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Learning by doing: Action performance facilitates affordance perception

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Abstract

We investigated the effect of action performance on perceptual judgments by evaluating accuracy in judging whether doorways allowed passage. Participants made judgments either before or after walking through doorways of varying widths. Participants in the action-first group benefited from action feedback and made more accurate judgments compared to a perception-first group that judged doorways before walking through them. Action feedback aided perceptual judgments by facilitating scaling to body dimensions: Judgments in the action-first group were strongly related to height, weight, and torso size, whereas judgments in the perception-first group were not.

Keywords

action; perception; affordance; body-scaling; perceptual learning

Perception and action are intricately linked. Perception provides the requisite information for selecting and guiding actions adaptively (Gibson, 1958). For example, we require visual information to steer a car along a winding road, navigate around a puddle, or turn to squeeze into a crowded elevator. Visual information specifies when the curve is too sharp for the current speed, the puddle too wide to allow a detour, or the opening too narrow to fit the body. In these cases, visual information alerts us to possibilities for action in advance so that we can guide actions adaptively.

Possibilities for action—what Gibson (1979) termed "affordances"—depend on the current fit between the physical properties of the body and the physical features of the environment (Adolph & Berger, 2006; Warren, 1984). For example, squeezing through a narrow doorway might be possible for a small child but impossible for a large adult; a person with a more flexible chest region can push through a smaller opening than someone of the same size with a less compliant body. For a given individual, the dimensions and dynamic capabilities of the body relative to the dimensions and pliability of the doorway determine whether the opening is passable. Affordances change from moment to moment because the body and environment are continually in flux (Adolph & Berger, 2006; Michaels, 2003): On the actor s side of the affordance relation, bulky clothing, protruding accessories, or a stiff neck can change possibilities for squeezing through openings; reciprocally, adjustments in the size of the opening or the amount of resistance to pressure can change the environment side of the

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affordance relation (Adolph, Eppler, & Gibson, 1993). Thus, possibilities for action vary with changes in local conditions.

Previous research shows that people perceive possibilities for action relative to body and environmental constraints. When tested with openings varying in size, participants attempted to reach through openings larger than their hand size and refused to attempt openings smaller than their hand size (Ishak, Adolph, & Lin, 2008). They spontaneously minimized hand size by pressing their fingers together and accurately scaled attempts to their compressed hand size. When hand size was enlarged with a prosthesis that added a centimeter to the width of their hands, participants instantly rescaled their perceptual judgments to their new hand size as they brought their hand up to the opening.

Similarly, people perceive affordances for navigating their whole bodies through openings (Higuchi, Takada, Matsuura, & Imanaka, 2004; Wagman & Malek, 2007; Wagman & Taylor, 2005; Warren & Whang, 1987). When viewing doorways varying in width, participants walked through doorways larger than their body size and refused to attempt doorways smaller than their body size within 2–3 cm of accuracy (Franchak, van der Zalm, Hartzler, & Adolph, 2009). Participants turned sideways to accommodate narrow doorways, meaning that they perceived doorway width relative to their smallest sideways dimensions, even though they approached the doorways with their bodies facing forward. Pregnant women rescaled their perceptual judgments to reflect changing affordances as their bellies grew throughout the course of their pregnancies and shrank postpartum (Franchak et al., 2009). Despite the rapid changes in their bodies, the pregnant women were just as accurate as participants in a control group (including men) who were not (and had never been) pregnant. Participants can even judge novel affordances for rolling through doorways (Higuchi et al., 2004) or under barriers (Stoffregen, Yang, Giveans, Flanagan, & Bardy, 2009) while sitting in a wheelchair.

How is it that participants can judge affordances for passage so accurately? In the case of fitting the hand through an opening (e.g., Ishak et al., 2008), participants can view their hand size against the size of the opening prior to reaching through it. In fact, participants sometimes raised their hand to the opening and then lowered it after deciding that it wouldn t fit. But, in the case of walking or rolling through a doorway in a wheelchair, participants cannot view their bodies and the opening at the same time. Moreover, while actually walking through narrow doorways, participants spontaneously turn sideways and contort their bodies (sucking in belly, wriggling side to side) as they squeeze through (Franchak et al., 2009). Thus the defining body dimensions (e.g., sideways torso depth and body compliance) are not easily accessible to vision. What sources of information are available to guide actions when the relevant body dimensions are not readily visible?

Previous research shows that adults judge affordances relative to intrinsic information about their bodies (Mark, 1987; Mark, Baillet, Craver, Douglas, & Fox, 1990; Warren, 1984; Warren & Whang, 1987). Eye-height, for example, is used to make judgments about the distance and relative size of doorways (Warren & Whang, 1987) and to judge affordances for stair climbing and sitting (Mark, 1987; Mark et al., 1990). Manipulating eye height—by dressing participants in platform shoes—altered their perceptual judgments of climb-up-able stair heights and sit-on-able chairs in line with their new taller dimensions. Recalibration is not merely the output of a cognitive strategy due to awareness of altered eye height. When participants stood on a false floor that covertly increased their eye height, they recalibrated their judgments of passable doorway widths in line with their altered dimensions: Participants in the raised floor condition consistently overestimated their abilities to fit through doorways, but participants in the flat floor condition did not. Participants were unaware of the floor manipulation, suggesting that the reliance on eye-height information is an automatic perceptual process.

Can Action Inform Perception?

Previous research on affordance perception emphasizes the role of perception in guiding action. Presumably, however, the relation between perception and action is not one-sided. Perception and action are linked in a continuous feedback loop; every action provides feedback about the just-performed movement and generates information that can be used for guiding the next movement (Adolph & Berger, 2006; Patla, 1998). As Gibson (1979) argued, “We must perceive in order to move, but we must also move in order to perceive” (p. 223).

Simply being in motion can facilitate perception of affordances. For example, to dodge traffic while crossing a busy street (Oudejans, Michaels, van Dort, & Frissen, 1996) or gauge whether a fly ball is catchable (Oudejans, Michaels, Bakker, & Dolne, 1996), movement leads to increased accuracy in perceiving affordances. Pedestrians who walked up to the curb matched crossing time more closely to the time allowed by traffic flow compared with observers who judged whether to cross from a static position (Oudejans, Michaels, van Dort et al., 1996). Participants who took a few running steps in the outfield made more accurate judgments about their ability to catch fly balls compared with stationary observers (Oudejans, Michaels, Bakker et al., 1996). Being in motion facilitates perception of affordances because movements provide information about the dynamic capabilities of the body.

Ongoing movements also facilitate perception of changing affordance relations. For example, platform shoes increase leg length, thereby increasing the height of chairs that are possible to sit on (Mark et al., 1990). When first standing up in their platform shoes, participants erred in the direction of their familiar leg length. But perceptual judgments of maximum seat height became more accurate over successive trials. Learning the new affordance relations required only subtle stepping and swaying movements of the body. When postural movements were eliminated by requiring participants to press their backs against a wall, judgments were inaccurate and did not improve over trials. A later investigation showed that specific patterns of incidental postural sway predict learning (Stoffregen, Yang, & Bardy, 2005).

Some movements are intentionally exploratory, that is, performed expressly for the purpose of gathering information. For example, touching a ground surface provides a wealth of information about size, slant, rigidity, and friction that can be used to gauge affordances and sharpen up perceptual judgments (Joh & Adolph, 2006). Even novice walking infants exhibit intentional exploratory movements, such as touching the edge of a slope with their feet or hands, to gain information about the stability and friction of the surface (Adolph, 1995, 1997).

Information generated by ongoing movements and exploratory activity may have considerable overlap with information obtained while performing the target action. For example, the information obtained during ongoing locomotion or while approaching an obstacle for exploration (visual flow, motion parallax, postural sway, etc.) is likely similar to the information obtained during the approach for performance (e.g., passing through the narrow doorway). But additional sources of information may arise as the result of performing the target action, a sort of learning by doing: the outcome (success or failure) and degree of difficulty of the action, the penalty for errors, and the visual, haptic, and proprioceptive feedback that is correlated with performance (Adolph & Berger, 2006; Adolph et al., 1993). Sliding easily through a large doorway and becoming wedged in a too-small doorway provide differential feedback about the affordance for passage. The perceptual learning literature is replete with examples showing that feedback (or knowledge of results) improves the accuracy of judgments of object properties, such as the length of wielded rods or the relative mass of colliding balls (Jacobs, Michaels, & Runeson, 2000; Wagman, McBride, & Trefzger, 2008; Withagen & Michaels, 2005).

Besides providing feedback information about whether the action succeeded or failed, the act of squeezing through a doorway might help walkers detect information about their bodies that they might not be able to perceive by other means. Specifically, fitting through a small opening depends not only on the size of the body, but also the degree to which it can compress. And body compression is variable between individuals—compression in sagittal body depth ranged from 3 to 8 cm in a sample of college-aged participants, a 10% to 24% reduction in sideways body dimensions (Franchak et al., 2009). Although there may be other ways to learn about the compression of the body, actually squeezing into a small space provides direct and immediate information about the body s dynamic capabilities.

Previous research provides inconclusive evidence about the effects of learning by doing. In some studies, performing the target action facilitated perception of affordances. For example, participants demonstrated one-trial learning after falling on a deformable foam surface on their initial attempt to walk over a platform (Joh & Adolph, 2006). On subsequent trials, participants leaped over the foam pit or stepped gingerly into it to avoid falling. When exploring a novel action system—locomoting in a wheelchair—perceptual judgments improved with experience navigating through doorways, but only after 8 days of practice (Higuchi et al., 2004).

However, other lines of evidence suggest that perceptual judgments do not benefit from performing the target action. Practice sitting on variable chair heights (with and without platform shoes) did not lead to improvements in judging maximal seat height for sitting (Mark et al., 1990). One session of practice navigating a wheelchair through doorways did not lead to more accurate judgments about affordances for passage (Higuchi et al., 2004). Practice navigating a wheelchair under barriers that varied in overhead clearance did not lead to more accurate judgments compared with participants who simply practiced wheeling around (Stoffregen et al., 2009). Similarly, crawling and walking infants who received intense daily or weekly practice descending slopes were no better at perceiving affordances than infants who simply practiced crawling and walking on flat ground at home (Adolph, 1997; Adolph, Tamis-LeMonda, Ishak, Karasik, & Lobo, 2008; Gill, Adolph, & Vereijken, 2009). Thus, the question of whether action performance facilitates perception of affordances remains open.

Current Study

In the current study, participants completed two tasks in succession: an action performance task and a perceptual judgment task. The action task served two purposes: It gave participants experience squeezing through narrow doorways and it provided us with an estimate of the affordances for passage. Participants attempted to walk through doorways of varying width, and we estimated affordance thresholds based on the smallest doorway they passed through on 50% of trials. The perception task was designed to assess how accurately participants perceived affordances for passage. Participants reported their judgments while standing 2.5 m away from the doorway. We estimated perceptual judgment thresholds based on the smallest doorway they judged to be passable on 50% of trials. The difference between the two estimates provided a measure of perceptual judgment error.

To test the effect of action performance on perception of affordances, an *action-first* group walked through doorways before making perceptual judgments, and a *perception-first* group made perceptual judgments before walking through doorways. We focused on two sources of evidence for learning by doing. First, increased accuracy of perceptual judgments following experience performing the target action would indicate a facilitative effect of action performance. Second, practice performing the action might induce participants to adopt a more robust scaling factor. If perceiving affordances is independent of action feedback, then participants should make similarly accurate perceptual judgments in both the perception-first and action-first conditions. If, however, action feedback affects perception of affordances, then participants in the action-first condition should judge affordances more accurately than those in the perception-first group and show evidence of better scaling to relevant body dimensions.

We focused on affordances for walking through doorways for several reasons. First, walking through narrow openings is a highly practiced, everyday task. As in reaching through openings, passage during locomotion does not depend solely on static, geometric dimensions of the body relative to the doorway. Compression of the body is dynamic and depends on body composition and pain tolerance. Some people can bear very little compression, but others have bodies with more give. Other dynamic factors during approach to the doorway such as walking speed, and direction and degree of body rotation affect the likelihood of success (Franchak et al., 2009). As a result, there was no a priori way to determine participant's affordance thresholds before they walked through the doorway. Thus, we could not provide a feedback-only condition to separate action performance from feedback. Moreover, unlike previous studies that report *pi numbers* —relating the critical dimensions of the environment to dimensions of the body (Warren, 1984; Warren & Whang, 1987) — we could not calculate pi numbers because the affordance relation does not depend on a single, critical body dimension.

An especially interesting aspect of perceiving affordances for passage is that participants cannot see their bodies relative to the doorway. The relevant body dimensions are not readily accessible for visual comparison when making judgments from a distance or while walking through the doorway. In contrast, while reaching through openings, the hand remains in the visual field framed against the opening (Ishak et al., 2008). Furthermore, perception and action involve different body orientations. Judging doorway passage is challenging because participants make judgments from a frontal body orientation, but most people spontaneously turn sideways to pass through narrow doorways. They judge doorways from a different position during approach compared with the position used to walk through.

Method

Participants

Twenty-five college students (13 female, 12 male) participated to fulfill a course requirement. One participant was excluded for not following instructions. Participant's mean age was 20.56 years (*range* = 18 to 24 years). All had normal or corrected-to-normal vision.

Apparatus

We constructed a wooden platform with an adjustable doorway (Figure 1). Participants walked over the elevated platform (490 cm long × 98 cm wide × 64 cm high). A stationary wall (122 cm wide × 173 cm high) attached to the platform stood perpendicular to a moving wall (114 cm wide × 191 cm high). The stationary wall provided support along the edge of the walkway so that participants did not feel uncomfortable walking near the walkway s edge as they approached the doorway. The movable wall adjusted in 0.2 cm increments to create doorways ranging in width from 0 to 70 cm. Trials began from a starting line 2.5 m from the doorway. A screen behind the doorway prevented participants from using landmarks in the room to judge doorway width.

Three cameras recorded each trial: A panning side-camera followed participants as they walked toward the doorway; an overhead camera captured their movements as they passed through the doorway; a measurement camera projected calibration markings onto a monitor, allowing precise adjustments of the doorway. A digital capture computer mixed all three views into a single video file recorded at 30 frames/s.

Procedure

Participants were assigned in alternating order to an *action-first condition* (completed the action performance task before the perceptual judgment task) or a *perception-first condition* (completed the perceptual judgment task before the action performance task). Each order was counterbalanced for gender.

In the action performance task, participants completed 20 trials in which they attempted to walk through each doorway. Participants were instructed to walk through each doorway regardless of whether they believed they could fit. They faced away from the doorway while an experimenter adjusted the width and then attempted to walk through the doorway when cued. Participants were told that they could use any strategy to walk through the doorway. Every participant turned sideways to fit through narrow doorways. In addition, many went on tiptoes or sucked in their stomachs while attempting to squeeze through the narrowest doorways. The experimenter coded each trial as a success (passed through doorway) or failure (squeezed their body into the doorway, but could not fit through).

To determine affordances for passage, we calculated an affordance function for each participant based on the proportion of successes at each doorway width (triangular symbols in Figure 2). As in Ishak and colleagues (2008) procedure, functions were fit to a cumulative normal distribution using maximum likelihood estimates for the slope and threshold. The affordance threshold was a point estimate of a 50% success rate. For the first 6–8 trials, the experimenter used a binary search procedure to find a rough estimate of each participant s affordance threshold—on successive trials, the experimenter presented the doorway width at the midpoint between the smallest doorway the participant walked through and the largest doorway the participant failed to walk through to hone in on the threshold doorway width. Then, participants received 12–14 randomly selected doorway widths within a 3 standard deviation range of the current threshold estimate. All 20 trials were used to calculate each participant s affordance function.

In the perceptual judgment task, participants completed 40 trials in which they responded “yes” if they judged they could fit through the doorway and “no” if they judged they could not. The experimenter explained that “fitting through the doorway” meant turning their bodies to the side and squeezing into the doorway. Participants faced away from the doorway while an experimenter adjusted the width. They turned to face the doorway when cued and then stood on the starting line and reported their decision. We calculated the proportion of “yes” responses at each doorway width (circular symbols in Figure 2), and used the same procedure to estimate perceptual judgment functions and thresholds as affordance functions. We collected 40 trials for the perceptual judgment task compared with 20 for the action performance task because pilot data revealed greater variability of perceptual judgment functions (compared to affordance functions), suggesting that more trials would be required to determine an accurate perceptual judgment function.

At the end of the session, experimenters measured participant's standing height (with a stadiometer), weight (on a digital scale), and torso dimensions (from photographs). Preliminary data showed that chest circumference measurements are noisy due to participant's breathing and difficulty identifying appropriate body landmarks, so we used a computer program (ImageJ) to calculate participant's widest frontal and sagittal torso dimensions from photographs with a visible, standard metric. The entire session took approximately 45 minutes.

Results

Affordances for Passage

Across conditions, affordance thresholds ranged from 14.40 to 23.60 cm (*M* = 18.92 cm). Affordance thresholds in the action-first (*M* = 18.90 cm, *SD* = 2.46) and perception-first conditions (*M* = 18.95 cm, *SD* = 1.84) were nearly identical, *t*(22) = 0.07, *p* > .05. The slope parameters of participant's affordance functions were equally small in both groups (action-first: *M* = 0.19, *SD* = 0.25; perception-first: *M* = 0.32, *SD* = 0.28), *t*(22) = 1.13, *p* > .05, indicating a sharp transition from passable to impassable openings. Individual differences in affordance thresholds reflected variations in participant's body dimensions. The first column of Table 1 shows the correlations between affordance thresholds and four body measurements (height, weight, frontal width, sagittal width). All four measurements positively correlated with affordance threshold, *r*s(22) ε .46, *p*s < .05, indicating that people with smaller bodies could fit through smaller doorways. Weight correlated most strongly with affordance thresholds (Figure 3). Weight, height, frontal, and sagittal dimensions were intercorrelated, *r*s(22) > .36, *p*s < .09.

Because all four body dimensions were correlated with affordance thresholds and because body dimensions were intercorrelated, we conducted a hierarchical linear regression to determine the unique contributions of the four body dimensions in explaining the variance in threshold doorway size. Predictors were entered one at a time to observe the individual effects of each on R^2, partialling out the effects of previously entered predictors. To test whether weight was indeed the best predictor of affordance thresholds, we entered the three other body measurements first followed by weight to see whether weight could explain unique variance after controlling for the other three. Together, height, frontal width, and sagittal width accounted for 47.8% of the variance in doorway passing ability. Adding weight to the model explained an additional 19.4% of the variance, indicating that weight was the strongest predictor of affordance threshold. The final model using all four predictors accounted for 67.2% of variance in affordance thresholds, *F*(4, 17) = 8.69, *p* < .01.

Perceptual Judgments

Across conditions, perceptual judgment thresholds ranged from 12.15 to 26.30 cm (*M* = 18.48 cm, *SD* = 3.67). Perceptual judgment thresholds did not differ between the action-first (*M* = 17.87 cm, *SD* = 3.29) and perception-first conditions (*M* = 19.10 cm, *SD* = 4.06), *t*(22) = 0.82, *p* > .05. Judgments in the perception-first condition were equally variable (based on the slope parameters) compared with judgments in the action-first condition, *t*(22) = 1.51, *p* > .05. Overall, slope parameters of perceptual judgment functions (*M* = 1.11 cm, *SD* = 0.63) were larger than slope parameters of affordance functions, *t*(23) = –6.19, *p* < .05, indicating that perceptual judgments were variable relative to actual possibilities for action.

Perceptual Judgment Errors

The degree to which perceptual judgment thresholds related to affordance thresholds represents how accurately participants scaled judgments to their actual abilities. Across both groups, affordance and perceptual judgment thresholds were strongly correlated, *r*(22) = .60,

$p < .01$, (Figure 4). But this relation did not hold equally across the two conditions: Perception-first participants showed a relatively weak correspondence between judgments and abilities, $r(10) = .40$, $p > .05$, whereas action-first participants closely matched judgments to abilities, $r(10) = .84$, $p < .01$.

The difference between perceptual judgment and affordance thresholds provided a measure of judgment error (dashed line in Figure 2). Positive judgment error indicates that participants tended to overestimate which doorways were possible by responding ‘yes’ to doorways that were impossibly small. Conversely, negative judgment error indicates that participants tended to underestimate what doorways were possible by saying ‘no’ to possible doorways. Overall, judgment errors did not differ from 0 ($M = 0.44$ cm, $SD = 2.93$), $t(23) = .73$, $p > .05$. Participants were just as likely to overestimate or underestimate their ability to fit, and judgment error did not differ between conditions, $t(22) = -0.99$, $p > .05$.

However, mean judgment error did not truly measure the accuracy of judgments because positive and negative errors canceled each other out. To better assess judgment accuracy, we calculated the absolute value of judgment errors—the overall magnitude of each participant’s error regardless of error direction. Absolute judgment errors differed from 0, indicating that performance was not perfect ($M = 2.36$ cm, $SD = 1.72$), $t(23) = 6.72$, $p < .01$. But absolute judgment errors were greater for participants in the perception-first condition ($M = 3.11$ cm, $SD = 1.85$) relative to those in the action-first condition ($M = 1.62$ cm, $SD = 1.26$), $t(22) = 2.30$, $p < .05$, revealing a benefit to accuracy for participants who received action feedback.

Body Dimensions and Perceptual Judgments

Perceptual judgments were fairly accurate for all participants, but were more accurate for participants who performed the target action prior to making perceptual judgments. Since body dimensions largely determined affordances, accurate perceptual judgments should be scaled to body dimensions. Because action-first participants made more accurate judgments, there should be a stronger relation between their judgments and body dimensions than for participants in the perception-first condition. The second and third columns of Table 1 show the correlations between perceptual judgment thresholds and the four body measures for the action-first and perception-first groups. Perceptual judgments and body dimensions were highly correlated for action-first participants, rs(10) ε .61, ps < .05 (Figure 5). Although perception-first participants erred by only 1.5 cm more than action-first participants, their judgments did not significantly correlate with any measure of body dimensions (ps > .05, Figure 5).

To determine which body dimensions action-first participants scaled judgments to, we conducted a hierarchical linear regression to measure the unique contributions of each body measurement in explaining the variance in perceptual judgment thresholds (Table 2). Since weight was the best predictor of affordance thresholds, we expected that it might be the best scaling factor for perceptual judgments. However, the strongest correlation was between height and perceptual judgment thresholds (Table 1). We first entered weight into the regression, and it accounted for 79.4% of the variance in judgment threshold. Entering frontal and sagittal body dimensions only accounted for an additional 0.3% of variance, indicating that neither predictor could explain any variance that weight did not account for. Yet, height accounted for an additional 10.2% of the variance after controlling for the other three predictors, suggesting that height information may play a role in participant’s judgments. All four predictors accounted for a total of 89.9% of the variance, $F(4, 6) = 13.34$, $p < .01$. Note, removing the tall outlier from the action-first group does not change the direction or degree of these effects.

In a second regression model, we entered height in the first block and the other three predictors together in a second block. When entered first, height accounted for 86.8% of the variance in perceptual judgments thresholds for action-first participants. The other three predictors did not account for any significant variance after controlling for height. Taken together, these two hierarchical regression models strongly suggest that action-first participants scaled their perceptual judgments to height (or a combination of factors that includes height information) even though weight was the best predictor for their actual affordance thresholds.

If the improvements in accuracy were the result of height scaling, then participants in the perception-first group should have been more accurate if they made judgments that scaled to height. We calculated linear regression parameters that predicted perceptual judgment thresholds from height in the action-first group. Using these parameters and participant’s heights, we predicted height-scaled perceptual judgment thresholds (PJT) for participants in the perception-first condition:

$$PJT_{predicted}=(0.66 \times height) - 25.67 \quad (1)$$

Indeed, perceptual judgments would have been more accurate had they been scaled to height: Mean judgment error would have been reduced from 3.11 cm to 2.09 cm for the perception-first group. Of the 12 participants, 9 would have reduced the magnitude of their errors had they scaled judgments to height alone.

Discussion

The current study investigated the effect of learning by doing. Performing the target action of walking through doorways facilitated participant’s judgments about the affordances for passage compared to participants who did not have specific experience with the target action. Action-first participants scaled perceptual judgments to their body dimensions more closely than participants in the perception-first group.

The action task allowed us to calculate affordance functions for each participant. High measurement resolution (0.2 cm) proved to be critical: The probability of fitting through the doorway steeply dropped from passable to impossible over a span of only a few millimeters. Small changes in doorway width drastically altered the affordance for passage. Furthermore, affordances thresholds varied from individual to individual: Some participants could fit through doorways as small as 14.4 cm, but others could not pass through a 23.6 cm doorway. Body dimensions accounted for the individual differences in affordance thresholds, with weight as the best predictor of threshold doorway width. To our surprise, sagittal body width—participant’s smallest sideways dimension—and frontal body width were the weakest predictors. Possibly, our technique of estimating body width from photographs was noisy compared with height and weight. Furthermore, the geometry of the body while standing freely does not reflect the compressability of the body while squeezing through narrow openings.

The action task served a second purpose. It provided the action-first group with experience performing the target action. On each of the 20 trials, participants walked up to the doorway and attempted to fit through. Previous studies that failed to find an effect of action performance used practice trials that were distributed widely from possible to impossible. Because of the high resolution of the apparatus, we were able to present participants with doorway sizes in a narrow region relative to their thresholds—small changes in doorway size from trial to trial shifted the outcome from success to failure. Possibly, practice performing the target action in the critical region around the threshold explains why the current study showed an effect of action performance when other studies did not.

The average judgment error for participants who first performed the target action was 1.5 cm more accurate than participants who made perceptual judgments without action experience. The difference in performance was reliable, but small in magnitude. The small size of the effect compared to measurement resolution may also explain why other studies failed to find evidence of learning by doing. Higuchi and colleagues (Higuchi et al., 2004) probed judgments using aperture increments of 5 cm (compared to 0.2 cm in the current study). Stoffregen and colleagues (2009) used the method of constant adjustment to find judgment thresholds, however, their screen apparatus moved at 2 cm/s—they did not report the minimum adjustment increment.

In previous studies, participant’s verbal estimates about fitting through doorways always overestimated the spatial requirements (Higuchi et al., 2004; Warren & Whang, 1987). Researchers attributed this bias in judgments to a so-called “safety margin”—participants consistently reported that passable doorways were impossible to fit through. However, in the current study, we found no systematic bias in the direction of errors. Roughly half the sample erred on the side of caution, as in previous studies, but the other half erred in the opposite direction by choosing doorways that were too small to successfully navigate. Possibly, the task used in previous studies—walking through without turning the shoulders or touching the sides of the doorway—biased participant’s to adopt a more conservative strategy than participants in the current study, who were free to turn their bodies and attempt to squeeze through.

Unlike previous studies, we did not compare the effect of performing the target action to a condition of non-specific movement experience (e.g., Higuchi et al., 2004; Stoffregen et al., 2009). We do not consider this to be a shortcoming, however, because of the high familiarity of the action we studied—typical walking. All of the participants walked to the lab, passing through a number of doorways along the way. Walking through narrow openings is a highly practiced action, which may in part explain why the magnitude of the effect was small—participants fine-tuned their pre-existing abilities to perceive affordances for fitting through apertures. Most likely, participants were already close to ceiling performance before receiving action experience. Indeed, participants who made perceptual judgments without specific practice on the doorway apparatus erred by only 3.11 cm.

What, then, did participants learn from performing the target action? One possibility is that action experience increased perceptual sensitivity. However, we found no evidence that perceptual judgment functions were sharper or more finely attuned for action-first compared to perception-first participants. For both groups, the slopes of the perceptual judgment functions were shallower than the slopes of the underlying affordance functions. The region of uncertainty in perceptual judgments spanned a few centimeters. Even when perceptual judgments closely matched the probability of success, most participants did not make consistent responses across trials. That is, participants did not pick a single criterion doorway size and say ‘yes’ to every larger doorway and ‘no’ to every smaller doorway. Instead, they often responded differently to same-sized or almost same-sized doorways throughout the perceptual judgment task, regardless of condition.

More likely, feedback from performing the action highlighted the relation between dimensions of the doorway and participant’s bodies as they tried to fit. We found evidence that performing the target action led to differences in how participants scaled decisions to their body dimensions. Whereas perception-first participant’s thresholds did not correlate with body dimensions, action-first participants showed remarkably strong correlations between height, weight, and perceptual judgment thresholds. But although weight was the best overall predictor of affordance thresholds, participant's judgments were best predicted by height. If action performance helped participants scale decisions to body dimensions, why did participants scale to a less robust predictor?

Possibly, participants scaled judgments to height rather than weight because they have direct perceptual access to their eye-height (Mark, 1987; Mark et al., 1990; Warren & Whang, 1987), but they do not have direct visual access to their weight or width or compression of their bodies. Although height does not perfectly predict participant's ability to pass through doorways, it is still strongly correlated with affordance thresholds. Scaling judgments to eye-height might not be exact, but could serve as a close-enough approximation. We predicted perceptual judgment thresholds for the perception-first group using the scaling relationship that action-first participants used. As a group, perception-first participants would have been more accurate had they scaled decisions for height, and the majority of participants would have been more accurate.

The current study differs from traditional studies of perceptual learning in that participants judged an affordance, the ability to pass through the doorway, as opposed to an extrinsic, perceptual property, such as distance, size, shape, or color. Although metric properties of the doorway are relevant to the perceptual judgment of the affordance—the observer must perceive doorway width in relation to body dimensions—how accurately the observer perceives metric properties in isolation may be another question altogether. For example, Stefanucci and Geuss (2009) found that broad-shouldered participants underestimate the width of an opening (through a perceptual-matching response) compared to narrow-shouldered individuals: Judgments of perceptual properties are biased by the possibilities for passage. However, in the current study, we found no systematic bias in the direction of errors based on body dimensions. Most likely, asking participants to judge affordances for passage rather than doorway size eliminated biases because affordance judgments, by definition, relate body size to doorway size.

In conclusion, observers can use past experiences performing a target action to improve the accuracy of future judgments about that action. Action performance provides feedback about the consequences of performing the action. The current study suggests that participants can exploit feedback from specific action experience—walking through doorways—to make more accurate judgments than participants with only general action experience—walking in an upright posture. In other words, learning by moving is good, but learning by doing is better.

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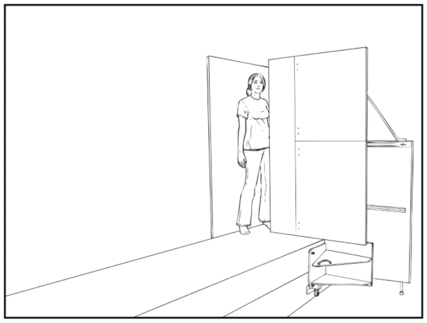

Figure 1.
Adjustable doorway apparatus.

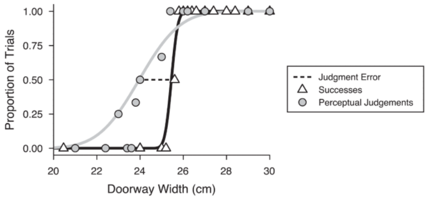

Figure 2.

Example data from one participant. Triangles show the proportion of trials with successful passage at each doorway width in the action task. Circles show proportion of ‘yes’ responses during the perception task. The affordance function (black) is fit to success rate and the perceptual judgment function (gray) is fit to the rate of ‘yes’ responses. The dashed line represents judgment error—the discrepancy between the 50% thresholds of each function.

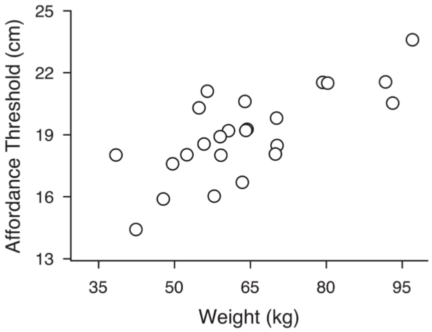

Figure 3.

Relation between weight and affordance thresholds across all participants.

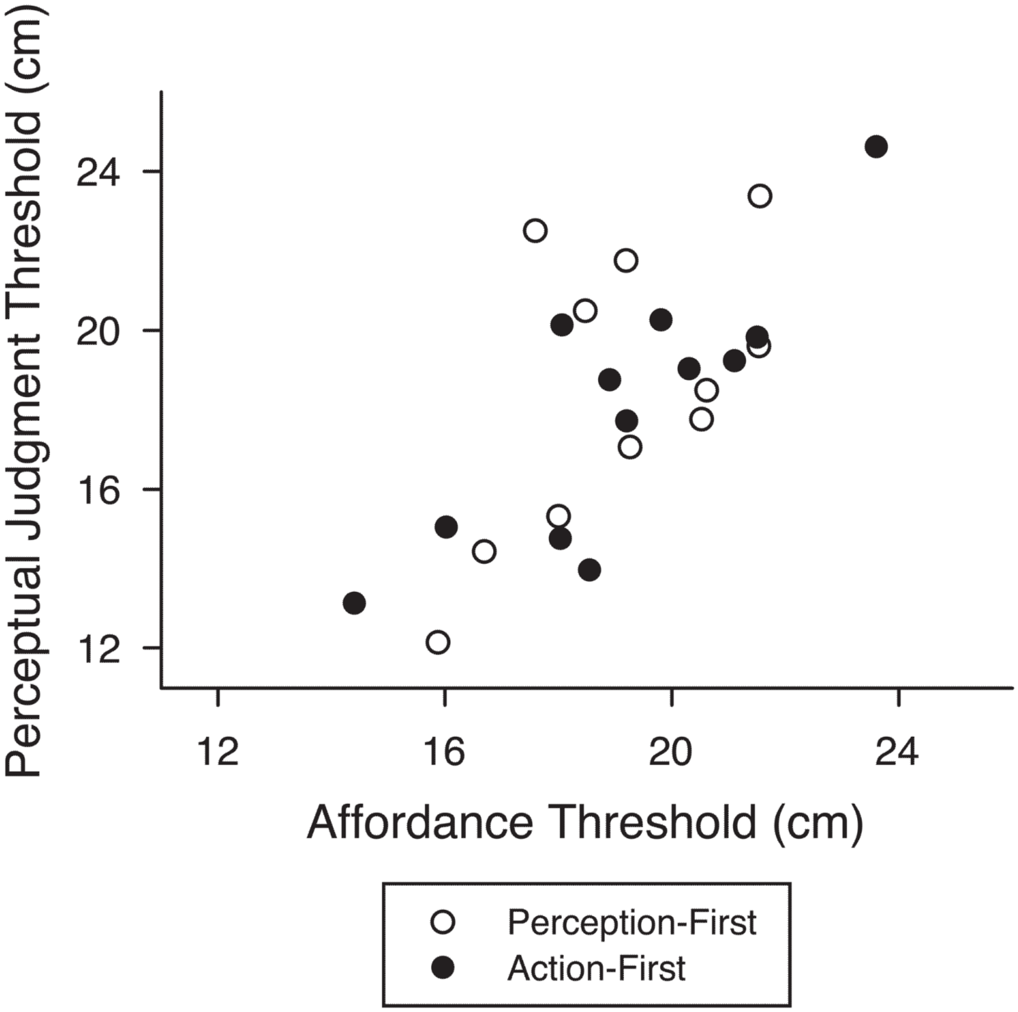

Figure 4.
Relation between affordance thresholds and perceptual judgment thresholds by condition.

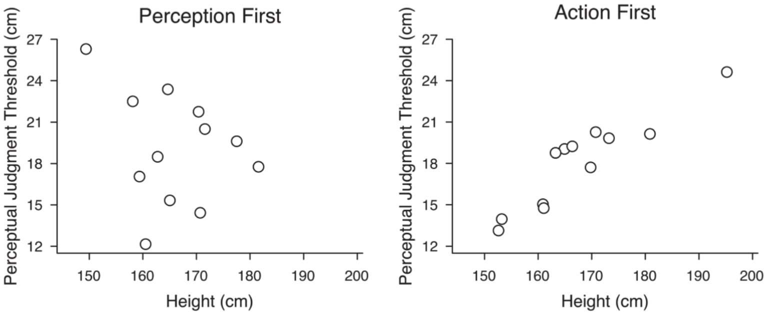

Figure 5.
Relations between participant’s height and perceptual judgment thresholds by condition.

Table 1

Correlations between body dimensions, affordance thresholds, and perceptual judgment thresholds.

	Affordance Threshold	**Perceptual Judgment Threshold**	
Body Dimension	**Both Conditions**	**Action First**	**Perception First**
Height	$.62^{**}$ $n = 24$	$.93^{**}$ $n = 12$	−.28 $n = 12$
Weight	$.77^{**}$ $n = 24$	$.89^{**}$ $n = 12$	−.02 $n = 12$
Frontal width	$.55^{**}$ $n = 23$	$.61^{*}$ $n = 11$	.18 $n = 12$
Sagittal width	$.46^{*}$ $n = 22$	$.62^{*}$ $n = 11$	.18 $n = 11$

Note:

[*] $p < 0.05$ level,

[**] $p < 0.01$ level

Table 2

Hierarchical regression testing the contributions of weight, sagittal width, frontal width, and height in predicting perceptual judgment thresholds for action-first participants.

Predictor	R^2	R^2 **Change**
Weight	.794	.794**
Sagittal width	.795	.001
Frontal width	.797	.002
Height	.899	.102*
Final Model	$F(4,6) = 13.34$**	

Note:

*$p < 0.05$ level,

**$p < 0.01$ level