2014) estimated an anchoring effect for their steep hill that had a confidence interval from 25.2° to 33.3°. In the present data, the mean anchoring effect for the palm board (for slants of 30° and 42°) was 25.6°. For the corresponding free-hand measure, Shaffer et al. (2014) reported an anchoring effect with a confidence interval of 8.1° to 23.1°. In the present data, the mean anchoring effect for the free-hand measure (for slants of 30° and 42°) was 19.7°. In both cases, the present means were reasonably similar to those reported in the previous study.

For the shallower (6.2°) of the two hills tested by Shaffer et al. (2014), the mean verbal slant estimate that they reported was 24.6°. On the basis of the 1.5-gain model, this corresponds to a near slant of about 16.4°, which is quite close to the 18° ramp in the present experiment. From their palm board results, Shaffer et al. (2014) estimated an anchoring effect for their shallow hill that had a confidence interval from 16.4° to 29.8°; in the present data, the mean anchoring effect for the palm board for the 18° slant was 16.5°. For the corresponding free-hand measure, Shaffer et al. (2014) reported an anchoring effect with a confidence interval of 11.3° to 16.3°; in the present data, the mean anchoring effect for the free-hand measure (for slants of 18°) was 15.8°. In both cases, the present means are similar in magnitude to those reported previously.

Overall, the anchoring effects found in the present experiment for near slants are similar in magnitude to those reported by Shaffer et al. (2014) for perceptually similar hills. This observation is consistent with the idea that these anchoring effects primarily reflect perceptual uncertainty in haptic/proprioceptive perception rather than in visual perception.

Moreover, note that the correlations between our verbal and haptic measures persist, even though only the haptic measures are strongly affected by anchoring. This is consistent with the idea that the correlation reflects a common intended estimate (based on the visual perceptual information). This common underlying representation is probably masked in many experiments by strong manual anchoring effects, in addition to a difference in the scaling of manual and haptic measures.

As is shown in Fig. 1, the effect of anchoring on both of the manual measures in the present data is to make them straddle the true slant orientation. On the whole, manual slant estimates in near space are thus fairly accurate. This does not mean that these manual measures are based on a different, more accurate underlying representation than the verbal measures (otherwise, the two measures would likely not be correlated), but it is consistent with the theory that manual actions must tend to be calibrated so that they are effective in acting on the world, even when perceptual experience is distorted (Li & Durgin, 2012; Li et al., 2013). For example, participants asked to set their (unseen) hand to "45°" will only set it to about 34°, and this corresponds to the visual slant that they describe as appearing to be 45° (Li & Durgin, 2012). This can account for why their manual matches to a 34° surface can be accurate: If they think the 34° surface is about 45° and adjust their hand until it feels like it is 45°, they will match the surface pretty well.

Discussion

Palm boards have previously been held up as privileged measures because of their apparent accuracy at matching hills. But a growing body of evidence suggests that palm boards are biased and potentially noisy methods for assessing perceived slant. Moreover, rather than dissociating from verbal measures, they actually correlate with them (across subjects for a given physical slant). Here we have shown that the anchoring effects that we first reported for palm board and free-hand slant estimates with outdoor hills generalize to indoor ramps, and thus appear to primarily reflect haptic or proprioceptive uncertainty rather than visual uncertainty.

We tested ramps across a large range of angles, from 6° to 54°. The anchoring effects for near surfaces were similar to those found for more distant hills outdoors by Shaffer et al. (2014). Manual anchoring biases are thus intrinsic to the use of manual measures and need to be taken into account when interpreting such measures. It is a logical error to interpret manual slant estimates as reflecting an underlying accurate slant representation, on the grounds that their outputs correspond to actual slant values. Manual slant estimates are strongly affected by initial hand orientation. Nonetheless, they also fluctuate with (i.e., are correlated with) verbal estimates given by the same participants, which suggests that verbal and manual estimates are based on the same perceptual representation of spatial layout.

The apparent matches between manual estimates and hills may be artifacts. As is predicted by calibration theory, once anchoring is taken into account, manual slant estimates are aligned better with near than with far surfaces. In order for manual estimates to match outdoor hills (which appear much steeper than similarly sloped near surfaces), a number of biases may need to be employed. Recent work has identified two sources of bias: (1) Manual adjustments signaling orientation that are made low in peripersonal space will tend to have a lower orientation than those made higher in peripersonal space (Coleman & Durgin, 2014). (2) Similarly, hand gestures and other manual adjustments initiated from horizontal will tend to produce lower slant estimates than will manual adjustments initiated from vertical. By codifying a procedure that included a waist-high palm board and a horizontal anchor, the pioneering work of Proffitt et al. (1995) may have acted as a sort of recipe for producing the cognitive illusion that manual hill slant estimation was accurate.

Among the present data, the closest condition to producing accurate estimates was the free-hand measure initiated from horizontal. This may reflect that we are most likely to be well calibrated for reaching out to near objects with our free hands (e.g., Durgin, Hajnal, et al., 2010), and that most of our reaching involves lifting rather than lowering our hands. It is not that our hands have special access to a correct representation of the geometry of surfaces; rather, our hands may be guided by the same geometrically distorted visual information that produces exaggerated verbal estimates. The reason for manual accuracy in near space (i.e., the accurate reaching actions demonstrated by Durgin, Li, & Hajnal, 2010) could be based entirely on visuomotor adaptation of proprioception (Harris, 1963).

Conclusions

Manual estimates of slant are surprisingly noisy, even in near space. The present data provide further evidence against the two-systems theory of geographical slant perception by showing that a large anchoring bias may explain why manual action measures have sometimes appeared to accurately represent hill slant. Moreover, the presence of consistent and reliable correlations between manual and verbal measures of slant lends converging support to the idea that a common underlying perceptual representation of surface layout controls both types of measures. The susceptibility of manual measures to large artifactual biases renders them an unreliable source of evidence regarding the accuracy or inaccuracy of underlying perceptual representations.

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