Memory for target height is scaled to observer height

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Abstract According to the embodied approach to visual perception, individuals scale the environment to their bodies. This approach highlights the central role of the body for immediate, situated action. The present experiments addressed whether body scaling—specifically, eye-height scaling—occurs in memory when action is not immediate. Participants viewed standard targets that were either the same height as, taller than, or shorter than themselves. Participants then viewed a comparison target and judged whether the comparison was taller or shorter than the standard target. Participants were most accurate when the standard target height matched their own heights, taking into account postural changes. Participants were biased to underestimate standard target height, in general, and to push standard target height away from their own heights. These results are consistent with the literature on eye-height scaling in visual perception and suggest that body scaling is not only a useful metric for perception and action, but is also preserved in memory.

Keywords Memory · Body scaling · Eye-height scaling · Embodied cognition

In recent years, the “embodied” approach to understanding cognition has been applied to a range of domains, such as perception, language, emotion, social cognition, and mem-

ory (for reviews, see Barsalou, 2008; Fischer & Zwaan, 2008; Glenberg, 2010). A central claim in this approach is that cognition is grounded in the body, such that psychological processes are shaped and constrained by individuals’ morphologies, physiologies, and emotional states.

One example, from the domain of visual perception, is body scaling. Body scaling is one way to address the problem of how optical information, which consists of visual angles and changes in visual angles, can be transformed into units that specify surface layout. For example, in order to perceive extent and size, visual angles need to be transformed into distance-appropriate units. If a key purpose of visual perception is to guide action, then the body is an appropriate metric for scaling the environment. Evidence for such body scaling comes from studies in which individuals have scaled the size of graspable objects to hand size (Linkenauger, Witt, Bakdash, Stefanucci, & Proffitt, 2009), the distance to objects in near space to arm length (Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989; Linkenauger et al., 2009), and the heights of objects to eye height (EH; Sedgwick, 1973). Morphology—specifically, EH—is one way in which visual perception is influenced and body scaled. But a number of other factors that are not morphological affect perception and action capabilities as well. For example, participants who are fatigued (Bhalla & Proffitt, 1999) or have low levels of energy (i.e., blood glucose) perceive hills to be steeper than do unencumbered individuals (Schnall, Zadra, & Proffitt, 2010). In these cases, morphology remains constant, yet action capabilities and perceptions are still altered.

To date, the research on body scaling in visual perception has emphasized the importance of the body for immediate, situated action. However, if body scaling is involved in cognition more broadly, then we would expect to find a role of the body even when immediate action is

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not the goal. Some evidence for embodiment and non-immediate action comes from the language literature. For instance, merely listening to action-related sentences that describe hand or foot movements elicits changes in motor cortex activity for the effector mentioned in the sentence (Buccino et al., 2005). In addition, using transcranial magnetic stimulation to excite the hand or foot area of the motor cortex leads to faster recognition of hand- or foot-related action words, respectively (Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005). These studies suggest that the body may be important for cognition even when there is no immediate action. This raises the question of whether body scaling, an important metric for perception and action, is a useful metric within memory.

Contrary to the popular belief that memory is purely about storing information, Glenberg (1997) has proposed that memory instead “evolved in service of perception and action in a three-dimensional environment, and . . . memory is embodied to facilitate interaction with the environment” (p. 1). If the purpose of memory is to serve perception and action, then one should expect body scaling to affect memory. Several accounts from the memory literature provide insight into why a particular process used during perceptual encoding might be utilized during memory storage and retrieval. According to proponents of the *proceduralist* approach, the same neural pathways that are activated during perceptual encoding are activated during memory storage and retrieval (Cowan, 2003). A reasonable assertion would be that, if an object is perceived in terms of body-scaled units (e.g., EH), that process of scaling will be maintained in memory, because the perceptual and memory representations share the same neural network. A second explanation is provided by proponents of the *episodic processing* approach, who propose that the manner in which an experience is processed during perception (including task demands, context, affordances, etc.) will be maintained in memory (Whittlesea & Dorken, 1993). According to this account, individuals will recall object height using the same information that was used during the perceptual encoding experience.

The aim of this study was to explore the relationship between memory and body scaling by taking an established example of body scaling in visual perception—namely, EH scaling—and assessing whether it is preserved in memory.

Eye-height scaling in perception

In any given environment, many contextual cues are available that correlate with object size, such as texture gradient, relative size, and familiar size. EH, which coincides with the horizon, is one source of information

that is especially useful in perceiving the relative sizes of objects (Bertamini, Yang, & Proffitt, 1998; Sedgwick, 1973). Perspective structure and optic flow define EH as a boundary such that EH creates a discontinuity in space. All parallel contours in a scene (except those normal to the line of sight) converge at the horizon, and for a forward-moving observer, all optically specified texture elements above EH move up, whereas those below EH move down.

Bertamini, Yang, and Proffitt (1998) showed that observers are sensitive to EH when making relative height judgments. Their participants viewed two targets simultaneously and judged which target was taller. The participants completed trials both while seated and while standing, and target heights were close to either their seated or their standing EHs. Presumably, if participants scale object height to their EHs, then targets near their EHs should be easier to discriminate than targets that are taller or shorter than their EHs. As expected, participants discriminated the two target heights more accurately when the targets were near their current EHs, relative to when the targets were much shorter or taller than their current EHs. Bertamini et al. proposed that EH serves as a reference line when making relative judgments about target height. When two targets deviate from this reference, accuracy declines (see Fig. 1).

Second, manipulating individuals' EHs influences judgments of object height. Participants overestimated object height when their EHs were artificially lowered in a virtual environment, relative to when their EHs were not adjusted (Dixon, Wraga, Proffitt, & Williams, 2000). This study showed that people scale the height of objects to their EH.

Finally, EH is used to determine individuals' action capabilities. Mark (1987) had participants judge whether they could sit on or step onto a surface. He found that variability in perceived maximum seat height and perceived maximum step height was accounted for by the participants' EHs. When the participants' EHs were raised, by attaching wooden blocks to the bottoms of their feet, maximum seat and step height changed as a constant proportion of EH. Presumably, participants scaled seat and step height to their EHs in order to determine whether it was possible to sit on or step onto the surface.¹ Similar findings have been shown for judgments of “step-on-ability” and “step-over-ability” by children 6, 8, and 10 years of age (Pufall & Dunbar, 1992).

¹ This study also highlighted that a given change in EH would affect different action capabilities in unique ways. That is, standing on blocks raises EH, which increases actual maximum seat height but does not affect actual maximum step height. For the first few trials at their new EH, participants based their judgments on their actual EH. However, over multiple trials, participants recalibrated their judgments to their new EH; step affordance judgments decreased, and seat affordance judgments increased.

Fig. 1 Three situations of varying difficulty for making relative height judgments. In all three panels, the target on the right is farther away and shorter than the target on the left. Panel A depicts a context-free environment. In this scenario, it is difficult to discriminate target heights, because there is minimal information specifying the distance and size of the object. Panels B and

C depict an environment with the horizon (or eye height) specified, which can be used as a reference to improve discrimination accuracy. The discrimination judgment is easier in panel C than in panel B, because the heights of the target poles differ categorically relative to eye height: One is taller, the other shorter

These studies highlight that observers are sensitive to EH and use EH as information to judge object size. To understand how EH can then be used to scale object size, we turn to the work of Sedgwick (1973), who first formalized EH scaling by noting that when observers are standing on the same, flat ground plane as an object, their straight-ahead gazes will intersect with the horizon line. Furthermore, the observers' EHs and the horizon line are invariant sources of information that can be used to scale objects. Specifically, object height can be scaled as a ratio of A/B , where A is the extent from the observer's EH to the top of the object and B is the extent from the observer's EH to the ground (see Fig. 2). This A/B ratio remains constant with viewing distance and is specified

Fig. 2 Depiction of how observer eye height (EH) is used to scale object height. A = height from the observer's EH to the top of the object, B = observer EH, a = visual angle subtended by the top of the object to the observer's EH, and b = visual angle from the observer's EH to the ground. Adapted from Wraga (1999)

by a ratio of trigonometric functions applied to the visual angles relating the top and the bottom of the object to the horizon.

When two targets are placed at different distances from the observer (as in the Bertamini et al., 1998, experiments), unless one target is above EH and the other below, as in Fig. 1C, the observer must compare the A/B ratios between the two targets in order to discriminate object height. In a situation in which two targets are equidistant from an observer (as in the present study), the observer can judge relative size in two ways. First, the observer can notice whether one target is above and another target is below EH, as in Fig. 1C. Second, if both targets are above or below EH, the observer determines which extent between EH and the top of each target is greater. This extent is the A in the A/B ratio. Thus, for objects at the same observer-relative distance, relative size judgments can be based solely on A . The closer that targets are to EH, the smaller will be the absolute value of A , and thus, the larger will be the discrepancy between the two targets relative to A . For example, if $A = 10$ and 11 inches, respectively, for two targets, their relative difference is $10/11$, which is a small ratio. However, if the A s for the two targets are 1 and 2 inches, respectively, their relative difference is $1/2$, which is a large ratio difference and makes for an easier discrimination. Therefore, relative size judgments should be more accurate for targets near EH than for targets not near EH.

Object height is not always scaled to EH. First, the use of EH scaling depends on the height of the object. Specifically, Wraga and Proffitt (2000) found that effective EH scaling occurred when targets were near 1 EH, and EH scaling was not used for targets that were below 0.2 EH or above 2.5 EH. When targets were beyond this range, other sources of information, such as linear perspective, were

used for scaling. This claim is consistent with research by Wraga (1999), who found that object height was scaled to EH when participants were seated and standing, but not when participants were lying on the ground. Additionally, individuals do not use EH to scale object height when they do not perceive themselves to be immersed in the scene. That is, virtually manipulating participants' EHs had no effect on perceived object height when the objects were presented on a computer desktop (Dixon et al., 2000). These data suggest that the visual system's use of EH is flexible and depends on context.

Thus far, the research on EH scaling has suggested that when making online perceptual judgments about object height, EH is an influential source of information. What is unknown is whether EH scaling is preserved in memories of perceived object height. It seems reasonable that if EH affects perceived object height, this scaled information should be stored in memory, potentially to be used for acting in the future.

Body scaling in memory

There are, however, reasons to suspect that body scaling might not be preserved in memory. One reason is that body scaling is important for action planning in the present situation; therefore, its efficacy in visual perception is obvious. Individuals perceive spatial layout relative to their bodies to determine what actions are possible, given bodily constraints. However, with memory, no immediate action is required, so the body may not be an appropriate scalar. Furthermore, bodies move and change position over time, so that something viewed from a standing perspective may later be retrieved while sitting or lying down. It may not be valuable, and could be disruptive, to use the body's position at one time to encode information that will be retrieved later in another position. In such cases, size and extent may be remembered relative to the environment, in a perspective-invariant manner. For instance, when recalling the size of an office chair, its height may be remembered relative to the desk rather than to EH or leg length.

Overview of the present research

The literature on embodied cognition, language, and memory has suggested a role of the body in cognition, even when no immediate action is required. What is missing is strong evidence for a link between perception, memory, and body scaling. Specifically, research on body scaling and perception has suggested that individuals' perceptions are influenced by their bodies and by what actions are possible given a specific context (Linkenauger et al., 2009; Schnall et al., 2010). It is

not a far leap, then, to suppose that, just like perception, memories are constrained by how individuals' bodies can interact with the environment. Knowing that we scale objects to our bodies, even when action may be delayed, has the potential to reshape our understanding of how memory can guide action, in addition to better defining the scope and influence of body scaling on cognition.

In Experiments 1 and 2, we assessed whether individuals use their EHs to scale object height in memory or whether EH scaling is limited to perception. Recall that Wraga and Proffitt (2000) found that participants were most accurate for perceived object height when the targets matched participants' own EHs. If EH is also used when remembering object height, then participants should be most accurate when the to-be-remembered object height is equal to their own height, and accuracy should decline as deviations between object and participant height increase. If EH is not used during memory judgments of object height, this would suggest that body scaling may be specific to perception.

Experiment 1: The effect of observers' standing heights on memory for target height

In Experiment 1, participants viewed a target (standard) that was shorter than, taller than, or the same height as themselves. Participants then turned around to view a second target of varying height (comparison) and indicated whether the comparison target was shorter or taller than the standard target. The purpose of this experiment was to determine whether memory for the standard target height would be influenced by participant height. Because perceived object height is most accurate at EH, we hypothesized that participants would be most accurate discriminating target height from memory when the standard target height equaled their own heights, as opposed to when the standard target height differed from participants' heights.

Method

Participants Thirty-seven (10 male, 27 female) University of Virginia students participated in the experiment for course credit. One participant was removed from the data analysis due to an inability to maintain a consistent standing posture, leaving 36 participants for the analysis. All participants had normal or corrected-to-normal vision.

Materials Ten targets (five standard and five comparison) were created for Experiment 1. Each target consisted of a target stick (i.e., PVC pipe) that was inserted into a metal base and a schematic image of a face that was attached to the top end of each target stick (see Fig. 3).

Fig. 3 Experimental setup for Experiments 1 and 2. For each trial, participants viewed the standard target, turned to view the comparison target, judged whether the comparison target was shorter or taller than the standard target, and gave a confidence rating. In Experiment 2, participants were seated for half of the trials

Holes were drilled into the vertical part of each metal base (25.7 cm wide $\times$ 63.2 cm tall) at 1.3-cm increments. Fine adjustments could be made to the target heights by inserting a peg into the different holes and placing the target stick on top of the peg. Gross adjustments to target height were made using target sticks of different lengths, ranging from 91.4 to 213.4 cm, in 30.5-cm increments. The possible range of the standard and comparison target heights was 94.5–250.2 cm. The schematic image of a face was used in order to make the targets more “human-like” and to allow participants to make “eye contact” with the target. The top of the face was aligned with the top of the target stick, and the face had normal human face dimensions (22.9 cm in length, 15.2 cm wide, 10.2-cm forehead).

The bases of the standard and comparison targets were 87.6 cm apart, and participants stood in between both targets. When facing each target, the distance between the participant’s toes and the base of the target was 30.5 cm. The experiment took place in a working lab that had other equipment in the room. The backgrounds behind the standard and comparison targets were very different, so that participants could not use shared landmarks (e.g., where a cabinet intersected the target stick) as references for judging the target heights.

Design On each trial, participants viewed a standard target followed by a comparison target, in order to judge whether the comparison target was shorter or taller than the standard target. The standard and comparison target heights were determined on the basis of each participant’s height, which was measured at the beginning of the experiment. Participants viewed standard targets that were either equal to the participant’s height or 15.2 cm taller, 15.2 cm shorter,

30.5 cm taller, or 30.5 cm shorter than the participant. The comparison target was either the same height as or 1.3 cm taller, 1.3 cm shorter, 2.5 cm taller, or 2.5 cm shorter than the standard target. Each of the five standard target heights was paired with each of the five comparison target heights, for a total of 25 randomized target pairs per participant. Participants viewed each pair once, for a total of 25 trials per participant. Participant heights ranged from 154.9 to 193 cm ($M = 170.3$ cm).

Procedure Participant height was measured at the start of the experiment. Before each trial, participants closed their eyes while the experimenter placed the standard and comparison targets at the appropriate heights.² At the experimenter’s instruction, participants viewed the standard target for 3 s. Participants then closed their eyes and turned 180° to face the comparison target. Participants closed their eyes and kept them closed while turning to face the target, and then viewed the comparison target and indicated whether that target was shorter or taller than the standard

² The present experiments were not double blind, due to experimental constraints. However, several measures were taken to ensure that unintentional experimenter biases were reduced. First, experimenters followed a written script to ensure that all participants received the same set of instructions. In addition, the experimenters stood outside of the participant’s line of sight while the participant made judgments. Finally, to adjust target heights, experimenters referred to where a peg should be inserted into a hole on the target stand and what length of pole should be inserted into the target stand, rather than to the absolute heights of the targets. One experimenter changed the height of the standard target, and a second experimenter adjusted the height of the comparison target. These two factors reduced the chance that any experimenter would take notice of whether the current trial was *same* or *different*, because the experimenters attended to unique targets identified by arbitrary numbers.

target. Participants also indicated how confident they were in their judgments, using a scale from 1 (*not at all confident*) to 7 (*very confident*). After making the shorter–taller judgment and confidence rating, participants closed their eyes, faced the standard target, and waited for the experimenter to change the standard and comparison target heights for the next trial.

Results

Separate analyses were conducted to assess how participant height affected the accuracy and bias of target height from memory. A total of 12 trials (0.01% of the total trials) were removed from the data analysis, due to experimenter error in setting the target heights, and were replaced by the group mean for that condition. Degrees of freedom were corrected using the Greenhouse–Geisser method for correlated measures (Greenhouse & Geisser, 1959).

Accuracy If EH was used as a reference to discriminate between target heights in memory, then participants should be most accurate when the standard target height equaled the participant's own height. Performance should decline when the standard target height differed from the participant's height by 15.2 cm, and should be worst when the standard target height differed by 30.5 cm. All trials were excluded in which the standard and comparison targets were the same height, because for those trials, the correct answer was not a possible response option, given that participants were forced to choose “shorter” or “taller.”

Accuracy weighted by confidence Judgments were weighted according to confidence ratings, so that a correct judgment in which a participant was very certain (confidence rating = 7) could be differentiated from a correct judgment in which the participant was very uncertain (confidence rating = 1), with the same logic for incorrect judgments.³ Given two dichotomous judgments (shorter or taller) and seven confidence ratings (1–7), there were a total of 14 possible judgments. Thus, accuracy judgments ranged from 0 (*incorrect but very certain*) to 1 (*correct and very certain*) in 14 increments.⁴ All analyses were also conducted using proportion correct data (i.e., unweighted accuracy), and those results are reported in the [Appendix](#).

³ Accuracy weighted by confidence judgments is a more sensitive measure when making dichotomous judgments, and therefore is a useful method of analyzing the present data. Weighted accuracy is commonly used in psychophysical research in which participants are forced to choose between two options (Gescheider, 1976; Green & Swets, 1974; Strange & Halwes, 1971).

⁴ To calculate weighted accuracy, the following equations were used: For correct judgments, weighted accuracy = $.5 + [(1/14) * \text{confidence rating}]$. For incorrect judgments, weighted accuracy = $.5 - [(1/14) * \text{confidence rating}]$.

Weighted accuracy was assessed using a 5 (standard target height) $\times$ 4 (comparison target height) repeated measures analysis of variance (ANOVA).⁵ Standard target height was coded relative to participant height (i.e., ± 30.5 cm, ± 15.2 cm, and same height), and comparison target height was coded relative to the standard target height (i.e., ± 2.5 cm, ± 1.3 cm). As predicted, there was a significant main effect of standard target height, $F(4, 136) = 3.40$, $p = .011$, $\eta^2 = .09$ (see Fig. 4a). Accuracy when the standard target height equaled participant height was compared to the four other standard target heights. Planned contrasts revealed that participants were significantly more accurate when the standard target equaled the participant's own height, as compared to when the standard target was 15.2 cm shorter, $F(1, 34) = 4.63$, $p = .039$, $\eta^2 = .12$; 15.2 cm taller, $F(1, 34) = 4.31$, $p = .046$, $\eta^2 = .11$; and 30.5 cm taller, $F(1, 34) = 11.45$, $p = .002$, $\eta^2 = .25$. However, weighted accuracy did not differ significantly on trials in which the standard target equaled the participant's height, as compared to when the standard target was 30.5 cm shorter than the participant.

There was a significant main effect of comparison target height, $F(2.34, 79.38) = 12.37$, $p < .001$, $\eta^2 = .27$. Larger discrepancies between standard and comparison target heights produced more accurate discrimination than did small differences.⁶ Finally, there was a significant interaction between standard and comparison target height, $F(7.65, 260.08) = 2.27$, $p = .025$, $\eta^2 = .06$. This interaction indicated that comparison target height had different effects on weighted accuracy, depending on which standard target height was presented. In general, accuracy was worst when the comparison target was 1.3 cm shorter than the standard target height, with the exception of when the standard target was 30.5 cm taller than the participant (in which case, accuracy was worst when the comparison target was 1.3 cm taller than the standard target).

Confidence There was a significant association between accuracy and confidence judgments, $\chi^2(6) = 25.91$, $p < .001$. Participants were significantly more confident on trials in which they made a correct judgment ($M = 4.12$, $SE = .16$), as compared to when they made an incorrect judgment ($M = 3.51$, $SE = .17$), $t(35) = -5.98$, $p < .001$, paired-samples t test.

⁵ Gender was a significant covariate, $p = .05$, and was included in the model (the pattern of results remained the same without including this covariate). Overall, males performed better than females.

⁶ Planned contrasts confirmed that participants were significantly less accurate when the comparison target was 1.3 cm shorter than the standard target, as compared to when the comparison target was 2.5 cm shorter, $F(1, 34) = 20.03$, $p < .001$, $\eta^2 = .37$. Participants were also less accurate when the comparison target was 1.3 cm taller than the standard target, as compared to when the comparison target was 2.5 cm taller, $F(1, 34) = 7.84$, $p = .008$, $\eta^2 = .19$.

Fig. 4 Mean weighted accuracy (a) and mean weighted bias (b) as a function of the height difference between the standard target and the participant. Error bars denote one standard error. In graph b, the dotted line represents no bias. Values above this line indicate a bias to respond that the comparison target was “taller” than the standard target, and values below this line indicate a bias to respond “shorter”

In summary, memory for target height was influenced by the relationship between participant height and standard target height, which is consistent with the proposal that EH may be used as a reference line and used for object scaling in memory. Specifically, target discrimination was worse when the standard target was 30.5 cm taller, 15.2 cm taller, and 15.2 cm shorter than the participant’s height, relative to when the standard target height equaled the participant height. However, performance was comparable when the standard target equaled the participant height and when the standard target was 30.5 cm shorter than the participant. This may be due to the fact that EH still serves as a fairly reliable reference line for targets within the range used in this experiment. Larger target differences were used in Experiment 2 to address this potential limitation.

Bias A secondary goal of this study was to explore whether individuals were biased when discriminating target heights from memory. Memory delay introduces uncertainty and a possible reliance on other sources of information, such as context and prior knowledge (e.g., Bartlett, 1932; Graesser, Woll, Kowalski, & Smith, 1980; Mandler & Ritchey, 1977).

It seems reasonable that individuals might systematically (but unintentionally) bias height estimates when there is no direct, online feedback. That is, do individuals have a general tendency to underestimate or overestimate target height from memory, and is this bias influenced by the relationship between participant and target height?

Judgments were weighted according to confidence ratings, as in the accuracy analysis. The 14 possible judgments ranged from 0 (*shorter and very certain*) to 1 (*taller and very certain*) in 14 increments.⁷ Values below .5 indicated a bias to respond that the comparison target was “shorter” than the standard target, and values above .5 indicated a bias to respond “taller.” Thirteen trials (0.02%) were removed due to experimenter error and were replaced by the sample mean for that trial type.

Weighted bias was assessed using a 5 (standard target height) $\times$ 5 (comparison target height) repeated measures ANOVA. All trials were included in this analysis. The pattern of results suggested that memory for standard target heights was biased so that participants overestimated targets that were taller than themselves and underestimated targets that were shorter than themselves, pushing target heights away from their own heights in memory. This was evidenced by a significant main effect of standard target height, $F(4, 140) = 5.91, p < .001, \eta^2 = .15$ (see Fig. 4b). Bias when the participants’ heights and standard target heights were equal was compared to all other standard target heights. Contrasts revealed that participants were significantly more likely to respond that the comparison target was “taller” when the standard target was 15.2 cm shorter than the participant, as compared to when the standard target was the same height as the participant, $F(1, 35) = 6.43, p = .016, \eta^2 = .16$. As depicted in the left panel of Fig. 5, when participants viewed a standard target that was shorter than themselves, they underestimated the standard target height in memory, pushing the target’s height down, away from their own EHs (indicated by the dashed-line target). Consequently, participants were biased to respond that the comparison target was taller than the standard target. Participants were also significantly more likely to respond that the comparison target was “shorter” when the standard target height was 30.5 cm taller than the participant, relative to when the standard target was the same height as the participant, $F(1, 35) = 4.12, p = .05, \eta^2 = .11$. This effect is depicted in the right panel of Fig. 5. When participants viewed a standard target that was taller than themselves, they overestimated the standard target height in memory (indicated by the dashed-line target), pushing the standard target’s height up, away from their

⁷ To calculate weighted bias, the following equations were used: For taller judgments, weighted bias = .5 + [(1/14) * confidence rating]. For shorter judgments, weighted bias = .5 - [(1/14) * confidence rating].

Fig. 5 Depiction of the bias in Experiment 1. In the left panel, a participant views a standard target that is shorter than himself. Participants underestimated the standard target height in memory, and consequently were biased to respond that the comparison target was taller than the standard target. The right panel depicts the opposite scenario

own EHs. As a result, participants were biased to respond that the comparison target was shorter than the standard target.

There was also a significant main effect of comparison target height, $F(4, 140) = 87.45$, $p < .001$, $\eta^2 = .71$. This effect was not surprising, since we would expect that when the comparison target was actually taller than the standard target, participants would respond “taller” more often than “shorter,” which planned comparisons (Bonferroni correction) confirmed. There was also a significant interaction between standard target height and comparison target height, $F(16, 560) = 1.87$, $p = .02$, $\eta^2 = .05$. Overall, participants seemed to underestimate the standard target height ($M = .55$), $t(35) = 3.45$, $p = .001$.

The results from Experiment 1 suggest that individuals’ bodies influence memory for object height. First, accuracy for target discrimination was affected by a participant’s own height, so that accuracy was worst when the standard target was 30.5 cm taller than the participant. Participants were more accurate when the standard target equaled the participant’s height, as compared to when the standard target was 15.2 cm shorter or taller or was 30.5 cm taller, but not when the standard target was 30.5 cm shorter. Second, memory for target height was biased depending on the relationship between standard target height and participant height. That is, when the standard target was shorter than the participant, participants remembered the standard target as being shorter than its actual height. When the standard target was taller than the participant, participants remembered it as being taller than its actual height. This suggests that participants were biased to push standard target heights in memory away from their own heights. To obtain further evidence that object height was scaled to the body in memory, a wider range of target heights was used

in Experiment 2, and participant height was manipulated directly.

Experiment 2: Effect of observers’ seated versus standing heights on memory for target height

In Experiment 2, participants’ heights were manipulated by having the participants judge the heights of targets while standing versus sitting down. The purpose of this manipulation was to assess how the body influences memory for target height across a wider range of target heights, and also to determine the impact of postural changes.⁸ The literature on EH scaling and size perception has provided evidence that the system is flexible in this respect, so the hypothesis was that memory for target height would be best at participants’ current heights. That is, when participants were seated, accuracy would be best when the standard target matched the participant’s seated rather than standing height, and conversely, when participants were standing, accuracy would be best when the standard target matched the participant’s standing rather than seated height.

Method

Participants Thirty-two (17 male, 15 female) University of Virginia students participated in the experiment for course

⁸ In this study, we did not distinguish between EH and point of observation. See Warren and Whang (1987) for more information on how these can be dissociated by implementing subtle manipulations such as a false floor, which affects EH but not point of observation.

credit. All participants had normal or corrected-to-normal vision.

Materials The targets and experimental setup were the same as in Experiment 1. The only exception was that during the seated condition, participants sat in a rotating office chair, allowing them to view the standard target and then turn to face the comparison target while remaining seated. The center of the chair was placed equidistant from the standard and comparison targets.

Design The standard and comparison target heights were determined on the basis of the participants' standing and seated heights, which were measured at the beginning of the experiment. For Experiment 2, only two standard target heights were used. One was equal to the participant's standing height, and the second was equal to the participant's seated height. As in Experiment 1, comparison target height was coded relative to the standard target height (i.e., ± 2.5 and ± 1.3 cm). Both of the standard target heights were paired with each comparison target height, for a total of eight unique target pairs. Participants viewed each target pair four times, twice while seated and twice while standing, for a total of 36 randomized trials per participant. Seated and standing trials were blocked, and the order was counterbalanced. The participants' standing heights ranged from 157.5 to 188 cm (mean = 172.5 cm). Their seated heights ranged from 109.2 to 139.7 cm (mean = 133.6 cm).

Procedure The procedure was identical to that of Experiment 1, with the exception that all participants completed two blocks of 16 trials, one while seated and one while standing.

Results

The effects of participant posture on accuracy and bias for remembered target height were assessed. The results corroborated and extended on the findings from Experiment 1. That is, performance was influenced by the relationship between participant height and target height. Eight (0.008% of total) trials were excluded from the data analysis due to experimenter error and were replaced by the group mean for that condition.

Accuracy Weighted accuracy was analyzed as in Experiment 1. Standard target height was coded as either the "participant's seated height" or "participant's standing height." This created congruent trials (e.g., participants were seated and the standard target height equaled a participant's seated height) and incongruent trials (e.g., participants were seated and the standard target height equaled a participant's standing height). Degrees of

freedom were corrected using the Greenhouse–Geisser method for correlated measures.

Accuracy weighted by confidence A 2 (posture) $\times$ 2 (standard target height) $\times$ 4 (comparison target height) repeated measures ANOVA was conducted to assess weighted accuracy. Degrees of freedom were corrected using the Greenhouse–Geisser method for correlated measures.

Consistent with the proposal that EH scaling is preserved in memory, participants were most accurate when the standard target height matched their current heights. As predicted, there was a significant interaction between posture and standard target height, $F(1, 31) = 41.58$, $p < .001$, $\eta^2 = .57$ (see Fig. 6). When seated, participants were most accurate when the standard target matched their seated heights, relative to when the standard target was equal to their standing heights. When standing, participants were most accurate when the standard target matched their standing heights, as compared to when the standard target matched their seated heights.

There was no significant effect of posture, $F(1, 31) = 1.64$, $p = .21$, or of standard target height, $F(1, 31) = 0.46$, $p = .50$. There was a significant main effect of comparison target height, $F(2.24, 69.31) = 31.08$, $p < .001$, $\eta^2 = .50$. Participants were more accurate when the comparison target was 2.5 cm taller than the standard target ($M = .78$) than when the comparison target was 1.3 cm taller than the standard target ($M = .69$), $F(1, 31) = 27.76$, $p < .001$, $\eta^2 = .47$. Participants were also more accurate when the comparison target was 2.5 cm shorter than the standard target ($M = .68$) than when the comparison target was 1.3 cm shorter than the standard target ($M = .54$), $F(1, 31) = 35.83$, $p < .001$, $\eta^2 = .54$. Significant interactions were present between posture and comparison target height, $F(3, 93) = 7.73$, $p < .001$, $\eta^2 = .20$, and between standard target height and comparison target height, $F(2.21, 68.47) = 3.27$, $p = .039$, $\eta^2 = .10$.

Fig. 6 Mean weighted accuracy as a function of the participant's posture and the standard target height. Error bars represent one standard error

Confidence There was a significant association between accuracy and confidence judgments, $\chi^2(6) = 83.73$, $p < .001$. Participants were significantly more confident on trials in which they also made a correct judgment ($M = 4.32$, $SE = 0.17$), as compared to when they made an incorrect judgment ($M = 3.33$, $SE = 0.20$), $t(35) = -7.68$, $p < .001$, paired-samples t test.

In summary, participants were most accurate judging target heights from memory when the standard target height matched their current heights. These results are consistent with previous findings on perception and height estimation and suggest that the body—specifically, EH—is an effective source of information for scaling object height in both memory and perception.

Bias As in Experiment 1, bias for target height was explored. A 2 (posture) $\times 2$ (standard target height) $\times 4$ (comparison target height) repeated measures ANOVA was conducted to assess bias. A value greater than .5 indicated a bias to respond that the comparison target was “taller” than the standard target, whereas a bias less than .5 indicated a bias to respond “shorter.” Degrees of freedom were corrected using the Greenhouse–Geisser method for correlated measures.

Overall, participants were significantly more likely to judge the comparison target as taller than the standard target ($M = .56$), regardless of posture, $t(31) = 5.44$, $p < .001$. That is, after viewing the standard target, participants remembered the standard target as being shorter than its actual height, and as a result were biased to report that the comparison target was taller than the standard target. Thus, in general, participants underestimated the height of the standard targets.

There was a significant main effect of posture, $F(1, 31) = 23.18$, $p < .001$, $\eta^2 = .43$. Participants were more biased to respond that the comparison target was “taller” when they were standing ($M = .60$) than when they were seated ($M = .53$). There was also a significant main effect of comparison target height, $F(2.15, 66.77) = 135.23$, $p < .001$, $\eta^2 = .81$; not surprisingly, participants responded “shorter” more often when the comparison target was actually shorter than the standard target, and they responded “taller” more often when the comparison target was taller than the standard target. A significant three-way interaction between posture, standard target height, and comparison target height, $F(2.32, 71.98) = 18.67$, $p < .001$, $\eta^2 = .38$, showed that this relationship was stronger when participant posture and standard target height were congruent, relative to when they were incongruent.

Consistent with Experiment 1, participants generally remembered the standard target as being shorter than it actually was, suggesting an underestimation of target height when judging from memory. The results also suggest that

when judging target height from memory, performance was best at the observer’s current height, suggesting that the mechanism behind this effect was flexible, rather than true only at standing height. From Experiments 1 and 2, we can conclude that individuals use their bodies to scale the heights of objects when making judgments from memory. This suggests that just as the body is used as a metric during perception, its efficacy as a source of information remains over time, even when the original stimulus is out of sight.

General discussion

In two experiments, participant height influenced judgments of target height during a memory task. Consistent with research on perception and body scaling, participants were most accurate when the standard target matched their own heights. In addition, memory for target height was biased, depending on the relationship between participant height and standard target height.

Implications of findings

First, body scaling is a metric used to scale the environment into action-relevant units. For example, an overhang is scaled to EH in order to determine whether it can be walked under without bending one’s head, and a ball is scaled to hand size to determine whether it can be grasped. Therefore, body scaling is important for realizing possibilities for action and is typically associated with visual perception. The present experiments have shown that individuals spontaneously scale objects to EH, even when action is not immediate. That is, EH may be the default scalar for objects within EH range. This notion is consistent with studies in visual perception, in which participants scaled target heights to EH even in the absence of an explicit intended action (Bertamini et al., 1998; Wraga & Proffitt, 2000).

Second, these findings impact our understanding of the purpose of memory by showing that memories are grounded in the body and can inform future actions. This supports Glenberg’s (1997) claim that the purpose of memory is to inform perception and action, and that memory, perception, and body scaling are mutually involved in action planning. In essence, the same information that influences perception also affects memory.

The mechanism underlying EH scaling in memory is unknown, and was not directly tested in the present experiments. However, one possible explanation is that EH serves as a reference point. Individuals are more accurate remembering the location of a target when that

target is near a physical landmark in space (Bryant & Subbiah, 1994; Nelson & Chaiklin, 1980). EH is an optically specified landmark in perceived space; it is robustly specified by perspective structure and optic flow. Object heights can then be categorized as being either above or below that point. In addition, observers can judge the distance between EH and the top of each target and determine which is greater (for targets equidistant from the observer).

In both experiments, we predicted that participants would be most accurate at discriminating target heights from memory when the standard target matched the participant's own current height. While this pattern appeared in the data for Experiment 1, the effect was mainly driven by poor performance when the standard target was 30.5 cm taller than the participant, relative to when the target equaled participant height. The effect was much stronger in Experiment 2. This difference might be attributed to the fact that, in Experiment 2, the height discrepancy between participant and target height was larger, providing a stronger manipulation. Recall that as a scalar, EH is most informative for targets that are near an observer's EH, and its efficacy deteriorates as target heights diverge more from EH (Wraga & Proffitt, 2000). The target heights used in Experiment 1 were closer to 1 EH relative to the target heights used in Experiment 2, which might account for the better overall accuracy in Experiment 1. However, the results from Experiment 2 suggest that changing individuals' postures to match targets that would otherwise deviate from their EHs by a large amount leads to improvements in accuracy. For example, participants were more accurate for shorter targets when they were seated, as compared to when they were standing. Collectively, Experiments 1 and 2 provide evidence that object height is scaled to observer height in memory, within a given range, and even when posture is manipulated.

A secondary goal of these experiments was to explore whether participants were biased to remember the standard target as being shorter or taller than its true height. In Experiment 1, memory for standard target heights was biased away from the participants' own heights. That is, when the standard target was taller than the participant, the comparison target was judged to be shorter than the standard target, suggesting that the standard target was remembered as being taller than its actual height. In contrast, when the standard target was shorter than the participant, the comparison target was judged to be taller than the standard target, suggesting that the standard target was remembered as being shorter than its actual height.

A similar pattern of bias has been found in the large literature on category effects in memory, which has shown that when a continuous dimension, such as size, place, or time, is divided by a category boundary, estimates of

stimuli near the boundary tend to be biased away from it. Huttenlocher, Hedges, and Duncan (1991) argued that such biases are the byproduct of a Bayesian process that increases the accuracy of estimates by using category information to limit their potential variability. Their model posits that, all else being equal, such accuracy gains will be greatest when boundaries are most precise, which allows for maximal certainty in classification decisions. This framework suggests that EH may be employed as a category boundary, dividing heights into shorter than and taller than the self, because it is so accurately coded (see Fig. 1C). In Experiment 2, the bias results were less clear. Given the design of the experiment, we were unable to directly measure bias, because both observer posture and standard target height were being adjusted. However, as in Experiment 1, participants displayed an overall bias to underestimate target heights.

Future directions

These experiments provide preliminary evidence that body scaling is a useful metric in perception and memory. In the present study, participants made their memory judgments after only a 3-s delay from initial perceptual encoding. Thus, these results do not apply to long-term memory, but rather, to immediate retention or visual working memory. Future studies should address whether the effect of body scaling on judgments depends on how long that item is held in memory. For example, changes to viewing duration and response delay might affect how observers' heights are integrated into judgments. Over time, memories become degraded so that individuals rely on other sources of information, such as experience, context, and heuristics, to make judgments. Because height is a constant and reliable source of information, the body may become an even stronger scalar over time.

In addition to understanding how duration influences memory and body scaling, future studies should address how these effects change across the lifespan. For example, for elderly individuals, memory often declines, yet EH remains relatively stable. How do changes in cognitive abilities affect the influence of the body on memory for object height? Furthermore, how are memories of target height affected when both the observer's height and target height are changing? Individuals may experience that a landmark or object encountered from childhood seems larger in memory than when that object is revisited during adulthood. The same may be true when recalling a sibling's height from memory over different time periods. Tracking memory changes over time, while individuals are growing, could reveal how body scaling is integrated into memories during development and within a dynamic relationship.

Conclusions

On the basis of the results from Experiments 1 and 2, body scaling does not seem to be limited to immediate action or perception. Indeed, participants scaled target heights to their own heights from memory, mimicking the findings from perception and EH scaling. However, memory for target height also reflects biases to remember targets as being shorter, in general, and to treat EH as a category boundary, such that targets are biased away from EH. These results support the notion that cognition is grounded in the body, and they extend our understanding of body scaling to include scaling in memory and nonimmediate action.

Appendix

All analyses were also conducted on the raw (i.e., unweighted) data. In general, the unweighted results followed the same pattern and interpretation as the weighted accuracy analysis. The unweighted analyses are presented below, as well as any discrepancies between the two types of analyses.

Experiment 1

Accuracy These results followed the same pattern and interpretation found in the weighted accuracy analysis, with two exceptions. First, gender was not a significant covariate. Second, the main effect for standard target height was not significant, $F(4, 140) = 2.18, p = .075, \eta^2 = .06$. Overall, performance was greater than chance, $t(35) = 17.23, p < .001 (M = .74, SE = .01)$. There was a significant main effect for comparison target height, $F(2.20, 76.91) = 13.82, p < .001, \eta^2 = .28$, as well as a significant interaction between the standard and comparison target heights, $F(12, 420) = 2.35, p = .006, \eta^2 = .06$.

Each participant completed five trials in which the standard and comparison targets were the same height, but the participant was forced to respond that the comparison target was taller or shorter. On these trials, participants were biased to respond that the comparison target was taller than the standard target ($M = .58, t(1, 35) = 2.051, p = .048$). This is consistent with the finding that participants, in general, underestimated the height of the standard target in memory.

Bias The pattern and interpretation of the data were the same as for weighted bias, except that the interaction was not significant. There was a significant main effect of standard target height, $F(4, 140) = 5.24, p = .001, \eta^2 = .13$, along with a significant main effect of comparison target height, $F(4, 140) = 88.45, p < .001, \eta^2 = .72$.

Experiment 2

Accuracy The pattern of results and interpretation were the same as with the weighted accuracy analysis, except that gender was a significant covariate, $p = .016$, that was included in the model. Overall, males performed better than females. There was a significant interaction between posture and standard target height, $F(1, 30) = 49.78, p < .001, \eta^2 = .62$. There was no significant effect of posture, $F(1, 30) = 0.41, p = .53$, or standard target height, $F(1, 30) = 0.79, p = .38$. There was a significant main effect of comparison target height, $F(3, 90) = 20.45, p < .001, \eta^2 = .41$. There were significant interactions between posture and comparison target height, $F(2.26, 67.69) = 6.30, p = .002, \eta^2 = .17$, and between standard target height and comparison target height, $F(2.27, 68.01) = 3.55, p = .029, \eta^2 = .11$.

Bias The results were consistent with the weighted bias analysis, except there was also a significant main effect of standard target height, $F(1, 31) = 7.13, p = .012, \eta^2 = .19$. The bias to respond that the comparison target was “taller” than the standard target was larger when the standard target equaled the participant’s seated height ($M = .62, SE = .02$), as compared to when the standard target equaled the participant’s standing height ($M = .55, SE = .02$). There were a significant effect of posture, $F(1, 31) = 15.92, p < .001, \eta^2 = .34$, a significant effect of comparison target height, $F(3, 93) = 137.16, p < .001, \eta^2 = .82$, and a significant three-way interaction between participant posture, standard target height, and comparison target height, $F(3, 93) = 16.79, p < .001, \eta^2 = .35$.

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