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Anchoring in action: Manual estimates of slant are powerfully biased toward initial hand orientation and are correlated with verbal report

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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. In the current work, four replications (total N = 204) carried out by two different laboratories tested an alternative, anchoring hypothesis that manual action measures give low estimates because they are always initiated from horizontal. The results of all four replications indicate that the bias from response anchoring can entirely account for the difference between manual and verbal estimates. Moreover consistent correlations between manual and verbal estimates given by the same observers support the conclusion that both measures are based on the same visual representation. Concepts from the study of judgment under uncertainty apply even to action measures in information rich environments.

Key words: Geographical slant, action measures, anchoring, two-systems

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Action measures in the study of visual space are widely regarded as providing access to special forms of representation or processing or as bypassing cognitive artifacts that might be associated with verbal estimation. A famous and widely cited example in the literature is the use of manual estimates of slant which are said to dissociate from verbal reports and provide access to a separate more dorsal-like representation (Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Proffitt & Zadra, 2011). While it is certainly true that actions may provide an important source of converging evidence regarding perceptual experience or underlying perception systems, it has become clearer in recent years that interpreting the mean output of an action measure may provide an insufficiently contextualized understanding of the output. For example, when participants are asked to reproduce distances they have previously seen by walking, they show response compression in their outputs (Li, Sun, Strawser, Spiegel, Klein & Durgin, 2013).

For the past two decades, people's estimates of slant have often been measured both verbally and manually (Bhalla & Proffitt, 1999; Bridgeman & Hoover, 2008; Creem & Proffitt, 1998; Creem-Regehr, Gooch, Sahm, & Thompson, 2004; Durgin, Hajnal, Li, Tongue, Stigliani, 2010a; Durgin, Klein, Spiegel, Strawser & Williams, 2012; Durgin, Li & Hajnal, 2010b; Feresin & Agostini, 2007; Hajnal, Abdul-Malak & Durgin, 2011; Li & Durgin, 2011; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Proffitt, Creem & Zosh, 2001; Schnall, Zadra, & Proffitt, 2010; Shaffer,

McManama, Swank & Durgin, 2013; Stefanucci, Proffitt, Clore, & Parekh, 2008; Stigliani, Li & Durgin, 2013). In most of these studies, manual estimates are made using a *palm board* – where people rest their hand on and rotate the palm board up from horizontal to match their haptic perception of the palm board to their visual perception of the slope of the hill (e.g., Bhalla & Proffitt, 1999; Feresin & Agostini, 2007; Proffitt et al., 1995; Taylor-Covill & Eves, 2013). More recently, an alternative, free hand, technique has been developed in which estimates are made by holding up an unseen forearm and/or hand to match the slope of the hill proprioceptively (e.g., Bridgeman & Hoover, 2008; Durgin et al, 2010a; Stigliani et al., 2013). Whereas verbal estimates suggest that hills appear much steeper than their physical inclination (a hill that looks about 30° is probably less than 10°), palm board estimates have proven to be fairly accurate in matching the true inclinations of hills. Free hand estimates have tended to be intermediate between the other two. The reason for the apparent difference between palm board estimates and verbal estimates has been proposed to be the perception-action distinction between visual awareness and visually guided action (Bhalla & Proffitt, 1999; Goodale & Milner, 1992; Proffitt et al., 1995; Shaffer & McBeath, 2005; but see Durgin et al., 2010a). But a relatively unappreciated aspect of the standard procedures used in nearly all of these papers is that manual estimates of slant are nearly always initiated from a horizontal hand position.

Here we will show that even a physical action, like manual estimation of slant (whether by palm board or by free hand) is susceptible to surprisingly large biasing effects due to response anchoring. Anchoring refers to the biasing of responses by

an initial value. Effects of anchoring and adjustment have been shown to apply not just to numeric estimates (Tversky & Kahneman, 1974; Wilson, Houston, Etling & Brekke, 1996), but also to matching tasks involving physical quantities like loudness and weight (LeBoeuf & Shafir, 2006). A psychophysical matching procedure is likely to be biased if always initiated from one end of a scale. But the concept of anchoring has not been applied previously to action measures such as manual estimates of slant. Feresin, Agostini and Negri-Salviolo (1998) did observe evidence of anchoring when participants were asked to produce palm board settings that corresponded to a specific numeric slant estimate, and a similar effect, conceptualized as *hysteresis*, has been reported for the haptic adjustment of rod orientation (Tarnutzer, Schuler, Bockisch & Straumann, 2012; see also Fitzpatrick, Carello, Schmidt & Corey, 1994). However, no prior study has considered that such response anchoring might also affect the manual estimation of hill slant itself.

By our count, over the last 20 years, there have been 10 papers reporting 28 studies using 33 different groups of participants, using palm board estimates to study hill perception that have concluded that palm board estimates are either accurate, or fairly accurate for many naturalistic outdoor inclinations (Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Creem-Regehr et al., 2004; Durgin et al., 2010a; Feresin & Agostini, 2007; Proffitt et al., 1995; Proffitt et al., 2001; Schnall Harber, Stefanucci & Proffitt, 2008; Taylor-Covill & Eves, 2013; Witt & Proffitt, 2007), yet every single one of these studies has anchored participants' estimates to horizontal by setting the initial position of the palm board to horizontal. Although Feresin et al. (1998) had considered that anchoring affected palm board production

of numeric values, when Feresin and Agostini (2007) developed an ergonomic palm board, they still explicitly anchored it to the horizontal. The general reason for doing so seems to be concern that it is important to provide a reference frame for manual judgments, but given the strong theoretical claims that have been made concerning the accuracy of palm board measures, it seems important to evaluate just how horizontal anchoring might actually affect them when judging hills.

The use of free hand measures, while more recently developed, demonstrates the same procedural bias: In at least five studies using 10 different groups, free hand estimates have always been anchored to horizontal and have produced estimates that overestimate hill slant, but are reliably less than verbal estimates (Bridgeman & Hoover, 2008; Durgin et al., 2012; Durgin et al., 2010a; Shaffer et al., 2013, Stigliani et al., 2013). In part the use of a horizontal reference can be justified as reducing variance, and in measuring hand orientation, a baseline measure is often required to compensate for angular hand thickness (e.g., Durgin, Li & Hajnal, 2010b). Nonetheless, it seems important to understand whether manual orientation measures, in general, show response anchoring because this can help to settle the dispute about whether or not manual action measures, such as palm boards and free hand measures, tap into a distinct visual representation of slant.

Existing evidence of horizontal manual response anchoring effects in near space

Gibson (1950) developed palm boards as a way to register the orientation of the human hand, but discrepancies between freely-wielded hands and palm boards have been reported both for near and for far surfaces (Durgin et al., 2010a). On the face of it, a freely wielded hand should be preferable to a palm board measure, and

in their critique of palm boards, Durgin et al. found that palm board matches to near surfaces (i.e., surfaces within reach) were quite low, with a gain of less than 0.7, whereas the gain for a freely-wielded hand was nearly 1.0. Arguing that limitations of wrist-extension might be the source of low palm board gains, Durgin et al. showed that a similar low gain was observed when participant's forearms were required to remain flat on a horizontal surface while they attempted to raise their hand, by wrist-joint extension, to proprioceptively match their hand orientation to the slant of a visually-presented 2D oriented line. Durgin et al. proposed that this misperception of wrist extension was sufficient to account for measurement bias when using waist-high palm boards (most of which are operated primarily by wrist joint extension). However, the fact that both the palm board task and the wrist extension task involved horizontal anchoring of initial hand position may also be important to producing these low gains. Note that if horizontal anchoring is indeed responsible for artificially lowering palm board settings compared to a freely-wielded hand, then a freely-wielded hand should show less anchoring than a palm board. Conversely, eliminating horizontal anchoring in palm board measures might make them have a gain closer to 1.0 in near space. There is evidence for this latter conjecture.

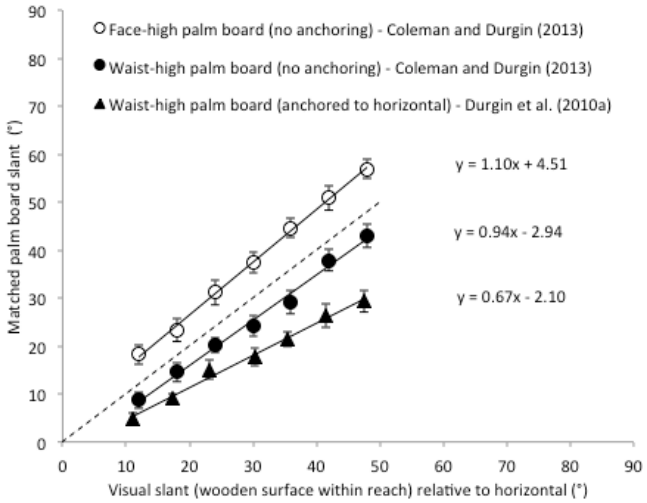


Figure 1. Palm board matches to near surfaces collected with and without anchoring procedures. The black triangles are from a procedure with the palm board just above the waist and with the palm board reset to horizontal (horizontal response anchoring) prior to each trial (Durgin et al., 2010a). The black circles represent a similar procedure except that the palm board was not reset between trials (Coleman & Durgin, 2013). The white circles (also no anchoring) show the effect of placing the palm board at eye-level rather than waist level changes the intercept of the function. Standard errors of the means are shown.

The authors of a recent study that examined palm board matches to near surfaces, being aware of the present work, avoided anchoring palm board responses to horizontal by not resetting the palm board position between trials (Coleman & Durgin, 2013). In that study the height of the unseen palm board (which was either near the waist or near eye level) produced a large additive offset in palm board matches (both to visual slanted surfaces and haptic slanted surfaces) in accord with egocentric errors in haptic perception. Importantly however, these offsets were accompanied with gains of nearly 1.0. The data from that study, which did not use response anchoring, are compared to the data from Durgin et al. (2010a), who did use horizontal anchoring, in Figure 1. The difference between the low gain of the

black triangles and the relatively normal gain of the black circles might be regarded as evidence of an anchoring effect on palm-board matches to near surfaces. The gain of nearly 1.0 for the recent study that avoided anchoring manual palm board responses to horizontal is consistent with the conjecture that the lower (0.7) gains for near-surface matching found by Durgin et al. (2010a) were primarily an effect of horizontal anchoring rather than of limitations of wrist flexion/extension. In the present study, we will more directly test this anchoring interpretation with an experimental manipulation of anchoring using outdoor hills.

A test of horizontal anchoring effects on manual matches to hills

The present study tested whether manual action measures of hill slant show evidence of significant anchoring effects that might mask their correspondence to verbal estimates. As a secondary matter, the design we used additionally facilitated analyzing correlations between manual and verbal estimates (see Stigliani et al., 2013) as a way of assessing whether the two measures are based on the same perceptual representation of hill slant. Specifically, we used a design in which participants gave only a single manual estimate, which was followed by a verbal estimate in the absence of visual feedback about actual hand position. Whereas an absence of correlation between two measures might be due to different sources of variance in their production (e.g., bias toward multiples of 5° in verbal estimation, and calibration error in proprioception of hand orientation in manual estimates), positive evidence of correlation suggests the possibility of either contamination or of a shared perceptual representation (especially when a single stimulus is used across all measures and observes so that stimulus-specific interactions are

experimentally controlled). Prior studies using free-hand measures have reported correlations between verbal estimates and free hand measures (Durgin et al., 2012; Stigliani, Li & Durgin, 2013), but no such analyses have previously been reported for palm boards.

Experimental Methods

Our laboratories collaborated to conduct four replications of the same basic anchoring experiment[1]. We tested two forms of action measure (free hand and palm board) on two different hills. In each replication, different sets of participants made a single manual estimate of a single hill followed by a verbal estimate of the same hill. The hill used was either a fairly steep paved drive (6.3°) or a very steep grassy embankment (21.7°). In all cases the goal of adjustment was to make the manual measure parallel to the hill surface, but we varied, between participants, whether the manual measure in question was initiated from horizontal (the traditional approach) or from vertical. The request for a verbal estimate followed completion of the manual measure so that the verbal estimate would not contaminate the manual estimate. Moreover the verbal estimate was made after the participant had removed their hand from its posture during manual estimation so that the verbal estimate would be based on visual representation of hill orientation rather than on the manual match itself.

[1] A fifth replication (using a free-hand measure) is not reported because the procedure did not include measuring angular hand thickness, which is a source of additional measurement variance. Strong evidence of anchoring effects was also found in that replication, but inter-measure correlation was substantially reduced.



Figure 2. Hills used at SWAT (upper left; 6.3°) and at OSUM (upper right; 21.7°) are shown from the observers' viewpoint. Below are shown a palm board apparatus (middle left) with inclinometer (lower left) and a free hand apparatus (middle right) with inclinometer (lower right).

Participants

There were a total of 204 participants. Of these, 120 undergraduates (50 male) from The Ohio State University at Mansfield (OSUM) participated in one of two replications with a 21.7° hill in fulfillment of an Introductory Psychology requirement. Half were tested with a palm board; half with a free hand measure. Eighty-four undergraduates (39 male) from Swarthmore College (SWAT)

participated for a small payment in one of two replications with a 6.3° hill. Forty were tested with a palm board and 44 were tested with a free hand measure.

Apparatus

Photos of the two hills used are shown in Figure 2. Following the practice of Feresin and Agostini (2007), a marker on the hill (near eye level) was used to indicate the region to be judged. Photos of the palm board and free hand apparatuses used at SWAT are also shown in Figure 2. Similar apparatuses were employed at OSUM. For the free hand measure at each location, 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 held securely by elastic straps. Participants could not see their hand when making their settings. In the free hand replications, a level surface was employed at the conclusion of the experiment to measure the angular thickness of each person's hand so that settings could be re-referenced to the central axis of their hand; the human hand is wedge-shaped with an average angular thickness of about 13° (Durgin et al., 2010b).

As a manipulation check we determined that when re-referenced to the hand's central axis, participants' gestures of horizontal or vertical made prior to hill matching were unbiased. In the horizontal anchoring conditions, the average mean setting (corrected by adding half the angular width of the hand) was -0.4° (95% *CI*: -2.7° to 2.0°). In the vertical anchoring condition, after adding half the angular width of the hand, the average mean setting was 88.7° (95% *CI*: 86.4° to 91.0°).

Procedures

The palm board (when used) was situated at mid-torso level and was set to either a vertical or a horizontal anchoring position in advance. Assignment to anchoring condition was random. In the free hand experiments, a vertical screen blocking the participants' view of their hand was adjusted to shoulder height and, once the inclinometer was attached to the back of their hand, the participant was asked to set their hand to the appropriate anchor orientation. Participants were then either told to adjust the orientation of their hand or the palm board to make it parallel with the slope at the indicated point on the hill. After a digital reading was taken of the indicated orientation, participants were told to lower their hand to their side and then asked to estimate the slope of the hill in degrees from horizontal.

Results

The mean manual settings and mean verbal estimates in each of the four replications are shown in Figure 3. We will refer to each replication by an acronym composed of the location conducted and the manual measure used (i.e. *pb* or *fh*).

Analysis of anchoring effects

There are four conclusions we can draw from the mean responses.

1. There was significant anchoring of manual responses in all four replications. Mean differences between manual estimates in the horizontal and vertical starting condition were highly reliable in all four replications, OSUMpb: $t(58) = 12.1$, $p < .0001$, Cohen's $D = 3.2$; OSUMfh: $t(58) = 4.20$, $p = .0001$, Cohen's $D = 1.1$; SWATpb: $t(38) = 7.01$, $p < .0001$, Cohen's $D = 2.3$; SWATfh: $t(42) = 4.52$, $p < .0001$, Cohen's $D = 1.4$. Manual anchoring did not affect verbal estimates.

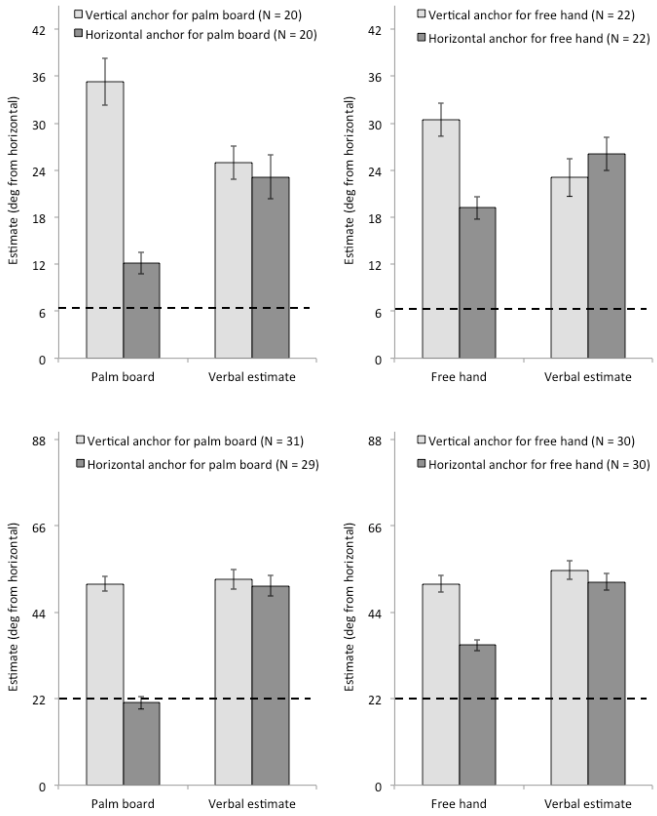


Figure 3. Results of all four experiments. Upper panels depict data for the SWAT (6.3°) hill. The lower panels depict data for the OSUM (21.7°) hill. Mean manual and verbal estimates (with standard errors) are shown as a function of the initial orientation of the palm board (left) or of the free hand (right) for the manual estimate. The dashed lines represent the actual slant of the hill.

2. The manual data in the horizontal anchoring conditions replicate prior findings. For a hill of 21°, palm boards are typically quite accurate (e.g., Bhalla & Proffitt, 1999, reported a mean match of 21.7° for a 21° hill). In the OSUMpb replication the mean setting made from horizontal was 21.0° (*CI_95%*: 17.7° to 24.2°). For shallower hills, palm board estimates are usually too high. For a hill of 6°, Bhalla and Proffitt (1999) reported a palm board setting of 10.3°; in the SWATpb replication, the mean setting was 12.2° (*CI*: 9.2° to 15.1°). Also consistent with prior studies, horizontally-anchored free hand settings (OSUMfh: M = 35.7°; SWATfh: M =

19.2°) are consistently higher than the corresponding palm board settings, OSUM: $t(57) = 4.61$, $p < .0001$, Cohen's $D = 1.2$; SWAT: $t(40) = 3.53$, $p = .0011$, Cohen's $D = 1.1$, but are lower than the corresponding verbal estimates, OSUMfh, $t(29) = 4.92$, $p < .0001$, $d = 0.90$; SWATfh: $t(21) = 2.99$, $p = .0070$, $d = 0.64$. These observations show that our horizontally anchored conditions appropriately replicate typical findings and are thus relevant to interpreting those findings.

3. Anchoring effects were larger for the palm board measure than for the freely wielded hand. Many prior reports have suggested that palm boards give lower estimates than free hand measures (e.g., Durgin et al., 2010a). If palm board settings in the literature have been lower than free hand settings because of horizontal anchoring effects, anchoring effects should be larger for palm board measures than for free hand measures. In fact, comparing across replications using the same hill, anchoring effects (mean differences between the two anchoring conditions) were about twice as large for palm boards as for free hand measures, and the confidence intervals for the mean anchoring effects for each measure were non-overlapping (OSUMpb: M = 30.2°, *CI*: 25.2° to 33.3°; OSUMfh: M =15.6°, *CI*: 8.1° to 23.1°; SWATpb: M = 23.1°, *CI*: 16.4° to 29.8°; SWATfh: M = 11.3°, *CI*: 6.3° to 16.3°). Larger anchoring effects may be a reflection of greater uncertainty when using a novel haptic device to respond rather than one's hand. These data show that the oft-replicated differences between free hand measures and palm boards can be explained by differential susceptibility to anchoring.

4. The manual data in the vertical anchoring conditions are all higher than or equal to the verbal estimates implying the anchoring bias may be symmetrical. If

palm board estimates differ from verbal measures primarily because of manual anchoring then we might expect to see symmetrical effects of horizontal and vertical anchoring, with vertical anchoring producing manual matches that are higher than verbal estimates. For the 6.3° hill, the overall mean verbal estimate was 24.6°. Within each replication for this hill, manual estimates from vertical (SWATpb: 35.7°; SWATfh: 30.5°) were reliably higher than corresponding verbal estimates, SWATpb, $t(19) = 3.87$, $p = .0020$, $d = 0.87$; SWATfh: $t(21) = 2.46$, $p = .0227$, $d = 0.52$. Anchoring effects were symmetrical, such that the overall means of the two anchoring conditions in each replication with this hill (SWATpb: 23.7°; SWATfh: 24.8°) did not differ from the mean verbal estimates, SWATpb: $t(39) = 0.12$, n.s.; SWATfh: $t(42) = 0.12$, n.s.

For the steep hill, manual estimates from a vertical initial position (OSUMpb: 51.2°; OSUMfh: 51.3°) were not reliably different than the corresponding verbal estimates (OSUMpb: 52.4°; OSUMfh: 54.7°), OSUMpb: $t(30) = 0.37$, n.s.; OSUMfh: $t(29) = 1.18$, n.s. However, the verbal estimates for the steep hill were somewhat higher than expected: For a 21° hill, Bhalla and Proffitt (1998) reported mean verbal estimates of only 40.2°, and similar predictions are made by Li and Durgin's (2010) model of perceived slant. Thus, even here there may be evidence for symmetrical bias: In neither replication did the overall mean manual estimates (OSUMpb: 36.6°; OSUMfh: 43.5°) differ reliably from 40.2°, OSUMpb: $t(59) = 1.54$, n.s.; OSUMfh: $t(59) = 1.55$, n.s. Overall, then, these results are consistent with the hypothesis that the mean differences typically observed between manual measures and verbal estimates are largely due to manual anchoring effects.

Analysis of correlation between manual and verbal estimates

According to the two-systems hypothesis, manual estimates give different values than verbal estimates because the two measures are based on different underlying visual representations. The anchoring hypothesis provides an alternative account of mean differences (that they are due to a source of measurement bias affecting manual measures only). Evidence of correlation between such different outputs as manual and verbal reports (e.g., Stigliani et al., 2013) tends to support the idea that both estimates are based on a common underlying representation. Such correlations for judgments of a single hill could arise from between-individual differences in perceived slant of the same hill.

Correlation analyses are, by definition, non-experimental methods and cannot rule out an alternative common third variable. Nonetheless, a correlation between verbal and manual estimates across observers is consistent with there being a common underlying representation, as also suggested by the experimental manipulation of response anchoring. To test for correlation we first removed anchoring biases, which might have tended to mask an underlying correlation between the measures. This was done by centering the data (subtracting off the means) within each anchoring condition. Scatterplots of the centered data are shown in Figure 4, along with the best-fitting regression lines.

A positive correlation was found in all four replications. In three of the four replications, t-statistics indicated that the correlation was reliable, OSUMpb: r = 0.26, $t(58) = 2.02$, $p = .0475$; OSUMfh: $r = 0.33$, $t(58) = 2.69$, $p = .0093$; SWATpb: r = 0.37, t(38) = 2.42, p = .0204; SWATfh: $r = 0.11$, t(42) = 0.68, p = .50. When the

centered data of all 204 participants are included in a single analysis, the overall correlation, 0.28 (*CI*: 0.15 to 0.41), was highly reliable, $t(202) = 4.22$, $p < .0001$.

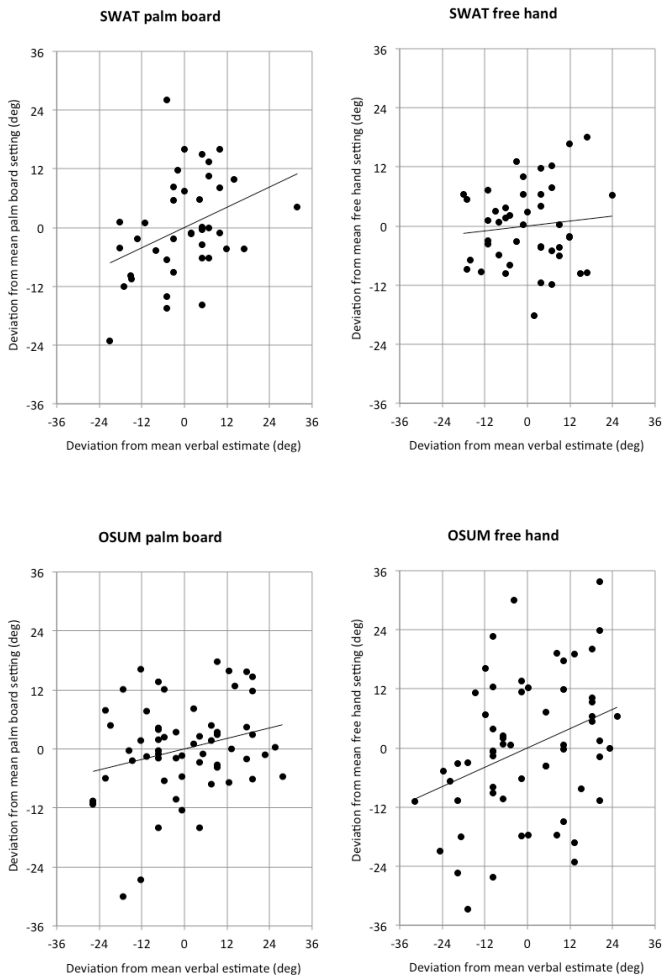


Figure 4. Correlations between manual and verbal estimates in the four replications of the anchoring experiment were estimated after compensating for anchoring effects by centering the data.

Analysis of the anchoring outcomes seems to provide an explanation of prior reports of dissociation between verbal and manual measures. However, the use of horizontal anchoring is deeply entrenched in the palm board literature. It is thus relevant that even if only traditional (horizontally-anchored) palm board data are considered, the centered data of the 49 participants in those conditions provide

strong evidence of a reliable correlation (r = 0.37) between palm board estimates and verbal estimates (*CI*: 0.10 to 0.59), $t(47) = 2.74$, $p = .0089$. Moreover, the overall positive correlation between manual and verbal estimates in the palm board conditions, $r = 0.29$, $t(98) = 3.00$, $p = .0035$, is similar to that in the free hand conditions, $r = 0.28$, $t(102) = 2.93$, $p = .0042$.

As noted above, verbal measures and manual measures are likely to have very different (i.e. independent) sources of measurement variance, which should tend to reduce correlations between their outputs and thus underestimate the true correlations between the underlying variables (Conway & Lance, 2010). The reliable correlations we have nonetheless observed between these two very different measures thus suggest that manual and verbal measures are based off a common perceptual representation. This view is supported by our experimental observations that palm board estimates differ from verbal estimates, at least in part, because of response anchoring effects. The quantitative similarity of correlation with verbal estimates across free hand and palm board methods also supports the hypothesis of a common representation.

Discussion

Action measures are sometimes treated as more robust than verbal reports of perceptual experience, but measures based on the performance of an action may also be susceptible to artifacts and biases (Coleman & Durgin, 2013; Durgin, Dewald, Lechich, Li & Ontiveros, 2011; Haun, Allen & Wedell, 2005; Li et al., 2013). Here we have used manual estimates of slant as a kind of case study in which we have shown that the widely cited differences between verbal estimates and manual estimates

might be primarily due to response anchoring. We have reported the results of four replications of the same basic experiment so as to provide a greater measure of confidence in our conclusions.

For 20 years, differences between verbal and manual measures of slant have commonly been interpreted as measuring different underlying visual representations. Two forms of argument have been used to make this case. The first was that manual matching of hill slant was surprisingly accurate (given how steep hills look). The second was the existence of manipulations that affected one of these variables and not the other. In the present investigation we have demonstrated the insufficiency of each of these arguments.

First, the previously reported accuracy of manual measures of perceived hill slant is evidently an artifact of a surprisingly large anchoring bias. Simply by adopting a different starting position from which manual estimates are performed, we eliminated or reversed in magnitude traditional differences between verbal and manual measures of hill perception. Thus action measures are also strongly susceptible to basic biases of response anchoring (see Feresin et al., 1998), even when made in an information-rich context like the presence of a hill.

Second, once anchoring was taken into account, verbal and manual estimates were positively correlated in all four replications of this experiment (see also Stigliani et al., 2013). The most likely explanation of this correlation is that when research participants perform manual actions to represent hill slant they intend to communicate the same perceptual experience as they intend to communicate verbally. Their intentions have typically been foiled due to response anchoring.

Dissociations between the means of two different measures based on an experimental manipulation may simply result from experimental artifacts that affect one measure differently than another even if both measures are actually measuring the same perceptual representation. For example, multiple studies have shown that the effects of heavy backpacks on slant estimation are probably due to explicit compliance with experimental demand (Durgin et al., 2009; Durgin et al., 2012; Shaffer et al., 2013) and, as such, may tend to affect verbal reports more than manual estimates for the simple reason that they do not actually affect perception.

Would verbal responses also show response anchoring?

In the present study we did not test for anchoring effects on verbal estimates. Past studies of verbal estimates of haptically-perceived and visually-perceived near surface slant have shown little evidence of response anchoring when manipulating whether vertical or horizontal was defined as 0° (Durgin et al., 2010b; Durgin & Li, 2012; see also Durgin & Li, 2011a). These studies have tended to show that horizontal verbal anchoring biases are not responsible for the systematic spatial biases observed for surfaces within reach.

Moreover, studies using classical psychophysical procedures that minimize anchoring effects (i.e., staircase methods) to estimate implicit measures of perceived slant have tended to align rather well with verbal estimates. That is, one implicit measure of perceived slant is the perceived aspect ratio of a L-shaped configuration of balls presented on slanted surfaces. Errors in this task can be interpreted as errors in slant perception (Li & Durgin, 2010). Results obtained with this method correspond well with verbal estimates to confirm, for example, that perceived slant

is exaggerated even in near space and that farther surfaces appear steeper as a result of greater depth compression from binocular information (Li & Durgin, 2010, 2013).

Generalization to other forms of action measure

Durgin et al. (2010a) argued that adjusting a palm board is not a visually-guided action because visually-guided actions (e.g., grasping, touching) are conducted with respect to the object of interest. Thus adjusting a mechanical device to represent the orientation of a hill is rather different than measuring, say, hand orientation in flight when reaching out to touch a visually-perceived surface within reach (e.g., Durgin et al. 2010a, Experiment 3). Thus, one limitation of certain forms of action measure is that the actions are produced in a sort of pantomime fashion that may not tap into the normal processes that govern, say, successful locomotor action on hills (see also Milner, Ganel & Goodale, 2012).

Li et al. (2013) compared the action response of walking out a distance blindfolded (not walking toward an object) with walking to an object that was visually previewed (i.e., visually-directed walking) and found much larger variability and much greater evidence of response compression with "pantomime" walking – the term developed by Philbeck, O'Leary & Lew (2004) to describe such a task – than with visually-directed walking. Even though visually-directed walking (walking without visual feedback to a previewed target) operates without visual guidance or feedback, it tends to show greater precision of response than merely walking out a previewed distance even though no external feedback was given in either case. However, vestibular and kinesthetic systems, which provide a form of calibrated

perceptual feedback may provide sufficient feedback during updating of position relative to a goal location such that the limits of visually-directed walking might be imposed more by visual imprecision during encoding of the target location.

Although visually-directed walking is thought to be unbiased in general (Loomis, Da Silva, Fujita & Fukusima, 1992), when systematic biases are found in visually-directed walking they tend to show undershoot, which is consistent with an anchoring effect (e.g., Andre & Rogers, 2006). During the process of walking without feedback to a target one might be regarded as being constantly (or at least, partly) in a state of making a decision about whether to stop or not. If there is any randomness or uncertainty in the system, then the decision is likely to reach a positive conclusion earlier rather than later as a result of random estimate fluctuation unfolding over time. Effects of anchoring on visually-directed walking are difficult to diagnose because the nature of the task necessitates starting from zero, but other forms of path integration show evidence of response compression that depends on the range of values used in the experiment (Li et al., 2013; Petzschner & Glasauer, 2011).

Of course, other forms of action bias can emerge as an adaptive solution to experimentally-controlled patterns of risk and reward (e.g., Trommershäuser, Maloney & Landy, 2003). Our concern here has been with the use of single-trial action measures in which such things as range effects and reward structures seem harder to evaluate, though these and other cognitive influences may certainly still play a role.

Methodological recommendations

Historically, in the early studies for which palm boards were first developed, a tilt rod or pointer on a dial was used for participants to make their indications, but it was uniformly started in a vertical position (Clark, Smith & Rabe, 1955; Gibson, 1950; Perrone, 1980; Smith, 1959, 1956). Consistent with the anchoring effects observed here, participants all underestimated (relative to vertical) the slant of rectangular, circular, or trapezoidal shapes tilted away from 90 degrees. That is, they acted as though that shapes looked like they were oriented at a steeper angle than they actually were – participants manually matched a position that was not as far away from 90 degrees as it should have been. While underestimation relative to vertical is to be expected based on other measures, action measures, in those instances, may have *underestimated* accuracy by being anchored to vertical.

Based on the accumulated evidence showing response anchoring for manual measures of near surfaces and of hills, a procedure that avoids response anchoring (or seeks to measure it) seems most appropriate[2]. Moreover, evidence of egocentric reference frame bias in the haptic perception of palm boards (Coleman & Durgin, 2013; see also Kappers, 2004; Volcic, Kappers & Koenderink, 2007), strongly suggests that a mid-torso posture is preferable when using palm boards (Feresin & Agostini, 2007).

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[2] Note, for example, that a recently proposed manual measure that involves a sort of hanging swing for the hand (Taylor-Covill & Eves, 2013) anchors the palm board at horizontal automatically (by gravity). Insofar as adjustment of such a device always starts from horizontal, psychophysical measurements made with such a device appear likely to be biased by horizontal anchoring.

Conclusions

The present paper provides evidence against the two-systems theory of geographical slant perception by showing why manual action measures have appeared to dissociate from other measures of slant: A surprisingly large anchoring bias has been built into the standard procedure for manual slant estimation. There is now a clear, experimentally-demonstrated reason to simply avoid response anchoring when using a manual measure: As with other psychophysical techniques, adjustment from only one end of a scale is clearly biasing.

In addition the presence of consistent and reliable correlations between manual and verbal measures of slant lends converging support to the idea that a common underlying visual experience controls both types of measure. Palm board estimates may differ from verbal estimates primarily because of systematic methodological biases (including horizontal response anchoring and egocentric position biases) that have been inadvertently incorporated into standard palm board procedures.

Action measures can be highly susceptible to the basic judgmental biases that have been so commonly reported in studies of human judgment under uncertainty. Seeing this demonstrated so powerfully for a well-known action measure may help scientists to avoid automatically interpreting action measures as unbiased assays of perceptual representations in other domains. Conversely, anchoring is clearly a more general principle than previously realized. Principles of judgmental bias can be studied not only in cognitive/symbolic judgments, but even by using actions intended as motor/analog judgments.

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