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Pushing people to their tipping point: Phenomenal tipping point is predicted by phenomenal vertical and intuitive beliefs

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Abstract

Previous work has shown that people overestimate their own body tilt by a factor of about 1.5, the same factor by which people overestimate geographical and man-made slopes. In Experiment 1 we investigated whether people can accurately identify their own and others' tipping points (TPs) – the point at which they are tilted backward and would no longer be able to return to upright – as well as their own and others' center of mass (COM) – the relative position of which is used to determine actual TP. We found that people overestimate their own and others' TP when tilted backward, estimate their own and others' COM higher than actual, and that COM estimation is unrelated to TP. In Experiment 2, we investigated people's intuitive beliefs about the TP. We also investigated the relationship between phenomenal TP and perceived vertical. Whether verbally (conceptually) estimating the TP, drawing the TP, or demonstrating the position of the TP, people believe that the TP is close to 45°. In Experiment 3, we found that anchoring influences phenomenal TP and vertical. When accounting for starting position, the TP seems to be best predicted by an intuitive belief that it is close to 45°. In Experiment 4, we show that there is no difference in phenomenal TP and vertical when being tilted about the feet or waist/hips. We discuss the findings in terms of action-perception differences found in other domains and practical implications.

Keywords Perception and action · Spatial cognition · Visual perception

Introduction

People overestimate how much they are tilted backward whether they are seated (e.g., Ito & Gresty, 1997; Jewell, 1998), or standing in a hand truck, Aerotrim, simulator, or inversion table (Ito & Gresty, 1997; Jewell, 1998; Shaffer et al., 2016). This work further shows that people significantly overestimate the degree to which they are tilted backward from vertical by a factor of ~1.5, consistent with people's overestimation of the orientation of geographic hills, man-made slants, and their own hands/forearms upward from horizontal (Bhalla & Proffitt, 1999; Bridgeman & Hoover, 2008; Durgin & Li, 2011; Durgin, Li & Hajnal, 2010; Li & Durgin, 2010; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Shaffer & McManama, 2015; Shaffer & Taylor, 2016; Shaffer et al., 2016). In our recent work, when we told people to estimate when they felt they were tilted backward at 45° (Experiment 1), or they were shown a line indicating an orientation of 45° and told to match their body tilt to that line (Experiment 2), they thought they were tilted at 45° when they were only tilted at ~28°, consistent with an *over*estimation of slant (Shaffer et al., 2016).

In the current work, we wanted to extend our work on people's perceptions of body orientation by evaluating people's perception of what we call their own and other people's *tipping point (TP)* – the earliest point at which you are tilted backward from upright and are no longer able to return to upright (Cholewiak, Fleming, & Singh, 2013; Firestone & Keil, 2016). The TP may also be specified by the *critical angle*, the maximal angle at which the person (in this case, or any object for that matter) can be tilted away from its upright position and still return to upright (Cholewiak et al., 2013). The critical angle is defined as the point at which the center of mass (COM) of an object or person is directly vertically above the base of the point of contact. Therefore, if we were to tilt a person backward, the critical angle would be

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defined as the point at which the COM of the person is directly vertically above the back of their shoe. To avoid confusion, we will refer to this position as the tipping point throughout the paper. The COM and TP are important physical properties that may help us know when to avoid objects that are going to fall over or allow us to help others and ourselves if we can accurately judge when they/we might tip over.

Work investigating how accurate people are at identifying the COM of objects has shown that children and adults alike are pretty accurate when identifying the COM of triangles, quadrilaterals, and balanced and unbalanced polygons oriented at different angles, with small errors in identifying the COM of the former two influenced by the shape of the object or the orientation of a salient angle, and small errors influenced by the eccentricity of the top for unbalanced objects (Baud-Bovy & Gentaz, 2004; Baud-Bovy & Soechting, 2001; Bingham & Muchinsky, 1993; Samuel & Kerzel, 2011). Observers identifying the stability of conical frustums are very good at visually estimating the overall stability of objects by using the minimum critical angle to judge object stability (Cholewiak et al., 2013). Observers are also good at identifying the COM of outlines of symmetric human figures while erring slightly in the direction opposite to an extended limb for asymmetric human figures (Friedenberg, Keating, & Liby, 2012). A similar finding has also been shown in identifying the COM for asymmetrical computer-generated shapes (Firestone & Keil, 2016). This work also showed that people err more in their estimates of the COM in the direction predicted by the formation in the participant's minds of an implicit three-dimensional representation of these object shapes. As the ability to make the three-dimensional representations of these object shapes increases (like viewing a pattern of dots compared to viewing an asymmetrical shape) so too does the error in estimating the COM consistent with people creating a three-dimensional (3-D) mental representation of the object shape. It has been shown that people can and do take the COM into account to keep themselves more stable, as experimentally manipulating the COM in people influences their own judgments of stability for walking on inclined surfaces (Regia-Corte & Wagman, 2008). The COM is also an important physical property to identify for one's own safety as it has been shown that the percentage of height of the COM is significantly higher in the elderly with frequent falls (Almeida, Castro, Pedreira, Heymann, & Szejnfeld, 2011).

Previous work has modelled a "stability cone" with boundaries forming what they call "stability limits" – essentially the points around which a person may sway before falling over (McCollum & Leen, 1989). These points of deviation from true vertical within which one may make ankle and hip movements to bring them back before falling over have also been referred to as the region of *tolerance* and *reversibility* (Riccio & Stoffregen, 1988) and the *region of permissible sway* (Adolph, 2000; Adolph, 2002; Stoffregen & Riccio, 1988). In work investigating this idea experimentally, it has been shown that this region predicts infants' behavior when traversing gaps and crawling down slopes (Adolph, 2002). While our postural control is not so perfect as to compensate for every deviation from true vertical, there is a certain range of deviations of the COM from true vertical that can be corrected to maintain one's stance and not fall over. Thus, in the current work, we first wanted to investigate the true and phenomenal limits of anterior-posterior postural sway. We then tested whether the phenomenal limits of anterior-postural sway were related to phenomenal COM, phenomenal vertical, and intuitive beliefs about the TP.

Experiment 1

Experiment 1 had four goals. First, we wanted to establish what the COM is for a normative group of individuals. Second, we wanted to test whether people are accurate at identifying their own and other people's COM as people have been shown to be fairly accurate at identifying the COM of objects and outlines of symmetric human figures (Baud-Bovy & Gentaz, 2004; Baud-Bovy & Soechting, 2001; Friedenberg et al., 2012). Third, we wanted to test how accurate people are at identifying their own and others' TPs. Fourth, we wanted to test whether identification of the COM accurately predicts the perceived TP for themselves and for others.

Method

Participants

There was a total of 42 participants (20 male). All participants were undergraduates from the Ohio State University at Mansfield who participated in the experiment in fulfillment of an Introductory Psychology requirement. Their mean age was 20.85 (*SD* = 6.19) years.

Materials and apparatus

Measuring the perceived TP and perceived vertical A Teeter Hang-Ups NCT-S® Inversion Table was used to tilt participants. The table has an adjustable ankle system to lock the participants' ankles in place. One of several weightlifting belts – depending on the size of the participant – was placed around the participants' waist and the back of the inversion table, securing the upper body of the participant (see Fig. 1). An Accuremote™ precision angle measurement gauge was placed on the spine-like frame of the inversion table to measure the angle at which participants were tilted when they gave their estimates. Participants were instructed to keep their hands down at their sides and keep their head flat against the inversion table while looking forward the entire time.

Fig. 1 Here the participant is shown being tilted back in the inversion table by an experimenter

Measuring the true and perceived centers of mass for participants and models Two Rubbermaid Commercial Products® scales with a 68-kg weight limit each were placed underneath a 2.44-m long flat wooden board on each end. Participants were instructed to lay on the board with their arms at their sides and to keep their feet flush to one end of the board, as shown in Fig. 2. We then measured the participants' weight on each scale. We also measured participants' foot length and height in order to calculate their COM and actual TP. As shown in Fig. 2, we calculated their COM, or "X" (in the figure), as: $COM = X = W_2 * l/(W_1 + W_2)$. We then calculated their true TP as: $90°\text{-}\tan^{-1}(COM/(\text{foot length}/2))$. In addition to doing this for each participant, we also measured this for each of three models for whom participants estimated the COM and TP.

In order to measure their perceived COM, we asked participants to stand in front of a mirror and point to the position on their body in the vertical direction where their weight would be equally distributed when their hands were both down by their sides, as shown in Fig. 3. We then measured this distance up from the ground. They then stood in front of one of the models and pointed to what they estimated to be the COM on the model's body and we measured the distance of the perceived COM by recording the distance of where they were pointing up from the ground.

Procedure

Participants stepped into the ankle supports and secured the belts around their waists as an experimenter adjusted the ankle supports. Prior to giving any estimates, all participants were given a brief review of standard geometry to clarify that they understood different angular positions. We explained that when the inversion table was standing vertically, it was defined to be at 0° and when the table was lying horizontally, it was at 90°. We did not proceed until all participants clearly understood the instructions. For each trial, participants were tilted backward manually with a rotational velocity of approximately 4–6° per second. They were instructed to tell us to stop when they felt like they were at the point where they would no longer be able to return themselves to upright and would fall over backward. We then asked them to estimate the TP of one of the three different models when viewing them being tipped backward. Participants stood to the side of the model while the model was being tilted backward.

Participants were then asked to estimate their own COM while standing in front of a mirror by pointing to the position on their body that represented the COM. They also estimated the COM of one of the models. The measurement of the perceived COM of the participant was taken with a tape measure that was held at the ground by one researcher, was taken by the participant or model, and drawn up past the COM, and the distance from the ground to where they were pointing was recorded by another researcher. The measurement of the perceived COM of the model was taken by having the participant point to the location on the model where they believed the COM to be, and then having the model point their own finger

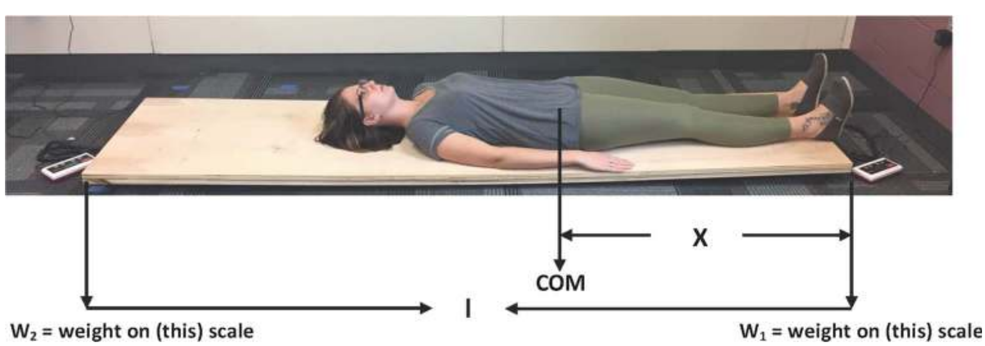

Fig. 2 The figure shows the layout for how participants lay on the board and the measurements we took that then went in to the computation of their center of mass. "X" indicates their center of mass and "l" indicates the length of the wooden board

Fig. 3 The figure shows what the participants did to estimate their own center of mass (COM)

to it. The participant then guided the model to make small adjustments of their finger up and down until the participant was satisfied. While we used three different models in the experiment, each participant estimated both the COM and TP of the same model. These estimates were counterbalanced across observers. Participants then lay on top of the board with the scales underneath so that we could measure their actual COM.

Results

Center of mass (COM) results

Actual versus perceived centers of mass (COM) Actual mean centers of mass (and corresponding standard deviations) for males and females are shown in Table 1. An independent-samples t-test showed that COMs for males were significantly higher than COMs for females, $t(40) = 4.56$, $p < .001$. COM Percent is simply calculated as the percentage of one's height the COM is up from the feet. The 95% confidence interval for males' COM Percent was [54.3, 55.52], while the 95% confidence interval for females' COM Percent was [51.93, 55.61].

Perceived COMs are also shown in Table 1. We created difference scores between the actual and perceived COM for each participant. We then performed a one-sample t-test comparing these difference scores to 0 and found that participants perceived their COM to be significantly higher than actual, $t(41) = 10.28$, $p < .001$. This was a very large effect, Cohen's $d = 1.59$.

We also created difference scores between the actual and perceived COM of the models for each participant. We then performed a one-sample t-test comparing these difference scores to 0 and found that participants perceived the models' COM to be significantly higher than actual, $t(41) = 8.6$, $p < .001$. This was a very large effect, Cohen's $d = 1.33$. For the last analysis, we wanted to compare estimates of the COM for each of the participants compared to where each of them estimated the COM of the models. A paired-samples t-test comparing the difference scores showed that participants overestimated the COM (in terms of how high up on the body it was) significantly more for themselves than for the models, $t(40) = 3.65$, $p = .001$. This was a medium effect, Cohen's $d = 0.56$.

Tipping point results

Actual and perceived TPs for participant and model We calculated the actual TP as: $90°- \tan^{-1}(\mathrm{COM}/(\text{foot length}/2))$. Dividing foot length in half is customary throughout the literature. This is in spite of the fact that normal standing postural sway in adults tends to be greater anteriorly than posteriorly by a few degrees (Wang, Skubic, Abbott, & Keller, 2010), and the limit of the ankle movement tends to be ~12° anteriorly while being only about 5° posteriorly (McCollum & Leen, 1989). This custom is probably due to the fact that the postural limit is dependent on

Table 1 Means and standard deviations are shown for actual and perceived centers of mass for male and female participants. Means and standard deviations are also shown for actual and perceived centers of mass for models (all models were female). The number (COM) given is the distance measured up the person's body from the ground

	Actual COM self (cm)	COM %	Perceived COM self (cm)	Actual COM model (cm)	Perceived COM model (cm)
Males					
Mean	96.9	54.85	110.06		
SD	4.55	1.4	9.04		
Females					
Mean	88.42	53.77	103.02	94.27	102.98
SD	7.14	4	8.31	4.47	6.65

hip, knee, and ankle flexion with respect to the COM, and these things can counteract the potential differences in maximal anterior and posterior body positioning prior to falling over. Although we did not test anterior limits, due to the fact that in the inversion table the ankles are locked in place, and the participants did not move their hips and knees, limits of anterior and posterior sway were likely pretty evenly distributed. We calculated perceived TP based on perceived COM as: 90°- $\tan^{-1}$(COM Estimate/(foot length/2)). Means and standard deviations for actual and perceived TPs for participants and the models are shown in Table 2. A paired-samples t-test showed that people's perceived TP when they were in the inversion table was significantly farther back than their actual TP as determined by their COM, $t(41) = 8.42$, $p < .001$, $M_{Diff} = 17.45°$, Cohen's $d = 1.3$. Another paired-samples t-test also showed that participants viewing models from the side when the models were in the inversion table estimated their TP as significantly farther back than the models' actual TP as determined by *their* COM, $t(41) = 7.61$, $p < .001$, $M_{Diff} = 14.98°$, Cohen's $d = 1.17$ (Fig. 4).

Tipping points based on actual and perceived COM Means and standard deviations for TPs based on actual and perceived COM for participants and models are shown in Table 3.

We compared the mean TP based on the actual COM to that based on the perceived COM for the participants and found that even though only 1.11° separated the two means, there was a statistical difference, $t(41) = 9.65$, $p < .001$, Cohen's $d = 1.48$. Due to the mean perceived COM for participants being slightly higher (on their body) than actual, this resulted in a mean perceived TP that was slightly *earlier* than actual.

Relationship between COM estimate and TP estimate for participant and model We found statistically significant and moderate relationships between actual and estimated COMs for participants ($r(40) = .463$, $p = .002$) and models ($r(40) = .357$, $p = .020$). Furthermore, while we also found statistically significant and moderate relationships between actual TPs and estimated TPs for participants ($r(40) = .413$, $p = .007$) and models ($r(40) = -.454$, $p = .003$), respectively, there was no relationship found between COM estimates and TP estimates for participants ($r(40) = -.007$, $p = .964$) or models ($r(40) = .161$, $p = .309$).

Discussion

Experiment 1 first showed the actual COM in a large group of young adults. We established a 95% confidence interval for a large group of young adults and found the seemingly widely known difference in COM heights for males and females, where males have a higher COM than females. Participants perceived their COM to be higher than actual for themselves and higher than actual for the models, and slightly but significantly higher for themselves than for the models. This might suggest that judgments are made more on the "safe side" for both themselves and models but more for themselves, as higher COMs lead to earlier TPs. Judgments on the safe side like this have been found before for balanced and unbalanced objects (Samuel & Kerzel, 2011), but is not a universal finding (*cf.*, Cholewiak et al., 2013).

Experiment 1 also showed that people perceive their own and other people's TPs to be farther backward than actual and that there was no difference between estimating the TP while in the inversion table or estimating the TP while looking from the side at someone else being tilted backward in the inversion table. In some ways, the finding that the TP is perceived farther backward than actual is at odds with the idea that people overestimate how much they are tilted backward (Ito & Gresty, 1997; Jewell, 1998; Shaffer et al., 2016). One might think that if people believe they are tilted backward at 45° when they are only actually tilted backward ~26–30°, people might perceive they are tilted backward at their TP *earlier* than actual, consistent with people's overestimation of their own body tilt and judgments on the safe side, which we found with perception of their own and others' COM. However, participants might have had a conceptual version or intuitive belief of what the TP of humans probably is and tried to match the feeling of being tilted backward that far. For instance, if people believe that being tilted about halfway backward from vertical is the TP (i.e., 45° backward), then they may try to match how far they feel they are tilted backward to 45°. In order to test this idea, we compared the perceived TP estimates found in Experiment 1 to those of Shaffer et al. (2016), who tilted participants backward in the same inversion table and asked them to indicate when they felt they were tilted backward at 45°. An independent samples t-test showed there was no difference between the mean perceived TP shown here in Experiment 1 and people's perception of what being tilted backward at 45° feels like, $t(100) = 0.96$, $p = .34$, $M_{Exp\ 1} =$

Table 2 Means and standard deviations are shown for actual and perceived tipping points (TPs) for participants and the models

Measure	Actual TP participant	Perceived TP participant	Actual TP model	Perceived TP model
Mean	8.75°	26.2°	7.72°	22.7°
SD	0.57°	13.67°	0.24°	12.65°

Fig. 4 The figure shows the mean perceived tipping point position (left panel) and the actual tipping point position based on the actual center of mass (COM) (right panel)

26.2, $M_{45°}$ = 28.34. This could also explain why we found no difference in magnitude between people's perception of being tilted backward to their TP and the condition where participants stood off to the side of the inversion table when a model was being tilted backward and estimated the model's TP. If people have an intuitive belief that the TP is halfway between vertical and horizontal, then they may use this to estimate the TP when in the inversion table and when looking at the inversion table being tilted from outside it. However, they also may have overestimated the tilt of the model in the inversion table because people overestimate the slant of objects even when viewing them from the side (Proffitt, Creem, & Zosh, 2001).

The task of estimating the TP in an inversion table may seem to be dissimilar from normally standing and indicating the point at which you should make a corrective movement prior to falling over. However, the maximum point around which people may tilt backwards prior to falling over is mainly dependent on the COM from the center of support. Additionally, while subtle ankle movements may normally allow us to make corrective adjustments to our stance by putting different pressure on the toes or heel depending on the forces acting on them, the critical parameter that determines the TP, which also accounts for the force able to be applied at the ankle, is the length of the foot (McCollum & Leen, 1989). While we may make subtle ankle movements when not standing in an inversion table, the static case without ankle movement represents well the boundaries for tipping over (McCollum & Leen, 1989). While we recognize that the point at which people may make adjustive corrections to their stance may occur prior to the TP, we were interested in evaluating people's conscious perceptions of where their TP is. In fact, by asking them to evaluate the maximum point at which they could be tilted prior to falling over, we expect that people would choose to make corrective adjustments long before their TP. Finally, though TPs may change if people are allowed to move their knees, hips, and ankles, the amount it changes is insignificant even when altering their height to lower their COM therefore increasing the amount their COM must deviate from true vertical before falling over. For instance, since one of our participants was 1.78 m tall with an 0.28 foot, and their COM was 0.98m, their TP would be 8.15°. The easiest way to dramatically change their COM would not be for a person to make movements of the ankles or hips, but to bend their knees to lower their COM in order to make it more difficult to tip over. If this same participant bent their knees to squat down to 1.73 m (a very large change in height, which people typically do not do to keep from falling over), the COM would change to 0.95 m (using the 54.85% of total height average we found in Experiment 1 for males), and the TP would change to 8.39°, a change of only 0.24°. This is all to say that the more static stance people held in the inversion table well

Table 3 Means and standard deviations are shown for tipping points (TPs) based on actual and perceived centers of mass (COMs) for participants and models

Measure	TP based on actual COM for participant	TP based on perceived COM for participant	TP based on actual COM for model	TP based on perceived COM for model
Mean	8.75°	7.64°	7.72°	7.87°
SD	0.57°	0.63°	0.24°	0.67°

represents TPs that would be found if people were free to move their ankles, hips, and knees more as we do every day.

In Experiment 2 we set out to see whether people intuitively believe that the TP is about halfway between vertical and horizontal, and then we tested whether there was a relationship between estimating TP and estimating vertical.

Experiment 2

Experiment 2 had three goals. First, we wanted to investigate people's intuitions regarding the TP in three different ways. Second, we wanted to investigate whether there was a relationship between phenomenal TP and phenomenal vertical. Third, we wanted to investigate whether phenomenal TP away from phenomenal vertical might lead to an accurate estimate of people's actual TP.

Participants

All participants were undergraduates from the Ohio State University at Mansfield who participated in the experiment in fulfillment of an Introductory Psychology requirement. Their mean age was 19.47 (SD = 3.9) years. In our first group, there were a total of 60 participants (22 male). In our second group, there were a total of 50 participants (27 male).

Materials and apparatus

Measuring the perceived TP and perceived vertical The same Teeter Hang-Ups NCT-S® Inversion Table used in Experiment 1 was used in the current experiment.

Procedure

The procedural details for the first group for the current experiment were the same as they were for Experiment 1 with one exception. After we tilted participants backward and they estimated their perceived TP, we then tilted participants forward manually from their perceived TP with a rotational velocity of approximately 4–6° per second. Participants were instructed to tell the experimenter to stop when they felt like they were standing completely upright or perfectly vertical – at an angle of 0°. After doing this, we asked them to verbally estimate the angle that best approximated their TP.

In our second group, participants were randomly assigned to one of two conditions. They either: (1) drew a straight line to indicate the angle at which a person would have to be tilted backward in order to fall over and would no longer be able to return themselves to upright, or (2) imagined someone was in the inversion table and moved the inversion table backward from straight up and down without anyone in it until they felt like the inversion table was at the point where the person in it would no longer be able to return themselves to upright and would fall over backward. We explained that when a drawn line or the inversion table was vertical, the line or inversion table was defined to be at 0° and when the line or table was perfectly horizontal, it was defined to be at 90°. We did not proceed until all participants clearly understood the instructions.

Results

Verbal (conceptual) estimates of TP People's mean verbal (conceptual) estimate of their TP was 41.38° (SD = 24.23). A one-sample t-test showed that this was statistically close to 45°, $t(59) = -1.16$, $p = .252$.

Drawing a line to indicate the TP We measured the angle of the line drawn by participants to indicate the point at which someone would tip over and not be able to return to upright. The average angle of the line drawn (away from 0° or vertical) was 42.38° (SD = 22.87°). A one-sample t-test showed that the mean drawn TP was statistically close to 45°, $t(24) = -0.57$, $p = .57$.

Moving the empty inversion table backward to represent the TP We measured the angle of the inversion table at which people thought the TP would be best represented and converted each participant's estimate in degrees into radians. We then calculated the gain of the equivalent of 45° (or 1) by each estimate converted into radians (by dividing 1 by each participant's estimate). The average estimated TP gain of the empty inversion table was 1.69 (SD =0.62). Interestingly, a one-sample t-test showed that this value closely approximates the factor of 1.5, $t(23) = 1.5$, $p = .149$, similar to that found when people estimate inclined surfaces via verbal estimation (Bhalla & Proffitt, 1999; Creem-Regehr, Gooch, Sahm, & Thompson, 2004; Durgin et al., 2010; Durgin & Li, 2011; Hajnal, Abdul-Malak, & Durgin, 2011; Li & Durgin, 2010; Proffitt et al., 1995; Shaffer & Flint, 2011) visual matching (Bhalla & Proffitt, 1999; Proffitt et al., 1995), pedal perception (Hajnal et al. 2011), haptic perception (Shaffer & Taylor, 2016), remote haptic perception (Shaffer & McManama, 2015), downward gaze (Li & Durgin, 2009), and body proprioception (Shaffer et al., 2016). This is also indicative that people believe the TP to be about 45°, or halfway between vertical and horizontal.

Estimating TP while in the inversion table Participants indicated that they were at their TP when they were oriented at 14.98° (SD = 9.89°). While we did not measure participants' COM in this Experiment (and so could not calculate the actual TP for each of the participants), we compared their mean phenomenal TP to 8.75°, the average *actual* TP of the 42 participants from Experiment 1. A one-sample t-test indicated that participants significantly overestimated their TP, $t(59) = 4.88$, $p < .001$. This was a medium effect, Cohen's $d = 0.63$.

Estimating vertical while in the inversion table Participants estimated they were in a vertical position when they were oriented at 6.2° (*SD* = 3.74°). A one-sample t-test indicated that participants were tilted backward significantly away from vertical when they thought they were oriented vertically, $t(59) = 12.84$, $p < .001$. This was a large effect, Cohen's $d = 1.66$.

Comparing perceived TP to perceived vertical while in the inversion table We showed that people perceived vertical to be tilted farther backward than true vertical and that they also perceived their TP to be tilted farther backward than actual. Therefore, we tested whether there was a relationship between the two. Perceived TP significantly predicted perceived vertical, $F(1, 58) = 51.73$, $p < .001$ ($r(59) = .69$). Thus, it could be that observers base their perceived TP on an erroneous perception of vertical and so perceive their TP to be that much farther backward than actual. In order to test this, we calculated difference scores for each participant (perceived TP – perceived vertical). The mean of the difference scores was 8.78° (*SD* = 7.81°). A one-sample t-test showed that this was statistically similar to 8.75°, the average *actual* TP of the 42 participants from Experiment 1, $t(24) = 0.03$, $p = .97$.

Discussion

In Experiment 2 we first showed that people's conceptual idea of what the TP is seems to be ~45°, whether this is done by verbally estimating it conceptually, drawing it, or viewing what it would look like from the side. We then showed that people overestimate their TP, but also misestimate phenomenal vertical in the direction of their TP. The difference between these two matches the difference between the true TP away from true vertical. While people's intuitive beliefs of their TP are exaggerated, people's proprioceptive perception of their TP seems to be pretty accurate, at least as it relates to perceived vertical.

Experiment 3

In the previous experiments, participants estimated their TP from a starting position of true vertical and then were rotated backwards until they reach the perceived TP. The feeling of being tipped over may have been uncomfortable, so perhaps participants gave estimates when they did to stop the trial and end the unpleasant feeling of being tipped over. While the way we tested the TP in fact defines "TP" – that is, people cannot be tipped over backward by moving forward, in our previous work we have shown large effects of anchoring of hand/forearm starting position for orienting the hand/forearm to man-made and geographical hills alike (Shaffer, McManama, & Durgin, 2015; Shaffer, McManama, Swank, Williams, & Durgin, 2014). Thus, people's estimates of their TP may have been anchored to true vertical where they always began the trial. Additionally, in Experiment 2, the rotational velocity was the same backwards as it was forwards. Due to this, participants could have made the vertical judgment simply by trying to wait as long to respond as they did in making the TP judgment. Therefore, we felt it necessary to conduct Experiment 3 in order to account for potential anchoring biases present in Experiments 1 and 2 and to present participants with a condition where they could not rely on a temporal lag in one direction (to the TP) as they could in Experiment 2.

Participants

Fifty-four undergraduates (22 male) from the Ohio State University at Mansfield participated in the experiment in fulfillment of an Introductory Psychology requirement. Their mean age was 19.22 (*SD* = 1.69) years.

Materials and apparatus

Measuring the perceived TP and perceived vertical The same Teeter Hang-Ups NCT-S® Inversion Table used in Experiments 1 and 2 was used in the current experiment.

Procedure

The procedural details for the current experiment were the same as they were for Experiment 1 with two exceptions. First, participants were told when estimating their TP to estimate the point at which they could no longer hold themselves upright, without any ability to move their feet, or bend their knees to regain balance. That is, we made it clear they were to estimate at what point they thought they would tip over standing like they were if no one were there to hold them up. Second, participants were randomly assigned to one of two conditions. The first condition replicated the procedure of Experiment 1. Participants began at true vertical (upright), were tilted backward until they indicated their TP, and were then tilted forward until they indicated they were positioned at perceived vertical. In the second condition, participants began at true horizontal, were tilted forward until they indicated their TP, and then were tilted forward until they indicated they were positioned at perceived vertical.

Results

Condition 1 – Participants began at true vertical, were tilted backward until they were positioned at perceived TP, and then tilted forward until they were positioned at perceived vertical Similarities between Condition 1 of the current experiment and the inversion table condition in Experiment 2 are as follows. First, participants indicated that they were at their TP when they were oriented at 16.39° (*SD* = 10.03°) compared to

14.98° from the same procedure in Experiment 2. Second, participants estimated they were in a vertical position when they were oriented at 6.09° (*SD* = 1.06°) compared to 6.2° in Experiment 2. Third, perceived TP significantly predicted perceived vertical, $F(1, 17) = 11.38$, $p = .004$ ($r(17) = .633$) compared to $r = .69$ in Experiment 2. Finally, we calculated difference scores for each participant (perceived TP – perceived vertical). The mean of the difference scores was 10.3° (*SD* = 7.73°). A one-sample t-test showed that this was not statistically different from 8.75°, the average *actual* TP of the 42 participants from Experiment 1, $t(18) = 0.87$, $p = .393$.

Condition 2 – Participants began at true horizontal, were tilted forward until they were positioned at perceived TP, and then continued to be tilted forward until they were positioned at perceived vertical Participants indicated that they were at their TP when they were oriented at 39.04° (*SD* = 15.51°) compared to 16.39° from Condition 1. Participants estimated they were in a vertical position when they were oriented at 17.31° (*SD* = 9.55°) compared to 6.09° in Condition 1. As it did in Condition 1, perceived TP significantly predicted perceived vertical, $F(1, 16) = 81.97$, $p < .001$ ($r(16) = .92$). Finally, we calculated difference scores for each participant (perceived TP – perceived vertical). The mean of the difference scores was 21.73° (*SD* = 7.8°). A one-sample t-test showed that this was statistically different from 8.75°, the average *actual* TP of the 42 participants from Experiment 1, $t(17) = 7.07$, $p < .001$.

Combining data from Conditions 1 and 2 When we combined the data from Conditions 1 and 2, participants indicated that they were at their TP when they were oriented at 27.41° (*SD* = 17.19°). Participants estimated they were in a vertical position when they were oriented at 11.55° (*SD* = 9.03°). Perceived TP significantly predicted perceived vertical, $F(1, 35) = 187.73$, $p < .001$ ($r(34) = .92$). Finally, we calculated difference scores for each participant (perceived TP – perceived vertical). The mean of the difference scores was 15.86° (*SD* = 9.6°). A one-sample t-test showed that this was statistically different from 8.75°, the average *actual* TP of the 42 participants from Experiment 1, $t(36) = 4.51$, $p < .001$.

Do TPs across horizontal and vertical anchors represent people perceiving they are tilted backward at 45°? In Shaffer et al. (2016), people overestimated how much they were tilted backward when asked to estimate when they were tilted backward at angles between 8° to 45°. The slope of the line that best described the pattern of overestimations across these angles had a gain of 1.457, similar to the gain of 1.5 that has been found for near and far surfaces and for both geographical slopes outdoors as well as man-made slopes studied in laboratories (Li & Durgin, 2010; Shaffer et al., 2015; Shaffer & McManama, 2015; Shaffer & Taylor, 2016). These results are consistent with those of Li and Durgin (2009, Experiment 2B) who had people produce five different head-pitch orientations, one of which was 45°, while wearing a head-mounted display. They too produced a mean forward head pitch comparable to the 28.35° found in Shaffer et al. (2016) when our participants were asked to tell us when they were tilted backward at 45°. We argued that if people were overestimating how much were tilted backwards by a factor of 1.5, then one would expect them to say they were at 45° when they were only at ~30°, because if they were only at 30° they would *feel* like they were tilted much farther backward – at 45°. In order to test whether the results in Experiment 3 when accounting for anchoring might be consistent with the idea that participants were estimating their TP to be what they feel is ~45°, we compared the average TP estimate of 27.41° to 30° using a one-sample t-test and found them to be statistically similar, $t(36) = -0.92$, $p = .365$.

Discussion

Experiment 3 showed that anchoring biases influence people's phenomenal TP and vertical. When combining the data across starting positions, participants' estimates of TP reflect that they believe the TP to be about halfway between true horizontal and true vertical.

Typically, anchoring biases evaluate what are thought to be "arbitrary" anchors, but that may have a great influence on behavior. For instance, in our work showing anchoring biases for palm and hand and forearm maneuvers made to mimic man-made and geographic slopes, we showed that starting the position of palm/hand and forearm flat (or at perfectly horizontal) biases people to not move their hand as far away from the starting position as it might normally. The positions of the hand/forearm in these two cases also mimic everyday activities of holding your hand/forearm on a desk or raising our hands to ask questions or wave to others. In the case of estimating the TP, people are worried about tipping over from upright similar to Experiment 1 and Condition 1 of Experiment 3, and not worried about tipping upward from a lying down horizontal position to what is perceived as their TP. If we were investigating people trying to position themselves in the inversion table at different angles, then starting position is arbitrary, and accounting for anchoring biases (as we did in Shaffer et al., 2016) would be relevant/necessary. Thus, it seems that if we are trying to identify people's TP as a more generic angle among all of the angles possible, then we certainly want to account for possible anchoring biases. However, in evaluating the TP the vertical starting position is not arbitrary, so it seems that the methodology employed in Experiment 1 might better fit the question that we are trying to answer regarding the TP, which is defined as the earliest point at which you are tilted backward from upright and are no longer able to return to upright (Cholewiak et al., 2013; Firestone & Keil, 2016).

Experiment 4

In each of the previous experiments, an inversion table was used. The inversion table rotates about the center (roughly the hips or waist of the participants) with the participants feet on a platform that rotates with the device, not rotated at the feet. In order to make the task more like the task of standing and tilting backward, we created a device that allowed us to do this to investigate whether there was a fundamental difference between phenomenal TP when being tilted about the feet rather than about the waist or hips.

Method

Participants

Fifty-one undergraduates (16 male) from the Ohio State University at Mansfield participated in the experiment in fulfillment of an Introductory Psychology requirement. Their mean age was 19.46 (*SD* = 3.33) years.

Materials and apparatus

Measuring the perceived TP and perceived vertical We attached a 1.83-m high Pro-Standard spinal board to a 1.32-m high Uline Loop Handle aluminum hand truck with two fastener belts. We placed a 0.61m × 1.22m piece of wood behind the wheels of the hand truck to prevent any slippage of the wheels. The apparatus is shown in Fig. 5.

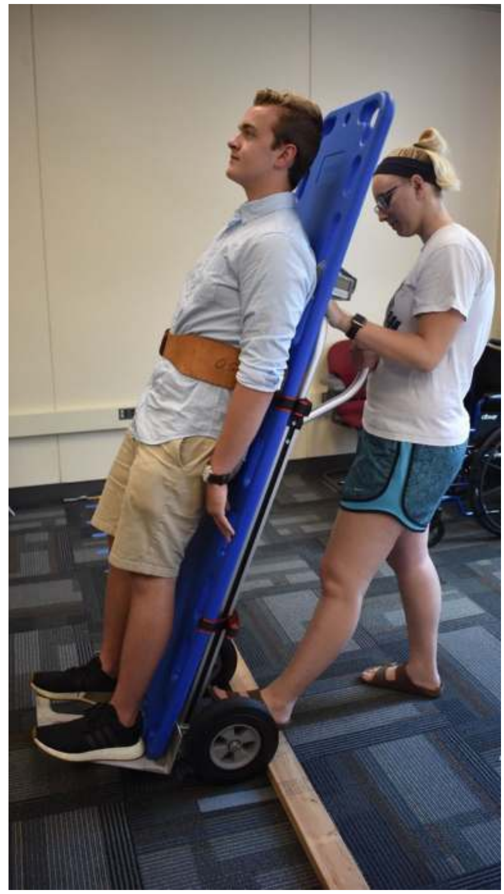

Fig. 5 Shown is the tilting apparatus

Procedure

The procedural details for the current experiment were similar to those for Experiment 3 with three exceptions. First, we used a spinal board attached to a hand truck as shown in Fig. 5. Second, for the condition where we started them tilted backward, we tilted them backward at 20°. This was because it was too difficult to start from any further backward and still be able to move them smoothly at the same rate as we did in the previous experiments. Finally, between estimates we stood participants straight up again. This was for two reasons. First, we wanted to prevent participants from using a time frame in making their second estimate. For instance, if one just waited to see how long it took to make their TP estimate, they could simply wait that long again to make their vertical estimate (if that was their second estimate). Related to this, we wanted to reduce any possible carryover effects. This is because in the previous experiments, participants were making relative judgments that may have been influenced by when or how they indicated their first estimate. This way, we could get more absolute judgments of TP and vertical that were less dependent on one another. Second, we were concerned that participants might be uncomfortable in the apparatus and may give earlier estimates due to that. Participants were randomly assigned to one of two conditions. In the first condition participants began at true vertical (upright), were tilted backward until they indicated their TP, and then were returned to upright. They were then tilted backward until they were at 20° and were tilted forward until they indicated they were vertical. In the second condition, participants began at 20° backward, were tilted forward until they indicated their TP, and were returned to upright. They were then again tilted 20° backward and were tilted forward until they indicated they were positioned at perceived vertical.

Results

Nine participants indicated that their perceived vertical was further backward than their perceived TP. Their data wdere removed and we proceeded performing analyses on the remaining 51 participants.

Analysis of differences across conditions We first performed an independent-samples t-test to see whether there were differences between TPs across starting point conditions. An independent-samples t-test indicated no statistical difference between conditions, $t(49) = 1.79$, $p = .081$, $M_{0°=}15.55°$

(SD=6.3°), $M_{20°}$=12.81° (SD=4.3°). A separate independent-samples t-test comparing vertical estimates found a small difference across starting point conditions, $t(49) = 2.39$, $p = .021$, $M_{0°=}$7.34° (SD=2.99°), $M_{20°}$=5.49° (SD=2.52°). This was a small effect, $R^2 = .1$. Due to the fact that the effect was small, the difference in angles was only 1.85°, and the vertical estimates from both conditions together averaged 6.42°, very close to the 6.2° estimate from Experiment 2, we collapsed across conditions for the remaining analyses.

Similarities between the inversion table condition in Experiment 2 and the current hand truck experiment are the following. First, participants indicated that they were at their TP when they were oriented at 14.1° (SD = 5.46°) compared to 14.98° from the same procedure in Experiment 2. This significantly overestimated participants' actual TP from Experiment 1 (8.75°), $t(50) = 7$, $p < .001$, and this was a large effect, *Cohen's d* = 0.98. Additionally, another one-sample t-test showed that there is no difference between TP estimates between groups tipped with the inversion table or the hand truck apparatus, $t(50) = -1.15$, $p = .254$. Second, participants estimated they were in a vertical position when they were oriented at 6.36° (SD = 2.88°) compared to 6.2° in Experiment 2. This significantly overestimated true vertical, $t(50) = 15.78$, $p < .001$, and this was also a large effect, *Cohen's d* = 2.21. Additionally, another one-sample t-test showed that there is no difference between estimates of vertical between groups tipped with the inversion table or the hand truck apparatus, $t(50) = 0.4$, $p = .692$. We next performed a regression analysis, which showed that perceived TP significantly predicted perceived vertical in the hand truck apparatus, $F(1, 49) = 11.45$, $p = .001$ ($r(49) = .435$), similar to the inversion table ($r = .69$ in Experiment 2). Finally, we calculated difference scores for each participant (perceived TP – perceived vertical). The mean of the difference scores was 7.74° (SD = 4.94°). A one-sample t-test showed that this was not statistically different from 8.75°, the average *actual* TP of the 42 participants from Experiment 1, $t(50) = -1.47$, $p = .149$.

Discussion

Experiment 4 showed that participants perceived the TP in the hand truck apparatus similar to how participants perceived the TP when they were tilted backward in the inversion table in Experiment 2. Using the hand truck in Experiment 4 also yielded similar results for vertical estimates as were found for vertical estimates while in the inversion table in Experiment 2. These results indicate that whether being tilted backward about the feet (as in the hand truck apparatus), or about the hips/waist (as in the inversion table) participants give similar estimates of their TP and perceived vertical.

General discussion

In the present work we have shown that people's intuitive beliefs about the TP seem to center around an explicit 45° when people verbally estimate the TP or draw the TP, and a perceived 45° when people view what the TP should look like from a side perspective or are tilted to their phenomenal TP while accounting for anchoring biases. However, when taking a more implicit measure like estimating their own COM, or a difference measure between two conscious estimates of phenomenal TP and vertical, the converted estimates are actually quite close to their actual TP, so long as estimates are all taken from the vertical starting position. This difference between perception and action found in Experiment 1 where people overestimated their TP consciously, but more accurately identified it indirectly with the estimated COM, is found in many domains including slant perception, where overestimating geographical and man-made slopes upward from horizontal by a factor of 1.5 does not make it difficult to climb different slopes (Bhalla & Proffitt, 1999; Durgin & Li, 2011; Durgin et al., 2010; Li & Durgin, 2010; Proffitt et al., 1995; Shaffer & McManama, 2015; Shaffer & Taylor, 2016; Shaffer et al., 2016) and intuitive beliefs about the flight of objects where misidentifying the apex and landing location of fly balls does not influence people's ability to catch fly balls as a different implicit strategy is used to do that (McBeath, Shaffer, & Kaiser, 1995; Shaffer & McBeath, 2005; Shaffer, Maynor, Utt, & Briley, 2009).

We feel that the answer to the question of what people's phenomenal TP is based on –perceived 45° between horizontal and vertical or the difference between phenomenal TP and vertical – depends on the question that one is asking. If the question concerns what is the TP of someone in space, or the point at which someone would more likely turn upside-down on a trapeze compared to holding themselves up, then we feel like anchoring biases should be accounted for because the coordinates for vertical are arbitrary. However, if you want to know the phenomenal point at which adults or infants feel they will no longer be able to hold themselves upright, then we feel that all of the estimates should be made from vertical. In this case, it should be recognized that the phenomenal TP is a conservative estimate of TP away from vertical due to the fact that estimates will undoubtedly be anchored in that direction to at least some degree. We have also shown that perceived TP and perceived vertical are estimated similarly whether one is being tilted about the feet or about the waist/hips. This points to a more universal understanding of or strategy for identifying perceived TP and perceived vertical.

The results from these studies have very practical applications. First, according to the CDC, falls are the leading cause of injury and death in older Americans (Centers for Disease Control, 2016). While decreased mobility and muscle weakness are certainly large contributors to this, it may also be that as we age our perceived COM is less accurate or our perceived vertical becomes farther away from true vertical, or that we can no longer correct for the discrepancy between true vertical and what we perceive as vertical. Second, since perceived vertical is tilted slightly backward from true vertical, this has implications for the designs of furniture, stadium seating, car seats, and car seat adjustments.

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