

# Palm board and verbal estimates of slant reflect the same perceptual representation

Dennis M. Shaffer<sup>1</sup> · Ally Taylor<sup>1</sup> · Eric McManama<sup>1</sup> · Allyson Thomas<sup>1</sup> · Echoe Smith<sup>1</sup> · Phil Graves<sup>1</sup>

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**Abstract** People verbally overestimate the orientation of slanted surfaces, but accurately estimate or underestimate slanted surfaces using a palm board. We demonstrate a fundamental issue that explains why the two different values typically given for palm board and verbal/visual matching estimates express similar perceptual representations of slanted surfaces. The fundamental problem in studies measuring palm board and verbal estimates is that the “measure”—either (1) reproducing a verbally given angle or the orientation of a slanted surface with an unseen hand or (2) verbally or visually estimating a visually perceived surface—has always been confounded with the “surface”—either using (1) a palm board or (2) a hill or ramp. Although reproduction has exclusively been used with palm boards in these studies, at the same time verbal estimation or visual matching has exclusively been used with hills/ramps. In three experiments, we showed that verbally estimating palm board orientations produces overestimates by a factor of 1.5, whereas reproducing the orientation of the surface of a ramp to verbally given angles produces gains of ~0.6. These values are similar to those seen for verbal overestimates of slanted surfaces, and to palm board gains for near surfaces and the relative palm-board-to-verbal gains for outdoor hills, respectively. Eliminating this confound eliminated the difference previously seen across surfaces. We discuss how and why different measures should produce different results if we overestimate slant in general and perceptually represent slant in the same way, both haptically and visually.

**Keywords** Slant perception · Spatial orientation · Pitch

For the last two decades, people have verbally overestimated the slant of visually perceived geographical, virtual, and man-made hills by between 5° and 25° (Bhalla & Proffitt, 1999; Creem-Regehr, Gooch, Sahm, & Thompson, 2004; Durgin, Hajnal, Li, Tonge, & Stigliani, 2010; Durgin & Li, 2011; Hajnal, Abdul-Malak, & Durgin, 2011; Li & Durgin, 2010; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Shaffer & Flint, 2011; Shaffer, McManama, Swank, Williams, & Durgin, 2014; Stigliani, Li, & Durgin, 2013). Two additional measures have also been used in several of these studies. The first of these two is visual matching (Bhalla & Proffitt, 1999; Creem-Regehr et al., 2004; Proffitt et al., 1995; Witt & Proffitt, 2007). In the visual matching task, participants manually adjust a pie-shaped segment of a disk, which consists of an adjustable section representing the cross-section of the inclination of the hill, to be equivalent to the slant of the hill. People overestimate the slant of hills using visual matching, and they do so by close to the same extent that they do when making verbal estimates of the hill (Proffitt et al., 1995). The second of these measures is haptic matching. In these studies, haptic matching estimates are often made using a palm board—people rest their hand on the palm board and rotate it up from horizontal to match the palm board to their visual perception of the slope of the hill (e.g., Bhalla & Proffitt, 1999; Proffitt et al., 1995; Taylor-Covill & Eves, 2013). Some of these studies have also used a free-hand measure for their haptic matching task (Bridgeman & Hoover, 2008; Durgin, Hajnal, et al., 2010; Durgin, Li, et al., 2010; Li & Durgin, 2011; Shaffer et al., 2014). This consists of holding one’s unseen hand and/or forearm parallel to the slope. Whereas verbal, visual matching, and free-hand estimates of visually perceived hills suggest that hills appear much steeper than their physical

✉ Dennis M. Shaffer  
shaffer.247@osu.edu

<sup>1</sup> Department of Psychology, Ohio State University–Mansfield, 1760 University Drive, Mansfield, OH, USA

inclination, palm board estimates have proven to be more accurate in matching the true inclinations of hills. The reason given for the apparent difference between palm board and verbal and visual matching estimates has been a dissociation in the visual pathways in the brain that inform visual awareness and visually guided action (Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Proffitt et al., 1995; Witt & Proffitt, 2007). The idea is that palm board estimates provide a more accurate representation of the physical world and are a reflection of the dorsal action stream of the brain that allows us to traverse hills without a problem, whereas verbal and visual matching estimates are reflections of the ventral conscious perception stream of the brain, which is more susceptible to illusions and biases.

The ideas that palm boards are accurate, are action measures, are reliable, and do not overestimate the true inclination of slanted surfaces has recently been brought into question by work highlighting wrist flexion and anchoring issues with palm boards (Durgin, Hajnal et al., 2010; Durgin, Li et al., 2010; Shaffer, McManama, & Durgin, 2015; Shaffer et al., 2014). For instance, it has been shown that palm boards provide biased and insensitive measures that are a reflection of the lack of wrist flexion when using them, and not measures that tap into a distinct visual representation of slant (Durgin, Hajnal et al., 2010; Durgin, Li et al., 2010). Moreover, the standard procedure calls for setting the palm board at waist level as its initial starting position. We have shown that when palm boards are adjusted from horizontal they give much lower hill matches (by 15° to 30°) than when they are adjusted to start from vertical, for both near and far surfaces and for ramps and geographical hills alike (Shaffer, McManama et al., 2015; Shaffer, Taylor, Thomas, Graves, Smith, & McManama, 2015). This contradicts the idea that palm boards reflect a more accurate action system for interacting with the physical world that is independent of a conscious perception system. Notwithstanding this evidence, recently other measures—matching extent and remote haptic perception—have been supportive of a single underlying representation that is exaggerated to the same extent as are verbal and visual matching estimates (Li & Durgin, 2010; Shaffer & McManama, 2015). Li and Durgin (2010) had one group of people compare the relative length of a frontal extent to the length of an extent that was placed up a virtual hill (tilted back in depth). This provided, by trigonometry, an implicit estimate of perceived slant. The other group gave verbal estimates of the same hill. The implicit slant measure gave the same results as the verbal estimates—both showed the same exaggeration of all slants. Shaffer and McManama (2015) used a remote haptic device in which the participant held one end of a wooden dowel (~1–1.5 m in length) while exploring an ~1-m inclined surface. Whereas the palm board measure is a perceptual matching task to a distal stimulus more than it is a haptic perception task or an action task that allows one to explore the surface itself using proprioception and proprioceptive feedback, the

remote haptic task allows exploration of the surface itself using proprioceptive feedback and is also an action-based measure very good at affording appropriate action upon the same slanted surface on which it is used (Fitzpatrick, Carello, Schmidt, & Corey, 1994; Malek & Wagman, 2008; Regia-Corte & Wagman, 2008). The slope of the gains of estimates across six inclinations using the remote haptic task was exactly the same slope of 1.5 (ratio of estimate : actual inclination) that has been shown for verbal estimates of virtual and geographical hills, nonverbal matching estimates, and haptic estimates using a finger to explore slanted surfaces (Durgin & Li, 2012; Hajnal et al., 2011).

Thus, verbal estimates, visual matching estimates, remote haptic perception estimates reflecting proprioception and proprioceptive feedback, and an implicit trigonometric estimate reflecting a ratio of frontal : depth extents all point to a single, exaggerated representation of the perception of slant. The only measure that gives different results from these is the classic anchored palm board task of Proffitt et al. (1995) and Bhalla and Proffitt (1999).

We believe that even if one does not account for the anchoring biases and wrist flexion issues, which are substantial for palm boards, the classic “accurate” palm board estimates still reflect an exaggerated underlying representation of hill slant. One line of research that includes our own work may shed more light on how palm board and verbal estimation tasks can lead to different values based on the same underlying representation. Let’s first start with the premise that people overestimate slant in general, whether via visual matching (Bhalla & Proffitt, 1999; Proffitt et al., 1995), pedal perception (Hajnal et al. 2011), haptic perception (Durgin, Li, & Hajnal, 2010), remote haptic perception (Shaffer & McManama, 2015), downward gaze (Li & Durgin, 2009), body proprioception (Shaffer, Taylor et al., 2015), or verbally (Bhalla & Proffitt, 1999; Proffitt et al. 1995; Shaffer, McManama et al., 2015). In work on body proprioception, Jewell (1998) tilted people backward in chairs, hand trucks, and a gyroscope, and found that when participants were asked to indicate when they felt they were tilted back at 45° (a matching task similar to the classic palm board task—matching their body slant to a verbally given angle), they asked the experimenter to stop when they were tilted back ~30° (across eyes-open and eyes-closed conditions). That is, when they were tilted backward 30°, they felt like they were tilted backward 45°. When we tilted people back in an inversion table at 32° and asked them to estimate the angle at which they were tilted (a verbal estimation task), they indicated they were tilted backward at ~45°. Just because Jewell found lower values (a gain of 30°/45° ~0.67) in his matching task than we found in our verbal estimation task (overestimates by a factor of ~1.5, a gain of 45°/30°), does this mean that a separate system processes the different mean estimates in Jewell’s task? Of course not—it shows that when asking people to estimate slant in two different ways, people

give different estimates of slant, both of which reflect that people feel they are tilted farther backward than they actually are, and this leads to predictable exaggerations of slant in both cases, pointing to the same underlying representation (Naylor & McBeath, 2008; Shaffer, Taylor et al., 2015).

So, if all measures of slant reflect one underlying representation of slant overestimation, and if slant is represented approximately equivalently across vision and proprioception, we believe there are three tasks in which people should stop short of the desired angle, or should give shallower angle reproductions, thus showing an overestimation of slant. The first is the classic palm board task, in which one reproduces the viewed slant of an inclined surface with their unseen hand. Here, placing your hand at 30° feels like it is at 45°, so we would expect that if people overestimate slant proprioceptively as they do visually, they should reproduce a shallower estimate of the desired angle, just as people do with body tilt (Jewell, 1998; Naylor & McBeath, 2008). In fact, this is exactly the case, since the relative gain of palm board orientation to visual measures of outdoor hills ranging from 2° to 34° is 0.58 (Durgin, Hajnal, et al., 2010, using data from Proffitt et al., 1995). The second is when one is asked to reproduce a verbally given angle with an unseen hand, similar to what Proffitt et al. (1995) did as an internal consistency measure. Here again, placing your hand at 30° feels like it is at 45°, so we would again expect that if people overestimate slant proprioceptively as they do visually, they should reproduce a shallower estimate of the desired angle. This is precisely what happens, because the relative gain of palm board orientation to verbally given angles is 0.5685 (using the means from Table 4 of Bhalla & Proffitt, 1999). The third task is one that is the visual equivalent to the second task and is similar in methodology to what people are asked to do in the classic palm board task: reproducing a verbally given angle by adjusting a surface that can be adjusted/inclined to any angle. Here, we would expect that when people are verbally given an angle of 45° to reproduce using an adjustable surface, they should stop at 30°, because a surface that is inclined at 30° looks as if it is inclined at 45°. Additionally, if all measures of slant reflect one underlying representation of slant overestimation, and if this is the reason people stop short of the desired angle in the classic palm board task, then if we ask people to estimate at what angle their unseen hand is oriented when it is placed at different angles, we would expect people to overestimate

where their hand is oriented by a factor of ~1.5, similar to what is found when people estimate inclined surfaces via verbal estimation (Bhalla & Proffitt, 1999; Creem-Regehr et al., 2004; Durgin, Hajnal, et al., 2010, Durgin, Li, et al., 2010; Durgin & Li, 2011; Hajnal et al., 2011; Li & Durgin, 2010; Proffitt et al., 1995; Shaffer & Flint, 2011; Shaffer et al., 2014), visual matching (Bhalla & Proffitt, 1999; Proffitt et al., 1995), pedal perception (Hajnal et al. 2011), haptic perception (Durgin, Li, et al., 2010), remote haptic perception (2015), downward gaze (Li & Durgin, 2009), and body proprioception (Shaffer, Taylor et al., 2015). So, as we see it, we have described two types of estimation tasks above—verbal estimation and reproduction—and two types of surfaces—palm boards and hills/ramps. We created a matrix for the estimation tasks and surfaces, which is shown in Table 1. If there is one underlying, exaggerated representation of slant, then verbal estimates of one’s hand or of a distal hill or ramp should both be overestimated by a factor of ~1.5. Although much research has shown that verbal estimates of distal surfaces are overestimated by a factor of ~1.5, no work of which we are aware has asked people to verbally estimate the orientation of their own hand while it is on a palm board. If there is one representation of slant, then if we hold the measure (verbal estimation) constant, the overestimation by a factor of ~1.5 should occur irrespective of the surface we are estimating. Conversely, a lot of work has shown that palm boards are oriented close to accurately for outdoor hills and produce shallower estimates for nearer surfaces. We have argued that this is consistent with an overestimation of slant; we should expect this if slant is overestimated. Also, we should expect shallower estimates than are requested when people adjust a ramp to a verbally given angle. If there is one representation of slant, then if we were again to hold the measure (this time reproduction) constant, shallower estimates (gains of ~0.57–0.61) should occur, irrespective of the surface estimated.

### Experiment 1

In Experiment 1, participants used a method of adjustment similar to that of the classic palm board measure—in which participants make a relative match of a palm board to a viewed slanted surface. However, in this experiment participants were asked to adjust the orientation of an adjustable ramp to a

**Table 1** Matrix for what we are calling the “measure” by “surface”

Surface	Measure	
	Reproduction	Verbal Estimation
Palm board	Typically closer to accurate (outdoor hills) or underestimate (near surfaces and verbally given angles) (gains ~0.57–0.61)	Experiments 2 and 3
Hills/ramps	Experiment 1	Overestimations by a factor of ~1.5

verbally given angle. We should expect that if people generally overestimate surfaces, then if we were to ask participants to match the orientation of the surface of a ramp to what they perceive as a particular verbally given angle, they would adjust the ramp to a lower orientation to fit the idea that we overestimate slant. Here, a shallower angle should look steeper if the perception of surfaces is overestimated.

## Method

**Participants** A total of 30 participants (17 female, 13 male) took part. All participants were undergraduates 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 m by 1 m) with a hinge. One piece of wood always stayed on the ground, whereas the other was the portion of the ramp that was adjusted. Four pairs of precut rods were used to hold the slanted portion of the ramp at the four different angles of inclination (8°, 16°, 24°, and 32°).

**Procedure** In order to avoid confounding haptics and vision, participants instructed a researcher to adjust the ramp up or down to the verbally given angle. The experimenter encouraged participants to request minor adjustments until they were satisfied with the match. The experimenter recorded their estimates, and then participants turned their backs while the ramp was repositioned to the initial position for the next trial.

Each participant stood 1 m from the base of the ramp. We wanted to get a wide range of angles to be estimated across all of our participants, but did not want any one participant to have to estimate more than a few angles, in order to avoid any carryover from one angle to the next if some angles were very similar. So first we omitted angles outside a certain range because in our experience people have a difficult time distinguishing among angles of the ramp that are close to 0° (~0° to 5°), and because slopes of 30° and more are typically overestimated by ~20°, a ramp angle of 70° might appear to measure about 90°. For this reason, we omitted angles of 5° and below and 70° and above. Since we also wanted the three angles that participants were estimating to perceptually be substantially different from one another, we categorized the angles as low (6°–23°), medium (24°–46°), and high (47°–69°). There are fewer possibilities in the low category, because a ramp oriented at 24° no longer looked shallow. We then randomized the entire range from 6° to 69° for each participant. The first three angles in the low, medium, and high categories were selected as that participants' set of angles. The angles were then kept in the same order that they appeared in the list, such that the category was also random across participants. We also wanted to pseudorandomize the directions that we moved the ramp to the different categories of

angles. There were six possible orders for each participant: low, medium, high and low, high, medium; medium, low, high and medium, high, low; and high, low, medium, and high, medium, low. Thus, if we started adjusting the ramp from 0° for every participant (as we did), then for all of the six possible orders, we would be moving the ramp upward to the low angle twice and downward to the low angle four times, upward to the medium angle four times and downward to the medium angle twice, and upward to the high angle always. To account for the upward movement of the ramp to the high angle all of the time, whenever the order for any participant started with the high angle as the first angle to be estimated of the three, we moved the ramp downward from 90° to the high angle. We kept the ramp at the previous position prior to reorienting it, in order to minimize any anchoring effects (see Shaffer et al., 2014, and Shaffer, Taylor et al., 2015), similar to the procedure in Coleman and Durgin (2014).

## Results

In order to test the gain of people's estimates of the angles at which they oriented the ramp, we plotted the estimates for each of the three different verbally given angles for each participant. We then calculated and recorded the slope for each participant. We first compared the gains to a value of 1, to test whether the gains were significantly lower than 1. A one-sample *t* test showed that the gains were indeed significantly lower than 1,  $t(29) = 2.52$ ,  $p = .008$ . We then compared the mean gains of the adjusted angle of the ramp to 0.61, the palm board gain found by Durgin, Hajnal, et al. (2010) for near surfaces, and found no statistical difference:  $M = 0.5687$ ,  $SD = 0.32$ ,  $t(29) = -0.7$ ,  $p = .49$ .

## Discussion

In Experiment 1, participants used a method of adjustment similar to that of the classic palm board measure to match the orientation of a ramp to a verbally given angle. We found that they adjusted the ramp to a lower orientation with a gain of ~0.57, consistent with the gain for palm boards estimating near surfaces (0.61; Durgin, Hajnal, et al., 2010), and consistent with the relative gains of palm-board-to-visual measures of outdoor hills ranging from 2° to 34° (0.58; Durgin, Hajnal, et al., 2010, using data from Proffitt et al., 1995) and in a haptic production task to verbally given angles (0.5685; Proffitt et al., 1995). In all of these cases, the reproduction task was the same; the difference was between adjusting the ramp surface we used in the present experiment and the palm board surface used in the other three. In spite of the difference in the surfaces, the resultant estimates are all the same because the underlying representation is the same. As expected, a shallower angle looked steeper in the present experiment, strongly suggesting that it may have felt steeper in the other three cases as well, because the

perception of the surfaces across measures was overestimated. We have now placed our results from Experiment 1 into the matrix from Table 1, appearing in Table 2. This shows that, consistent with there being one representation of slant, when we held the measure (reproduction) constant across surfaces, the shallower estimates (gains of ~0.57–0.61) appeared, irrespective of the surface estimated.

Consistent with the findings from Experiment 1, when Proffitt et al. (1995) had people set the palm board to eight different verbally given angles from 5° to 75°, haptic adjustments revealed underestimations of the verbally given angles on the order of a gain of 0.5685. Proffitt et al. (1995) derived haptic scores based on palm board orientations given to verbally given angles and used these to predict the palm board estimates given for outdoor hills. The palm board orientations to verbally given angles were good predictors of those produced for outdoor hills. Proffitt et al. interpreted these results as meaning that participants displayed an internal consistency for the haptic measures, in that they represented an angle in the same way, irrespective of whether it was made to the inclination of a visually perceived outdoor hill or to a verbally given angle. However, these data may also be interpreted as misperception of the palm board, consistent with Li and Durgin (2012), whose participants set their hands too low to match a set of verbally given angles; Li and Durgin interpreted this to mean that the participants overestimated their hand pitch orientations relative to a visual surface-matching task that the same participants also performed.

Thus, the work that has been done with palm boards and led to the conclusion that lower estimates of palm boards are evidence of separate visual pathways or systems, because the palm board estimates were accurate (e.g., Bhalla & Proffitt, 1999; Creem-Regehr et al., 2004; Proffitt et al., 1995; Taylor-Covill & Eves, 2013), actually supports the hypothesis that we perceptually overestimate slanted surfaces in general, whether via hand proprioception or vision, and is consistent with a single, underlying, exaggerated representation of slanted surfaces.

## Experiment 2

Experiment 2 was performed in order to investigate whether hand proprioception is overestimated similarly to verbal

estimates of slope, by directly asking people to estimate at what angle their hand was oriented when it was placed at a variety of different angles. Since we already know that verbal estimation of slanted surfaces is overestimated by a factor of ~1.5, we wanted to test whether, when using a verbal estimation task to assess the orientation of the hand, overestimates of hand orientation would match those of visually perceived surfaces. If the gains were in the 0.57–0.61 range, this would strongly suggest that the palm board results are probably a reflection of a system operating largely independent of, not in concert with, a system that is reflected by the verbal estimation measure. However, if gains were more in the 1.5–1.6 range, this would strongly suggest that the palm board and verbal estimation measures reflect the same underlying perceptual representational system.

## Method

**Participants** A total of 62 undergraduates from Ohio State University at Mansfield (43 male, 19 female) took part, who participated in fulfillment of an Introductory Psychology requirement. None had taken part in Experiment 1.

**Materials** The same palm board used in Shaffer et al. (2014) and Shaffer, Taylor et al. (2015) was used here. It was situated at waist level, similar to the classic style used by Proffitt et al. (1995). In the eyes-open task, a vertical screen blocking the participants’ view of their hand was adjusted to shoulder height, so that participants could not see their hand or the palm board when making their settings.

**Procedure** We oriented the palm board randomly at one of five different angles (0°, 8°, 16°, 24°, and 32°) three different times (for a total of 15 trials per participant), and participants verbally indicated at what orientation they felt their hand was positioned. Participants took their hand off the palm board prior to making a subsequent estimate, and were randomly assigned to the eyes-open and eyes-closed conditions. We used a maximum angle of 32°, because we had previously found that when participants were asked to orient their hands on a palm board at waist level to the maximum amount that their wrists could flex, the mean estimate was significantly less than 40°:  $M = 37.61$ ,  $SD = 10.31$ ,  $t(84) = -2.14$ ,  $p = .035$  (Shaffer & McManama, 2013).

**Table 2** Matrix for what we are calling the “measure” by “surface,” including the gain found in Experiment 1

Surface	Measure	
	Reproduction	Verbal Estimation
Palm board	Typically closer to accurate (outdoor hills) or underestimate (near surfaces and verbally given angles) (gains ~0.57–0.61)	Experiments 2 and 3
Hills/ramps	Gain of 0.5687 (Exp. 1)	Overestimations by a Factor of ~1.5

## Results

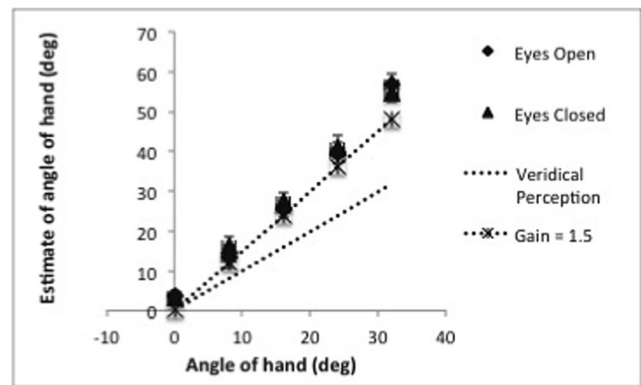
We first averaged the estimates of each of the angles across the three trials per angle per participant and used this average for all of the analyses. We removed three participants from the analyses because they clearly did not understand the instructions. Table 3 shows the means and standard deviations for each of the angles. We then performed five independent-samples *t* tests to compare the estimates of the five different angles between the eyes-open and eyes-closed conditions, using a Bonferroni correction of  $p = .05/5 = .01$  for each analysis of the multiple *t* tests. We found no statistical difference for any of the angles between the eyes-open and eyes-closed conditions— $0^\circ$ ,  $t(57) = 0.36$ ,  $p = .721$ ;  $8^\circ$ ,  $t(57) = -0.88$ ,  $p = .385$ ;  $16^\circ$ ,  $t(57) = -0.42$ ,  $p = .679$ ;  $24^\circ$ ,  $t(57) = -0.40$ ,  $p = .692$ ;  $32^\circ$ ,  $t(57) = 0.23$ ,  $p = .553$ .

We then compared people's estimates of where their hand was oriented to the actual orientation at each of the five angles with five one-sample *t* tests, using a Bonferroni correction of  $p = .05/5 = .01$  for each analysis to correct for performing multiple *t* tests. We found that people overestimated the orientation of their hand across all angles:  $0^\circ$ ,  $t(58) = 4.29$ ,  $p < .001$ , Cohen's  $d = 0.56$ ;  $8^\circ$ ,  $t(58) = 3.81$ ,  $p < .001$ , Cohen's  $d = 0.50$ ;  $16^\circ$ ,  $t(58) = 6.22$ ,  $p < .001$ , Cohen's  $d = 0.81$ ;  $24^\circ$ ,  $t(58) = 8.68$ ,  $p < .001$ , Cohen's  $d = 1.13$ ;  $32^\circ$ ,  $t(58) = 13.09$ ,  $p < .001$ , Cohen's  $d = 1.7$ .

In order to test the gain of people's estimates of the angles at which they thought their hand was oriented, we plotted the estimates for each of the five different angles for each participant, and then calculated and recorded the slope for each participant. We then performed two one-sample *t* tests (with a Bonferroni correction of  $p = .025$  for each analysis) comparing the gains in the eyes-open and eyes-closed conditions to 1.5, the gain that has been found for verbal estimates of visually perceived near and far surfaces, as well as for both geographical slopes outdoors and man-made slopes studied in laboratories. We found that the gains of our participants ( $M = 1.66$  and  $1.6$  for the eyes-open and eyes-closed conditions, respectively) were statistically no different from a gain of 1.5:  $t(29) = 1.96$ ,  $p = .06$ , and  $t(28) = 1.51$ ,  $p = .143$ , for the eyes-open and eyes-closed conditions, respectively. The average estimates of hand orientation at each angle are shown in Fig. 1. The best fit lines accounted for the data very well—

**Table 3** Means and standard deviations for verbal estimates of hand orientation for each of the angles in the eyes-open and eyes-closed tasks

Angle	$0^\circ$	$8^\circ$	$16^\circ$	$24^\circ$	$32^\circ$
Eyes open	$3.8^\circ$	$13.19^\circ$	$25.84^\circ$	$39.68^\circ$	$56.83^\circ$
Eyes closed	$3.21^\circ$	$16.28^\circ$	$27.27^\circ$	$41.2^\circ$	$54.65^\circ$
Mean	$3.51^\circ$	$14.71^\circ$	$26.54^\circ$	$40.42^\circ$	$55.76^\circ$



**Fig. 1** Mean estimates of hand orientation at each angle in Experiment 2, with error bars representing  $\pm 1$  SEM. The dotted line with no markers indicates how the line would look if people estimated the angles perfectly. The dotted line with markers indicates how the line would look if people overestimated the angles by a factor of 1.5

$R^2 = .989$  and  $.999$  for the eyes-open and eyes-closed conditions, respectively.

## Discussion

Our work shows that when we had people give verbal estimates of hand orientation, they made overestimates of hand pitch orientation equivalent to those seen for verbal estimates of visually perceived slanted surfaces. This finding provides evidence that verbal estimations of palm board and ramp orientations result in the same overestimates of slant. This suggests that the estimates of the hand and ramp reflect the same underlying perceptual representational system; the difference in gains across tasks is indicative of a general overestimation of slanted surfaces. The results of Experiments 1 and 2 are now placed in Table 4.

When people match their palm to a slanted surface, they orient it lower than the surface looks or is represented (for a verbally given angle) because their hand feels like it is oriented at a steeper angle than it actually is, and when their hand is oriented at a given angle and they have to estimate its orientation, they indicate an overestimate because their hand feels like it is oriented at a steeper angle than it actually is. This also extends and is consistent with the work of Li and Durgin (2012, Exp. 1—orientation production task), who found that their participants overestimated their hand pitch orientations by approximately the same amount as previous studies had shown that people verbally overestimate visually slanted surfaces, as was shown by reverse plotting their data. Li and Durgin's participants set their hands too low to match a verbally given angle, consistent with the participants in the present experiment, who verbally overestimated their hand pitch orientation. This is also consistent with the proprioception calibration hypothesis, which proposes that similar biases exist in verbal estimates of both visually perceived slant and proprioceptively perceived hand orientation (Li & Durgin,

**Table 4** Matrix for what we are calling the “measure” by “surface,” including the gains found in Experiments 1 and 2

Surface	Measure	
	Reproduction	Verbal Estimation
Palm board	Typically closer to accurate (outdoor hills) or underestimate (near surfaces and verbally given angles) (gains ~0.57–0.61)	Overestimation by a factor of 1.63 (weighted mean—Exp. 2) and Experiment 3
Hills/ramps	Gain of 0.5687 (Exp. 1)	Overestimations by a factor of ~1.5

2012). These authors concluded that perceptual coding for action purposes does not have to be accurate, as long as both vision and proprioception are misperceived in the same way. Our results are consistent with this.

### Experiment 3

Typically, palm board estimates are given while people are looking at the slanted surface to which they are orienting their hand. However, in Experiment 2 participants were not looking at a distal slanted surface while they matched their hand orientation to the surface. Perhaps looking at a hill while orienting your hand to its surface leads to differences in perceived proprioceptive (hand) orientation due to the visual guidance of the hand to the oriented surface. Additionally, in Experiment 1 we did not directly test proprioceptively perceived hand orientation and verbal estimates of visually perceived hill orientation in the same experiment with the same participants. So, in Experiment 3, after first orienting a palm board to the surface of a ramp, half of the participants verbally estimated the visually perceived orientation of the ramp, and the other half of the participants verbally estimated the orientation of their hand. This allowed us to directly compare verbal estimates of the hand to verbal estimates of the ramp while controlling for the task that was being used. Thus, any differences found would be due to what participants were asked to estimate—their hand or the ramp.

### Method

**Participants** A total of 30 participants (20 female, 10 male) took part. All were undergraduates from Ohio State University at Mansfield who participated in fulfillment of an Introductory Psychology requirement, and none had participated in Experiment 1 or 2.

**Materials** The same wooden ramp used in Experiment 1 was used here. Likewise, the same palm board and vertical screen blocking the participants’ view of their hand that had been used in Experiment 2 were also used in the present experiment.

**Procedure** Each participant stood 1 m from the base of the ramp and was told to adjust the orientation of the palm board to make it parallel with the slope of the ramp. Participants were randomly assigned to either the “estimating the orientation of the ramp” or “estimating the orientation of their hand” condition. Both groups made their estimates in degrees from the horizontal. A digital reading was taken of the indicated orientation of the palm board, and participants’ verbal estimates were also recorded. They were then told to close their eyes and remove their hand from the palm board as we changed the orientation of the ramp. We kept the palm board at the previous position while we reoriented the ramp, in order to avoid any anchoring effects (see Shaffer et al., 2014, and Shaffer, Taylor et al., 2015), similar to the procedure in Coleman and Durgin (2014).

### Results

We first performed analyses on the palm board orientations for each condition. The means and standard deviations are shown in Table 5. We performed four independent-samples *t* tests to compare the palm board orientations of the four different angles between the estimating-the-hand and estimating-the-ramp conditions. We used a Bonferroni correction of  $p = .05/4 = .013$  for each analysis to correct for the multiple *t* tests. We found no statistical difference for any of the angles between conditions: 8°,  $t(28) = -0.88, p = .387$ ; 16°,  $t(28) = -1.59, p = .123$ ; 24°,  $t(28) = 0.2, p = .367$ ; 32°,  $t(28) = 0.65, p = .518$ .

Therefore, we collapsed the palm board orientation data across the estimating hand and hill conditions for the remaining analyses. Next, we compared people’s palm board orientations to the actual orientations of the ramp using four one-sample *t* tests, with a Bonferroni correction of  $p = .05/4 = .013$  for each analysis to correct for performing multiple *t* tests. We

**Table 5** Means and standard deviations for palm board orientations of all four inclinations for both the hand and the hill

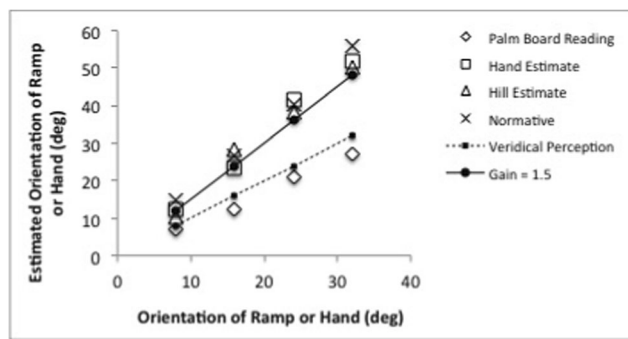
	8°	16°	24°	32°
Hand	6.22° (5.38°)	10.89° (4.29°)	21.66° (8.31°)	27.74° (10.55°)
Hill	7.84° (4.68°)	13.78° (5.57°)	19.31° (5.46°)	25.7° (5.89°)

found that the palm board orientations were statistically equivalent to the actual angle of the ramp for 8°, and slightly, but statistically, less for angles of 16°, 24°, and 32°: 8°,  $t(29) = -1.06, p = .30$ ; 16°,  $t(29) = -3.93, p < .001$ , Cohen's  $d = 0.17$ ; 24°,  $t(29) = -2.75, p = .010$ , Cohen's  $d = 0.5$ ; 32°,  $t(29) = -3.42, p = .002$ , Cohen's  $d = 0.62$ . These results of no difference between the palm board settings and shallower slopes and of slightly lower palm board settings for steeper slopes are consistent with previous findings (Durgin, Hajnal, et al., 2010; Proffitt et al., 1995).

For our central analysis, comparing the verbally estimated hand orientations to the verbally estimated ramp orientations, we performed four independent-measures  $t$  tests to compare the verbal estimates of the four different angles between the hill and hand orientation estimation conditions. We used a Bonferroni correction of  $p = .05/4 = .013$  for each analysis to correct for the multiple  $t$  tests. We found no statistical difference for any of the angles between the hill and hand orientation estimation conditions: 8°,  $t(28) = 0.89, p = .384$ ; 16°,  $t(28) = -1.34, p = .19$ ; 24°,  $t(28) = 0.75, p = .458$ ; 32°,  $t(28) = 0.23, p = .819$ . The means and standard deviations are shown in Table 6.

Since we found no statistical differences between estimating-hand and estimating-ramp-orientation conditions, we collapsed the data across the conditions to compare these estimates to the actual angles of the ramp for the four different angles. We used a Bonferroni correction of  $p = .05/4 = .013$  for each analysis to correct for the multiple  $t$  tests. We found that verbal estimates of the hand/ramp significantly overestimated the actual orientation of the ramp for all five angles: 8°,  $t(29) = 3.11, p = .004$ , Cohen's  $d = 0.57$ ; 16°,  $t(29) = 5.32, p < .001$ , Cohen's  $d = 0.97$ ; 24°,  $t(29) = 7.63, p < .001$ , Cohen's  $d = 1.39$ ; 32°,  $t(29) = 6.69, p < .001$ , Cohen's  $d = 1.22$ .

In order to test the gains of people's estimates of the angles at which they estimated that either their hand or the hill was oriented, we plotted the estimates for each of the four different angles for each participant. We then calculated and recorded the slope for each participant in each condition. We then performed an independent-samples  $t$  test comparing the gains of our 30 participants between conditions. We found no significant difference between the conditions:  $M_{\text{Hand}} = 1.81, SD_{\text{Hand}} = 0.49$ ;  $M_{\text{Hill}} = 1.53, SD_{\text{Hill}} = 0.56$ ;  $t(28) = 1.47, p = .154$ . Figure 2 shows the mean estimates plotted for each angle for the normative condition from Experiment 2 and the palm



**Fig. 2** Mean palm board orientations and mean estimates of hand and hill orientations, along with the mean estimates of hand orientation from Experiment 2 at each angle, with error bars representing  $\pm 1$  SEM. The dotted line with no markers indicates how the line would look if people estimated the angles perfectly. The dotted line with markers indicates how the line would look if people overestimated the angles by a factor of 1.5

board orientation and hand and hill estimate conditions from the present experiment.

We then performed a one-sample  $t$  test comparing the collapsed estimates of the hand and the hill to 1.5, the gain that has been found for near and far surfaces, as well as for both geographical slopes outdoors and man-made slopes studied in laboratories. We found no significant difference between the gains of our participants and a gain of 1.5:  $M = 1.66, SD = 0.53, t(29) = 1.7, p = .099$ .

We next performed a one-sample  $t$  test comparing the collapsed estimates of the hand and hill to 1.63, the weighted mean gain (across eyes-open and eyes-closed conditions) that we found for people estimating at what angle their hand was oriented in Experiment 2. No significant difference was apparent between the overall gain found in Experiment 3 across the conditions and a gain of 1.63,  $M = 1.66, SD = 0.53, t(29) = 0.31, p = .759$ .

**Discussion**

In Experiment 3, we first examined what would happen to proprioceptively perceived hand orientation estimates when participants were matching their hands to a distal slanted surface. We found that the overestimates of hand orientation matched those found in Experiment 2, when participants estimated their hand orientation without matching their hands to a distal visually perceived hill. Thus, looking at a hill while orienting your hand to its surface does not lead to a modified perceived hand orientation. We also found no difference between the conditions in this experiment, showing that proprioceptively perceived hand orientation is perceived in the same way as visually perceived hill orientation while looking at the hill, using the same task, hill, and participants.

The results from Experiments 1–3 are now all placed in Table 7. Consistent with the findings of Experiments 2 and 3, when we changed the palm board estimation task from a

**Table 6** Means and standard deviations for verbal estimates of all four inclinations for both the hand and the hill

Angle	8°	16°	24°	32°
Hand	12.2° (5.19°)	23.33° (9.39°)	41.33° (11.87°)	51.67° (16.33°)
Hill	10.33° (6.31°)	28.2° (10.42°)	38.2° (10.91°)	50.33° (15.29°)



**Table 7** Matrix for what we are calling the “measure” by “surface,” including the gains found in Experiments 1–3

Surface	Measure	
	Reproduction	Verbal Estimation
Palm board	Typically closer to accurate (outdoor hills) or underestimate (near surfaces and verbally given angles) (gains ~0.57–0.61)	Weighted mean of 1.63 (Exp. 2) and Collapsed mean of 1.66 (Exp. 3)
Hills/ramps	Gain of 0.5687 (Exp. 1)	Overestimations by a factor of ~1.5

matching task to one in which people verbally estimated the orientation of their hand, people showed overestimations of hand pitch orientation that were the same as verbal estimations of the same slanted surface. This suggests that the palm board and verbal estimation measures reflect the same perceptual representational system. The difference in gains across measures is indicative of a general overestimation of slanted surfaces. When people match their palm to a slanted surface or adjust a ramp to a verbally given angle, they orient at a shallower angle because the angle feels steeper than it actually is, and when their hand is oriented at a given angle and they have to estimate its orientation, the angle again feels steeper than it actually is, so they overestimate the orientation.

This work is also consistent with the proprioception calibration hypothesis, which proposes that similar biases exist in verbal estimates of both visually perceived slant and proprioceptively perceived hand orientation (Li & Durgin, 2012). Here again, both vision and proprioception were misperceived in the same way. Thus, palm board estimates can be biased due to wrist flexion and anchoring issues—which we know they are—and our perceptions of the orientation of our hand and of a ramp/hill can be gross overestimations of the true inclination of the ramp/hill. However, as long as we overestimate our hand and the ramp/hill in the same way (by the same magnitude), our actions will be aligned in the way they need to be in order to interact appropriately with surfaces.

## Conclusions

We have argued that previous work has shown that the perception of slanted surfaces is overestimated in general, and as such, reproduction tasks should give lower estimates, whereas verbal estimation tasks should give higher estimates, with both pointing together to a scale-expanded perception of slant. This is shown in Table 7, where within measures, but across surfaces, the estimates are almost identical, but very different values are shown across measures of reproduction and verbal estimation. So, when we removed the confound of different measures being used for different surfaces, we found that using different surfaces produced similar results. If slant in general is overestimated, and you were to verbally give

someone an angle to reproduce or show them a slanted surface and have them match their hand or a ramp to it, you would expect them to stop short of the perceived angle, because the hand and ramp that you were matching with would feel and look steeper than they actually were. This is exactly what occurred in Experiment 1 and with the palm board orientation of Experiment 3. Conversely, if you have a ramp, hill, or hand at a given angle and people verbally give a specific value to its orientation, one would expect overestimates because, again, the ramp, hill, or hand would look or feel steeper than it truly was. This is consistent with our findings in both Experiments 2 and 3. The present findings point to the fact that whether using a reproduction or verbal estimation measure, the perceptual representation of space is the same.

Previous work has documented that the different measures of palm boards and verbal estimation give different values for slanted surfaces, leading to the conclusion that this must point to the accessing of different information subserved by different streams in the brain (e.g., Bhalla & Proffitt, 1999; Creem & Proffitt, 1998; Proffitt et al., 1995). Hopefully our work here will help clarify some of the apparent differences found within and across articles. For instance, Durgin, Li, et al. (2010) and Durgin, Hajnal, et al. (2010) appreciated that palm boards might be misperceived, but they did not appreciate that anchoring effects were involved (Shaffer, McManama et al., 2015), which could explain the differences they noted between haptic perception and haptic production. By using reproduction measures for visual ramps, we have shown that the small discrepancies between haptic perception and production that were a puzzle to Durgin, Li, et al. (2010) can be resolved. Combining the conclusion that people overestimate surfaces in general with an appreciation of the effects of anchoring, for example, can fully account for most of the existing data concerning discrepancies between verbal reports and palm board measures.

Conversely, in our previous work (Shaffer et al., 2014), we found strong anchoring biases with the palm board but were not concerned with the differences between reproduction and verbal estimation (which were evident in the free-hand measures we used). The haptic reproduction task used in the present article was anchored from the horizontal, so we should expect the resulting perceptual discrepancies to be more like those of production tasks, discussed by Durgin, Li, et al.

(2010). Consistent with this, the gain values we observed were somewhat higher than 1.5, consistent with a contribution from horizontal anchoring when setting the palm board. Although we sought to minimize anchoring biases in Experiment 1, the similar gain in the slant production task in Experiment 1 may reflect residual effects of an initial horizontal anchoring bias based on the initial orientations for all but the steepest requested angle. Wrist flexion issues and anchoring biases probably introduce their own independent contributions to the differences seen, and may now be evaluated separately from the measure that is being employed.

We have found that the fundamental problem in all of the studies measuring palm boards and verbal estimates is that what we have called the “measure”—either using reproduction or having people verbally estimate the visually perceived slope of a slanted surface has always been confounded with what we have called the “surface”—either using a palm board or a ramp or hill. That is, in these previous studies, reproduction was used with the palm board, whereas verbal estimation was used with ramps or hills, without ever employing reproduction with ramps or hills or verbal estimation with palm boards. This has clouded a much more parsimonious picture of the perceptual representation of space in general, and of slant specifically, in which both verbal estimation and palm board measures represent perceptual space in the same way.

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