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What do hands know about hills? Interpreting Taylor-Covill and Eves (2013) in context☆☆

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Abstract

Hills appear much steeper than they are. Although near surface slant is also exaggerated, near surfaces appear much shallower than equivalently slanted hills. Taylor-Covill and Eves (2013) propose a new type of palm orientation measuring device that provides outputs that accurately reflect the physical slants of stairs and hills from 19 to 30° and also seems to accurately reflect the slants of near surfaces (25–30°). They question the validity of the observations of Durgin, Hajnal, Li, Tonge & Stigliani (2010), who observed that palm boards grossly underestimated near surfaces. Here I review our recent work on the visual and haptic perception of near surface orientation in order to place Taylor-Covill and Eves' arguments in context. I note in particular that free hand measures of real surfaces in near space show excellent calibration, but free hand measures show gross exaggeration for hills. This leads to the question of the grounds for preferring a mechanical device to a freely wielded hand. In addition I report an investigative replication of the crucial observations that led to our concerns about the value of palm boards as measures of perception and note the specific methodological details that we have accounted for in our procedures. Finally, I propose some testable hypotheses regarding how better-than-expected haptic matches to hills may arise.

Keywords

Haptic perception; Slant; Space perception; Measurement; Orientation perception

1. Introduction

Whereas relatively accurate palm board estimates for hills (compared to verbal overestimation) had been interpreted as a readout of motor accuracy (e.g., Bhalla & Proffitt, 1999; Creem & Proffitt, 1998), Durgin, Hajnal, Li, Tonge and Stigliani (2010) reported that similar palm boards provided poor (low) estimates for real surfaces within reach. In contrast, they observed that a freely gestured, but unseen hand provided an excellent match for near

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surfaces in the range of 0–48° when referenced to the central axis of the hand (see also Durgin, Li & Hajnal, 2010, Li & Durgin, 2011, 2012b), but overestimated hills substantially (see also Bridgeman & Hoover, 2008; Durgin, Klein, Spiegel, Strawser & Williams, 2012; Li & Durgin, 2011; Shaffer, Mcmanama, Swank & Durgin, 2013, submitted for publication; Stigliani, Li & Durgin, in press). Taylor-Covill and Eves (2013) propose that a modified palm-orientation measuring device based on a pivot well above the hand provides a better way to measure perceived slant. They call this a palm-controlled inclinometer (PCI) and they use a clever cover story to motivate their participants. The value of the PCI appears to hinge, in part, on the assumption that a more accurate readout of actual hill slant is evidence of a better measure of perception. In this regard, the PCI, like other methods that have been proposed to provide accurate measures of perceived slant, risks being a recipe for obtaining a desired outcome rather than a well-understood scientific measuring device. It is not clear why this particular device should be more accurate for hills than a freely gestured hand, nor, unless its apparent accuracy is an artifact, is it clear why the PCI should be accurate for stairs and other steep slopes, but not for shallower paths, such as the ones that we travel most frequently.

Of central significance to our investigations of palm boards were data my collaborators and I collected in the absence of palm boards. In particular, we showed that changes in hand orientation produced primarily by wrist hyperextension (dorsiflexion) are misperceived (Durgin, Hajnal, et al., 2010, Experiment 4), but that freely wielding an unseen hand produced excellent matches to surfaces in reach (Durgin, Hajnal, et al., 2010, Experiment 3) that were similar to natural reaching actions and differed from settings made with a standard palm board in the range from 0 to 48° (Durgin, Hajnal, et al., 2010, Experiment 3). Based on the difference between proprioception of wrist dorsiflexion and of elbow flexion, we suggested an alternative to Bhalla and Proffitt's (1999) argument about calibration between verbal and manual estimates: When people report that a 5° hill appears to be 20°, but set the palmboard to 10°, perhaps they simply experience that the 10° setting of the palmboard feels like 20°. If so, then they might set the palmboard too low in near space for a surface of 5° that looks like it is about 5°. Although we did not test all parts of this theory in our paper about palm boards, a later paper about near-space surface orientation perception (Durgin, Li, et al., 2010) showed that verbal estimates of the slants of (real) near surfaces (presented at chest height in reachable space), though mostly exaggerated, were not nearly as exaggerated as those of hills. Representative verbal data from Durgin, Li, et al. (2010, Experiment 1) regarding slant perception of real surfaces in near space is shown in Fig. 1 in comparison with the verbal hill data of Proffitt et al. (1995). We have replicated this general result several times using several different methods and controls (Durgin & Li, 2011, 2012; Durgin, Li, et al., 2010). This observation fit well with our discovery that palmboard settings (using the posture of Proffitt et al.) for such near surfaces tended to grossly underestimate them: Verbal reports were lower for surfaces in reach than for hills; palm board settings were lower for these surfaces than for hills; and free-hand setting were also lower for these surfaces than for hills. All of these observations seemed compatible.

Bridgeman and Hoover (2008) had demonstrated that near portions of hills appeared shallower than farther portions. Li and Durgin (2010) followed this up with a study conducted in a carefully-calibrated virtual environment (see also Proffitt et al., 1995, Experiment 3, which used virtual hills) in which viewing distance and slant of surfaces were parametrically varied. Both implicit (perceived shape) and explicit (perceived slant) measures indicated that perceived slant increased with viewing distance. A model of the resulting data (shown as a dotted line in Fig. 1) provided an excellent fit to the observations of overestimation of Proffitt et al. Because their participants stood at the base of their hills and gazed forward, viewing distance was farther for shallower hills. Using this model to calculate perceived slant as a function of hill orientation and viewing distance (eye-height: 1.6 m), and using a polynomial fit to the estimation data from Durgin, Li, et al. (2010, Experiment 1) to deduce the physical near-surface slant that would produce the same perceived orientation for each given hill, we can then apply the 0.61 gain for palm boards estimated by Durgin, Hajnal, et al. (2010) for surfaces in reach to predict palm board settings for hills. We have plotted the result of this simple prediction in Fig. 2, along with Proffitt et al.'s original palm board data as well as Taylor-Covill and Eves' (2013) palm board data to show that our predicted palm board settings for hills agree with their observations. In other words, the low settings we saw in the lab are consistent with the kind of palm board performance Proffitt et al. and Taylor-Covill and Eves observe for hills.

Our studies of the haptic perception of surface slant established that the small, but systematic bias observed in reports of near surfaces was present to the same degree in the haptic perception of those surfaces whether explored by the palm of the hand (Durgin, Li, et al., 2010) or by finger tip (Durgin & Li, 2012). Hajnal, Abdul-Malak and Durgin (2011) additionally showed that pedally-perceived slants (ramps underfoot) were perceived to be much steeper than they were – even by the congenitally blind. The perceptual distortion of slant underfoot was significantly larger than that for surfaces felt by hand. Free hand gestures to unseen ramps underfoot were also quite exaggerated (Hajnal et al.). Insofar as manual haptic perception and visual perception appear to suffer similar biases for chest-high surfaces in reach (as measured both by verbal report and the apparent bisection of vertical and horizontal at about 34°), a good haptic matching task should produce accurate matches in near space unless the posture used introduced biomechanical constraints.

Using haptic settings in response to verbal prompts (Bhalla & Proffitt, 1999, Table 4) Durgin, Li, et al. (2010, Fig. 11) compared haptic perception of palm board orientation from their production studies with haptic perception of rigid surfaces by the palm of the hand. Haptic settings of palm boards departed from normal haptic perception when the palm board settings requested became higher. This was likely due to biomechanical constraints necessitated by the posture recommended by Proffitt et al. (1995). When Proffitt and Zadra (2011) later argued that Bhalla and Proffitt's data showed a correspondence between verbal and haptic measures, they failed to note significant discrepancies between haptic settings and their corresponding matches (Durgin, Hajnal, Li, Tonge & Stigliani, 2011).

Taylor-Covill and Eves (2013) have replicated the basic observations of Proffitt et al. (1995) regarding palmboard matches to hills in order to propose a new device (the PCI) that does an even better job of matching steep hills. They propose this device as a measure of perception. It clearly has some ergonomic advantages over the traditional palm board, but the reasoning surrounding its use as a measure of perception (rather than a measure of hills) appears somewhat circular. On the one hand, Taylor-Covill and Eves show data that suggests that the

PCI produces matches to hills in the range of 19–30° that are similar, on average, to what an inclinometer would produce. On the other hand, Taylor-Covill and Eves approve the argument that this device therefore gives a better read-out of perception, and this is the point that remains unfounded. If slant perception were known to be accurate, then a measure that gives an accurate read-out of slant would be a better measure. But we don't have an independent reason to believe that perception is accurate. Developing a device that produces accurate outputs might indicate that the device is a biased measure. If perceptual accuracy were tantamount for action, the accuracy of such a device would seem self-evidently important, but what actions must the hand conduct with distant hills (Bridgeman & Hoover, 2008)? The existing evidence that a free-hand gesture provides a very different output than the PCI for hills indicates a point of genuine concern for scientists trying to interpret the PCI.

2. Points of dispute

Taylor-Covill and Eves (2013) take Durgin, Hajnal, et al. (2010) to task for using a noisy palmboard in their first two demonstration experiments, and here I must concede our data were noisier than we realized. The palm board my collaborators and I used for those two experiments was one we noted was frictional. It is possible that the greater between subject variability in the settings with that palmboard were due to that reason – or it may have been because, as we reported, both demonstration experiments were conducted as class laboratory exercises (Durgin, Hajnal, et al., 2010). In any event, our primary argument concerning variability was that palm boards seemed to have higher variability as measures than did verbal reports and free hand measures. A better way to make this argument would have been to appeal to Proffitt et al.'s (1995) own data, which were published in tabular form by Bhalla and Proffitt (1999) including means and standard errors. By converting the standard errors to standard deviations using the N's reported by Proffitt et al., and dividing the standard deviations by the reported means, one can arrive at the coefficients of variation (CoV; a normalized measure of variability) for the two measures. I have plotted these CoVs in Fig. 3. They show that the verbal reports collected by Proffitt et al. were proportionally less variable (i.e., more precise) than the palm board settings they collected using their palm board. This justifies our general concern about the relative sensitivities of the two types of measure leading to the questionable interpretation of null effects from palm boards as evidence of dissociation. There is not space to review the arguments about the importance of perceptual sensitivity further here except to remind the reader that Durgin, Hajnal, et al. (2010; Durgin & Li, 2011; Hajnal, Abdul-Malak and Durgin, 2011) have suggested that the control of action is best served by precise perceptual information (e.g., Powers, 1973). If verbal reports more precisely discriminate among different hill slants than do palm board measures, that seems quite relevant to this discussion.

3. The importance of near space

Whereas Taylor-Covill and Eves (2013) criticized our rough demonstration experiments, they did not seek to evaluate the more formal tests we have done in which palm board estimates for surfaces from 0 to 48° were observed to be consistently lower than the actual slant of the surface under the same viewing conditions for which genuine reaching actions were accurate and free hand gestures of slant were accurate (Durgin, Hajnal, et al., 2010, Experiment 3). Instead, Taylor-Covill and Eves note Proffitt and Zadra's (2011) argument that our palmboard data for near surfaces differed from theirs with hills. As indicated by Figs. 1 and 2, differences between palm board measures for near surfaces and for hills are to be expected. Near surfaces look shallower. The palm board used in Experiment 3 of our paper (PB2) pictured in Fig. 4 at right, was built by skilled carpenters who helped to ensure free movement of the palm board. Moreover, as we described in Durgin, Hajnal, et al. (2010), the axis of rotation was placed at the center of the board so as to remove any need for the palmboard to be frictional to maintain its set position. It was this second palm board that we used to measure palm settings in Experiment 3 of Durgin, Hajnal, et al. (2010) and in palm board data of Li and Durgin (2011).

4. A replication experiment

On the one hand, our basic haptic surface orientation perception data (i.e., from the haptic exploration of fixed surfaces, Durgin, Li, et al., 2010; Durgin & Li, 2012) agrees with visual perception of near surfaces; this suggests that haptic matches to near surfaces could be accurate. On the other hand, the standard method of collecting palmboard haptic estimates (as developed by Proffitt et al., 1995) appears, *a priori*, to be biasing: In what other psychophysical domain would one have people always make adjustments from one end of a scale (i.e. from horizontal), and treat the results as unbiased (Shaffer, Mcmanama, Swank and Durgin, submitted)?Near surfaces certainly appear shallower than hills of the same slant, so it would seem that if exactly the same method of matching is employed for both, it is surprising indeed to get similar matches. Nonetheless, it is quite reasonable to believe that one measure of perception might tend to tap into certain kinds of visual information more than another. Li and Durgin (2010) proposed that it was available binocular information that might be causing increasing slant perception at greater viewing distances (see also Allison, Gillam & Vecellio, 2009). Perhaps palm boards are insensitive to binocular stereoscopic visual information for example, in contrast to free-hand measures, implicit slant tasks (aspect ratio tasks – Li & Durgin, 2010), and verbal reports.

Taylor-Covill and Eves' (2013) observation that there was no reliable difference between palm board settings for outdoor hills and those for near surfaces is surprising. Had Durgin, Li, et al. (2010) done something odd with the low-friction palm board, as Proffitt and Zadra (2011) had implied, and Taylor-Covill and Eves also suggest? Had we mounted it too low, for example, thus exacerbating the wrist flexion problem? Was there some other detail of our design that had biased our results, such as the hemispheric dome we had used as a backdrop to eliminate environmental orientation information? Taylor-Covill and Eves propose that our means of blocking vision of the palm board might have interfered with our measures.

A partial replication seemed appropriate to further this discussion. For the replication, the same surface presentation device was used as in our prior studies, which is pictured in Fig. 5 (this meant that the surface could be presented at chest level, close to eye level, rather than on a table top; Proffitt et al., 1995, had participants look at hills at eye level). The palm board was modified only by placing a cover on it, also shown in Fig. 5, to address the Taylor-Covill and Eves' (2013) design concern that our optical barriers might have interfered with peoples' manual setting. (We believed we had addressed this issue by measuring actual reaches under the same conditions; but it was best to be sure). Both viewing distance and the height of the palmboard relative to the participants' waist were varied between participants. The study was run professionally, but was added on to other, unrelated, experiments being conducted in the lab because each participant only did a single trial. The method was approved by the local research ethics committee.

5. Methods

Feresin and Agostini (2007) have shown that palm board settings can be improved by training, and Feresin, Agostini and Negrin-Salviolo (1998) have shown that, without training, palm board settings (to verbal prompts) tend to be anchored to cardinal positions (e.g., horizontal). Because my goal was to mimic the situation of Proffitt et al. (1995), who stopped passersby and obtained palm board judgments without training and using a horizontal anchor, we did not train our participants in any special way. We simply asked them to indicate either where their navel was or where their waist was (this was the experimental manipulation of palm board height) and we set the height of the palm board to that height and had them position themselves comfortably in relation to the device.

About half of the 58 undergraduate–student participants (28; 12 male) were thus made to stand at a distance of about 0.7 m from the center of the visual surface; the rest (30; 14 male) were made to stand 4.5 m away. We asked them simply to set the palm board parallel with the observed surface. We used only a single visual surface with an orientation of 32.0°. That surface is also shown in Fig. 5. It is a gravel-coated surface such as the ones used by Durgin and Li (2011); Durgin, Hajnal, et al. (2010) and Durgin, Li, et al. (2010) used plain wooden surfaces for their studies of manual and verbal measures of slant perception in near space.

To emphasize generality, the following nine (9) differences between the present experiment and that reported by Durgin, Hajnal, et al. (2010, Experiment 3) are noted: First, the present experiment did not include the large hemispheric background (see Durgin, Li et al., 2010, Fig. 1, for a photograph). Second, palm board height was systematically varied so as to ensure that the height was set to each individual's waist or navel. Third, only a single surface orientation (32°) was used rather than testing the range from 0 to 48°. Fourth, a gravel surface was used rather than a set of plain wooden surfaces. Fifth, an attached digital inclinometer rather than motion-capture equipment was used to register the orientation of the palm board surface. Sixth, the hand of the participant was concealed by a “roof” on the palmboard apparatus (see Fig. 5) rather than by restricting goggles to block the view of the hand, as Durgin et al. did (2010a, Experiment 3; in some other experiments we had used a vertical barrier.) Seventh, whether or not the surface was in reach was manipulated between participants. (In Experiment 3 of Durgin, Hajnal et al., 2010, all surfaces were in easy reach of the hand.) Eighth, a larger number of subjects (58 rather than 12) were tested. Ninth, only palm board estimates were collected; the same participants did not use free-hand gestures or any other measure as part of the experiment.

It is also worth highlighting the following five similarities between the present experiment and that reported by Durgin, Hajnal et al. (2010, Experiment 3). (1) The same low-friction, professionally built, palm board was used. (2) The palm board (like that of Proffitt et al. 1995)was always set at 0° initially. A physical stop was used. (3) Participants were not trained in how to set the palm board, but simply showed how it worked and asked to set it parallel to the surface they viewed. (4) Some (about half) of the participants stood within reach of the surface. (5) The viewed surface was a solid surface at chest level.

When I tried to set the palm board myself, as one who is very practiced with palm boards and with the haptics of surface orientation, I set it quite accurately for this surface on my first attempt (which is consistent with the idea that haptic perception and visual perception are well calibrated in near space – Durgin & Li, 2012). Our goal, however, was to assess the settings of naïve participants treated like those in Proffitt et al.'s (1995) outdoor hill studies who might have tended to suffer from all the palm board biases identified by Feresin et al. (1998) and by Shaffer, Mcmanama, Swank and Durgin (submitted for publication).

6. Results

The mean settings for the 32° surface are shown in the left panel of Fig. 6. They closely replicate the settings observed by Durgin, Hajnal, et al. (2010) in that the settings are about half the actual slant of the surface. In the navel-height posture, the mean is 17.8°, which is 55% of 32°. Durgin, Hajnal, et al. (2010) reported that palmboard settings for reachable slants from 0 to 48° (measured within-subjects) were well fit with a regression line with a slope of 0.61 and intercept of 0°. The overall setting obtained (16.7°) was reliably less than the predicted value of 19.5° (i.e., 0.61 * 32.0°), $t(57) = 3.40$, $p = .0013$, but the settings in the higher (navel) palm board position (17.8°) did not differ reliably from the predicted value, $t(28) = 1.42$, $p = .167$. Thus, although there was a trend for settings to be slightly lower when the palm board was at waist level rather than at navel level, the use of the navel level for each participant produced essentially the same amount of underestimation for near surfaces as in Experiment 3 of Durgin, Hajnal, et al. (2010) who used a very different experimental design, as discussed above. An ANOVA with Sex, Viewing Distance, and Palm Board Height as factors revealed no reliable differences in settings due to these factors or to interactions among the factors. The overall CoV was 0.38,which replicates the 0.38 CoV computed from the data of Proffitt et al. (1995), for palm board matches (to a 10° hill) that had a similar mean setting (16°).

As a follow-up experiment, we tested an additional group of 18 participants without the stop at zero degrees, to see whether the physical stop contributed to producing an anchoring effect. These participants were spread approximately evenly across the same four conditions. In fact, the physical stop seemed to have increased the earlier settings. As shown in the right panel of Fig. 6, the mean palm board settings when no stop was used (M ± SD: 12.5° ± 5.7°), were reliably lower than the setting by the 58 participants for whom a physical stop had been present at zero (16.7° ± 6.4°), $t(72) = 2.38$, $p = .0200$.

7. Discussion

By replicating the basic observations of Experiment 3 of our original report (Durgin, Hajnal, et al., 2010) the present results suggest that our findings were not an artifact of some inadvertently biasing design choice made in our original study. Whereas the palm board we had employed in our Experiments 1 and 2 (PB1) is open to criticism as being too frictional, the palm board we used in Experiment 3 (PB2), which was used in an extended replication of Experiment 3 previously (Li & Durgin, 2011), is certainly not open to that criticism. Using this palmboard again, underestimation was observed that was similar to that we had previously observed for surfaces viewed at chest level. Note that my lab has previously used this same palm board outdoors (though at chest level to allow much greater freedom of movement) and found that it gave reliable *overestimates* of 20° outdoor hills (Durgin, Ruff & Russell, 2012, Experiment 1; such overestimation is consistent with the elevated posture – He, Hong & Ooi, 2007 – and with the idea that hills look steeper than near surfaces), so the present underestimation (of near surfaces) is not intrinsic to the mechanics of the palm board itself. The absence of any effect of viewing distance in the lab environment, though a null effect, is consistent with evidence of enhanced constancy of binocular spatial perception in naturalistic indoor environments (e.g., Durgin, Proffitt, Olson & Reinke, 1995; Li, Sun, Strawser, Spiegel, Klein & Durgin, 2013), and with our prior observations regarding perceived surface slant indoors (Durgin & Li, 2011).

Given that free-hand measures have been shown repeatedly to be quite accurate for near surfaces in reach (Durgin, Hajnal, et al., 2010, Durgin, Li, et al., 2010; Li & Durgin, 2011, 2012), but that free-hand measures have been shown repeatedly to overestimate hills (Bridgeman & Hoover, 2008; Durgin, Hajnal, et al., 2010; Durgin, Klein, et al., 2012, Durgin, Ruff, et al., 2012; Shaffer et al., 2013), our observations that palm boards underestimate the slants of near surfaces fits well with a large body of data indicating that near surfaces appear shallower than far surfaces – and with the interpretation of palm boards as non-ergonomic haptic matching tasks. If I am trying to match my haptic perception to my visual perception of a hill, then it would be surprising indeed if the matches were accurate both for hills and for near surfaces when the two appear visually quite different as measured by other means (see Fig. 1). This is not to say that the results reported by Taylor-Covill and Eves (2013) aren't intriguing, but it is to suggest that a question that needs to be addressed is why haptic matching with a PCI or any other particular palm board should be unique among all other measures in not differentiating between hills and near surfaces. Adjusting a palm board or PCI is clearly a pantomime action (with respect to a hill or other surface) rather than a visually-guided action. For near surfaces, there is a great deal of data, showing that free hand measures tend to both precise and accurate. The idea that palm boards ought to be accurate because they tap into an unconscious and informationally-isolated motor stream of visual information has proven quite appealing to a broad range of scientists (but see Haun, Allen & Wedell, 2005). But it is probably more reasonable to think of palm boards as a means of matching a haptic perception of slant to a visual perception of slant.

The following factors have been shown to affect palmboard outputs: (1) height of the palmboard (He et al., 2007; Durgin, Hajnal, et al., 2010, Experiment 5), (2) instructions and training with palm boards (Feresin & Agostini, 2007; Feresin et al., 1998), (3) viewing distance outdoors (Feresin & Agostini, 2007), (4) starting position (anchoring: Feresin et al., 1998; Shaffer, Mcmanama, Swank & Durgin, submitted for publication), and (5) the presence of a physical stop at 0° (present experiment). Almost no method section is sufficiently explicit about even these various aspects of the experimental design to be able to reliably evaluate these factors across studies and labs.

8. Future directions

What might be going on that could allow some types of palm board to behave in the interesting fashion that Taylor-Covill and Eves (2013) report for their PCI?

1. **Limb-based egocentric reference frames**. There is a great deal of evidence that the haptic perception of orientation is contaminated by egocentric reference frames tied to the limbs (Kappers, 1999, 2002, 2003, 2004; Kappers, Postma & Viergever, 2008). These are just the kinds of biases (observed in perceived yaw rotation; see also Philbeck, Sargent, Arthur & Dopkins, 2008) that should make palm board settings feel particularly steep near waist level. Indeed, Kappers (2002) found evidence of just such haptic orientation biases in the mid-sagittal plane for oriented rods: Haptically-explored orientation in this plane felt steeper (was set shallower) in lower portions of the plane than in higher portions. We have recently extended this observation to palm boards matched to both haptic and to visual reference surfaces (Coleman & Durgin, submitted for publication). This helps explain the positive effect on palm board settings of having a physical stop (initial reference) at 0° to partly counteract the arm reference. Such biases show that people might overestimate palm board orientation when making matches, and thus set the palm device low.

2. **Line-of-attention**. We know that the near parts of hills appear shallower to people than the farther portions (Bridgeman & Hoover, 2008). Because the palm board is typically placed in a relatively low part of the workspace, the portion of the hill to which the palm board may reasonably seem to refer might be a closer section than the portion (gaze forward) that the experimenter designates in the method used by Proffitt et al. (1995). When people match a steep surface with an unseen free hand they typically hold it up at chest level, nearly in line with their direction of regard. Attending to the near (lower) portion of a shallow hill might counteract the haptic reference-frame problem in point 1, making matches more accurate.

3. **Biomechanical properties**. The PCI is a new biomechanical interface. Li and Durgin (2012b) used motion capture to measure the natural use of elbow and wrist flexion for free hand measures and found that most participants achieved their excellent free hand settings for near surfaces by using about 80% elbow flexion and only 20% wrist dorsiflexion. The use of hand-swing does not resemble this kind of hand gesturing. Raising a swing-like device with the pivot forward of the shoulder, like the PCI, requires extending the elbow rather than flexing it. In this, using the PCI is a bit like reaching out as if to touch something – without the intention to touch it.

4. **Correlation**. Because Taylor-Covill and Eves (2013) tested their two devices in tandem, it would be of interest to know the correlation between their outputs. This information was never reported, for example, by Proffitt et al. (1995) between verbal and palm board estimates. We find fairly consistent evidence of correlation

(despite large gain differences) between manual estimates and verbal reports of hill orientation given by the participants for the same hill (e.g., Durgin, Klein et al., 2012, and Shaffer et al., submitted for publication; Stigliani, Li & Durgin, in press). Such correlations support the idea that two measures are measuring the same thing, but with different output gains. (The absence of correlation, like other null effects, is harder to interpret.)

9. Conclusions

In 2010, Durgin, Hajnal, et al. (2010) proposed that study of the perception of near surfaces would better motivate the use of motor actions, such as hand gestures, that were relevant for near surfaces, but seemed less relevant for hills. In a series of empirical papers our lab has since laid out evidence that cumulatively suggests that even near-space surface orientation perception is biased (though far less than hills), but that this bias is masked in tasks like reaching and free-hand gestures because such gestures are calibrated actions (Li & Durgin, 2012b). Verbal estimation data indicate that proprioception, normal haptic experience, and visual experience are all in close accord for near surfaces (Durgin, Li et al., 2010; Durgin & Li, 2012, Li & Durgin, 2012b).

For locomotor surfaces and locomotor space, a different set of considerations apply, but we again find correspondence between the exaggerated pedal (by foot) haptic perception of surface orientation (Hajnal et al., 2011; also Durgin et al., 2009) and the visual experience of distant surface orientation (see also Kinsella-Shaw, Shaw & Turvey, 1992). We have observed that a number of angular variables are systematically distorted in vision and that this systematic distortion may account for several well-known biases in distance perception (Durgin & Li, 2011; Foley, Ribeiro-Filho & Da Silva, 2004; Li & Durgin, 2009, 2012a; Li et al., 2013; Loomis, Da Silva, Fujita & Fukusima, 1992), height perception (Higashiyama & Ueyama, 1988; Li, Phillips & Durgin, 2011), and hill perception (Durgin et al., 2009, Durgin, Hajnal, et al., 2010, Durgin, Klein, et al., 2012; Hajnal et al., 2011; Li & Durgin, 2009, 2010; Shaffer et al., 2013). Angular distortions may aid action by retaining greater representational precision (Durgin & Li, 2011).

Based on data from verbal report and from horizontal/vertical bisection tasks, haptic perception in near space and visual perception in near space appear well aligned (Durgin & Li, 2012; Durgin, Li, et al., 2010). We continue to find, however, that when the palm board procedure used by Proffitt et al. (1995) to measure hills is applied to near surfaces at chest level, naïve participants show evidence of a haptic perceptual bias that is consistent with the "accidental" account we have offered of the palm board matching data of Proffitt et al. (1995) for hills. By accidental, we didn't mean random. We meant that specific palm board procedures may end up being detailed recipes for producing a particular outcome. It is possible that many details of these recipes affect the results in ways that are theoretically uninteresting, but give the appearance of theoretical interest whether in the form of "accuracy" or of dissociation from verbal measures. The interpretation of haptic devices (including the PCI) as direct measures of visual perception may be counterproductive to the goals of a cumulative natural science regarding the perception of surface layout.

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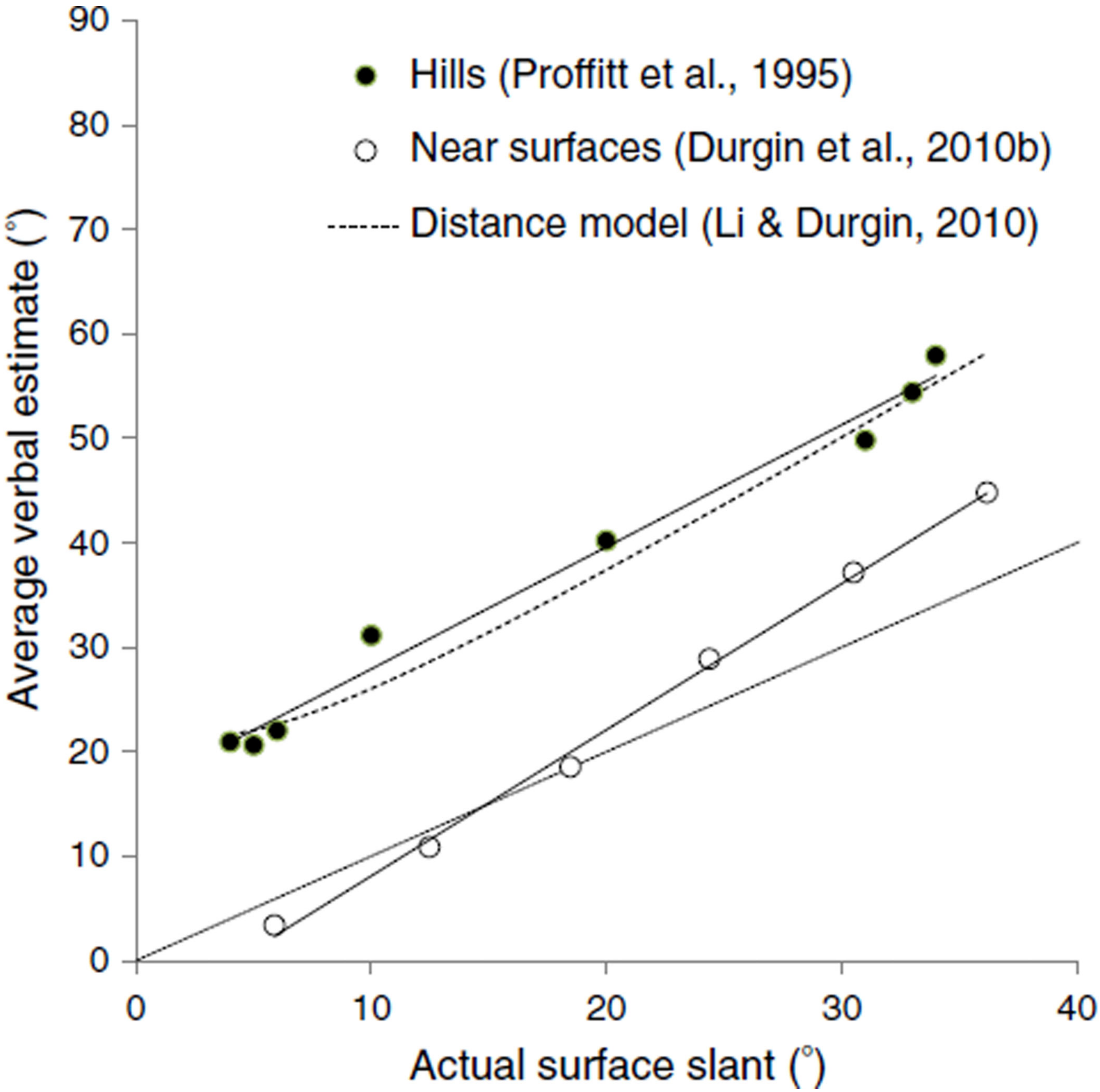

Fig. 1.

Verbal estimates for hill slants (4–34°) grossly overestimate their slant (Proffitt et al., 1995), but verbal estimates indicate that the perceptual exaggeration for the slants of near wooden surfaces (6–36°; Durgin, Hajnal, et al., 2010, Experiment 1) is much less pronounced. Predictions of the model of hill perception developed by Li and Durgin (2010; Durgin & Li, 2012) in a study parametrically manipulating of slant and viewing distance are also shown.

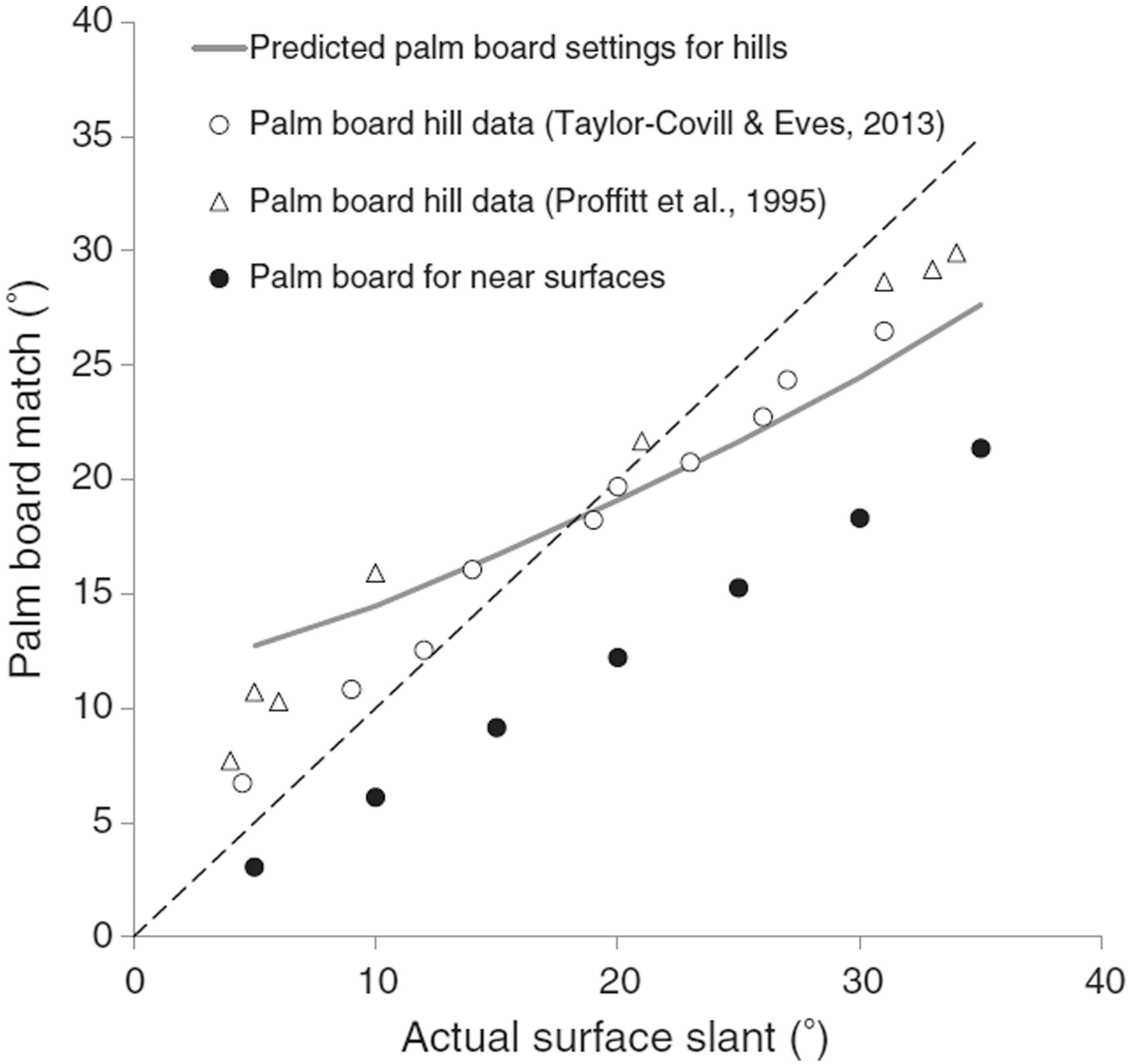

Fig. 2.

Predicted palm board settings for hills (solid line) vs near surfaces (black circles) based on combining (1) a model of the perceived (reported) slants of hill surfaces that takes viewing distance into account (Durgin & Li, 2012; Li & Durgin, 2010), (2) verbal report data for near surfaces (Durgin, Li, et al., 2010), and (3) palm board matches to near surfaces (Durgin, Hajnal, et al., 2010). The perceived hill slant model (Durgin & Li, 2012) is $h' = 1.5*h + 5*\ln(D)$, where h' is perceived slant (°), h is actual hill slant (°) and D is horizontal viewing distance (m) to the hill surface from the base of the hill, assuming an eye-height of 1.6 m. The polynomial model of the verbal report data (Durgin, Li, et al., 2010, Experiment 1) for near surfaces is $s = 0.000142 * s'^3 - 0.015 * s'^2 + 1.185 * s' + 0.525$, where s' is perceived slant (°) and *s* is the presented surface orientation (°). We deduce the *s* equivalent to a given *h* (the slant of a near surface that is perceptually equivalent to a given hill based on verbal report; Li & Durgin, 2011) by setting s' equal to h' for the given *h*. The palm board setting prediction for hill *h* is then 0.61 * *s* (Durgin, Hajnal, et al., 2010, Experiment 3).

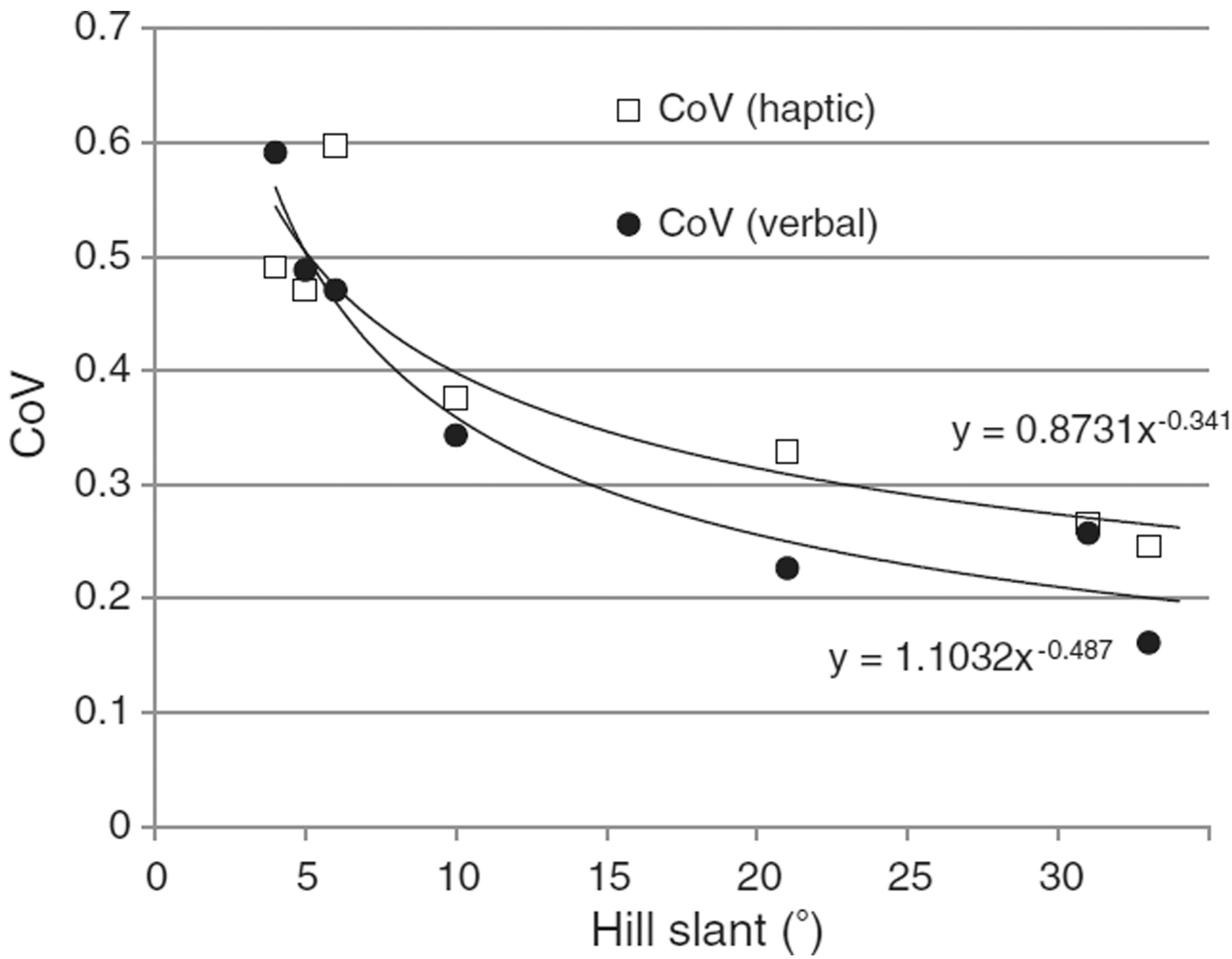

Fig. 3.

Coefficients of variation (CoV) for haptic (palm board) and verbal estimates of hill slope computed from the data of Proffitt et al. (1995) as reported in Bhalla and Proffitt (1999). In the range of hills from 5 to 34°, verbal estimates were proportionally less variable between participants than were haptic matches with a palm board, $t(6) = 2.83$, $p < .05$.

Fig. 4.
Two palm boards used by Durgin, Hajnal, et al. (2010). At left is shown the *simple palmboard* (PB1) used in the demonstration Experiments 1 and 2 of Durgin, Hajnal, et al. (2010; it was also used by Durgin, Ruff, et al. (2012), Experiment 2). The head of the tripod served as the axis of rotation; the tripod head must be somewhat frictional to hold its position when set. At right is shown the *low-friction palm board* (PB2) used in Experiment 3 of Durgin, Hajnal, et al. (2010; it was also used by Durgin, Ruff, et al. (2012), Experiment 1, and by Li & Durgin, 2011). The axis is through the center of the palm board and the surface can be rotated effortlessly. Hand orientation can be read to 0.5° from the protractor, or to 0.1° by attaching a lightweight inclinometer or lightweight motion-capture equipment (Vicon) as used by Durgin, Hajnal, et al. (2010).

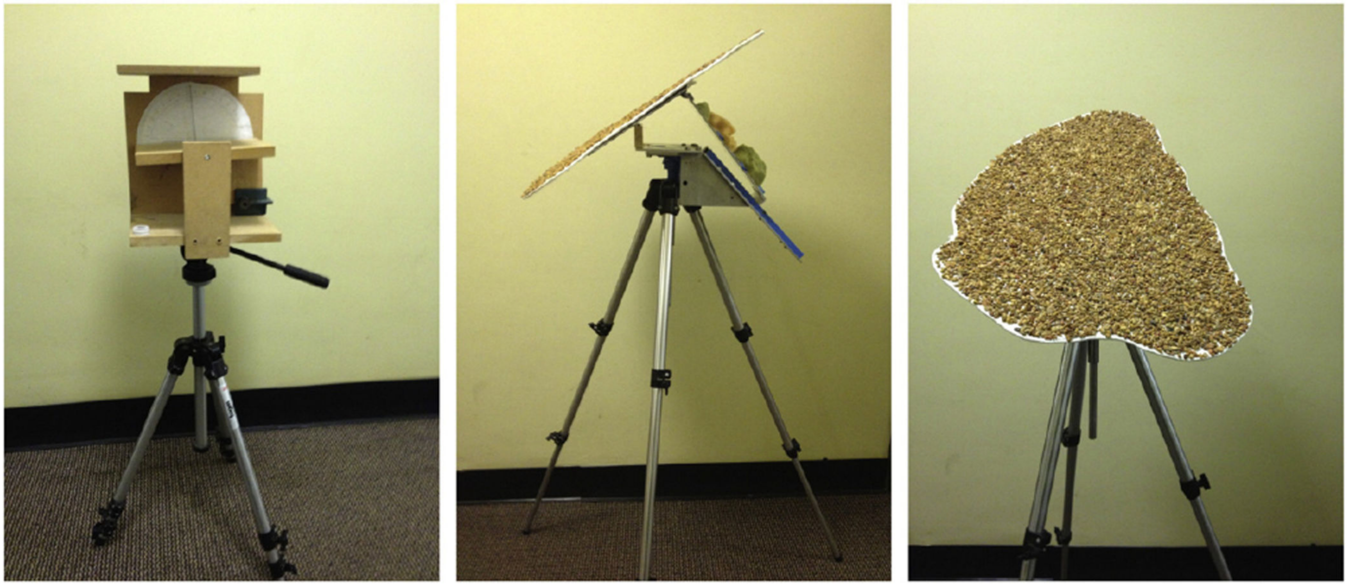

Fig. 5.

Apparatuses used in the present experiment. Left: A low-friction palm board with an added "roof" to block the view of the hand; a removable wooden stop marking 0° is clamped into place. Center: The *adjustable slant presentation device* (with a sample surface mounted on it). The same device was used in Experiment 3 of Durgin, Hajnal, et al. (2010); (see also Durgin & Li, 2011, 2012; Durgin, Ruff, et al., 2012; Li & Durgin, 2009, 2012b). It can be used to vary slant in small steps between horizontal and vertical. Right: The visual surface used here was gravel-covered. The surface is from the set used by Durgin & Li (2011) in studies of perceived near-surface orientation. Durgin, Hajnal, et al. (2010) used wooden surfaces of irregular shape. During the present experiment, the tripod holding the surface was covered by black felt.

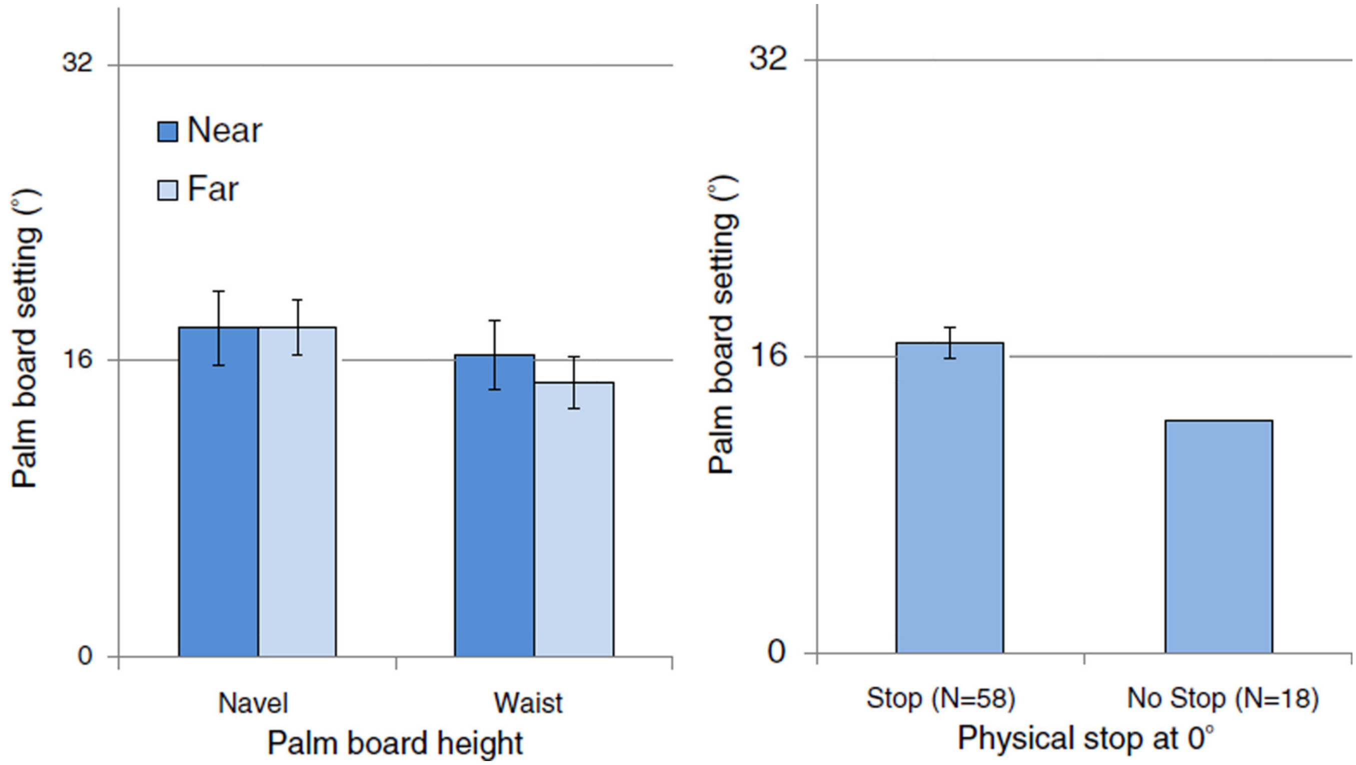

Fig. 6.

Experimental results. Left: The main experiment replicated the underestimation of near surface slant using a wrist-flexion palm board. Actual surface slant was 32.0°. Right: A follow-up experiment showed that estimates were even lower if the physical stop at 0° was not present in the palm board. Standard errors of the means are shown.