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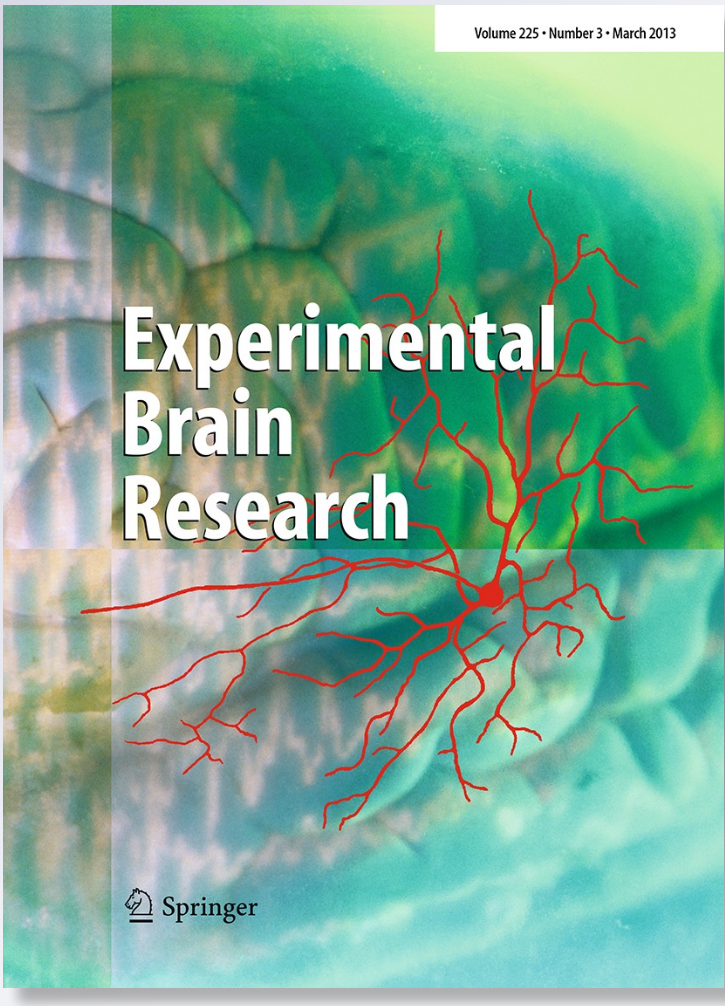

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RESEARCH ARTICLE

Perceiving affordances for different motor skills

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Abstract We examined several factors that affect people's ability to perceive possibilities for action. In Experiment 1, 24 participants crossed expanses of various sizes in three conditions: leaping, a familiar, launching action system; arm-swinging on monkey bars, an unpracticed skill that uses the arms rather than the legs; and crawling on hands and knees, a disused skill that involves all four limbs. Before and after performing each action, participants gave verbal judgments about the largest gap they could cross. Participants scaled initial judgments to their actual abilities in all three conditions. But they considerably underestimated their abilities for leaping, a launching action, and for arm-swinging when it was performed as a launching action; judgments about crawling, a non-launching action, and arm-swinging when it was performed as a non-launching action were more accurate. Thus, launching actions appear to produce a deficit in perceiving affordances that is not ameliorated by familiarity with the action. However, after performing the actions, participants partially corrected for the deficiency and more accurately judged their abilities for launching actions—suggesting that even brief action experience facilitates the perception of affordances. In Experiment 2, we confirmed that the deficit was due to the launching nature of the leaping and arm-swinging actions in Experiment 1. We asked an additional 12 participants to cross expanses using two non-launching actions using the legs (stepping across an expanse) and the arms (reaching across an expanse). Participants were highly accurate when judging affordances for these actions, supporting launching as the cause of the underestimation reported in Experiment 1.

Keywords Affordances · Visual perception · Motor action · Human locomotion · Perception–action links

Introduction

While walking on a rainy day, pedestrians encounter puddles of different sizes. What to do? Step over the puddle, leap over it, or detour around it? Deciding whether and how to cross a puddle illustrates a common problem for action: moving the body or part of the body over an expanse. People routinely cross puddles and other such obstacles using their legs and they similarly cross expanses with their arms in many everyday reaching tasks. To guide such actions adaptively, people must perceive which actions are possible and which are not.

Possibilities for action—what Gibson (1979) termed "affordances"—depend on the fit between body characteristics and environmental features. If the puddle is too large relative to leg length and walking skill, then stepping is impossible. Although perceiving affordances is a common problem in daily lzife, researchers know relatively little about the dynamic processes that affect affordances and the factors that affect perception of affordances. One impediment to progress is that previous work has focused on a small subset of highly familiar actions such as walking up stairs (Warren 1984; Mark 1987; Konczak et al. 1992; Pufall and Dunbar 1992), sitting on chairs (Mark et al. 1990), walking through doorways (Warren and Whang 1987; Higuchi et al. 2006; Franchak et al. 2010; Fath and Fajen 2011), and walking over slopes (Kinsella-Shaw et al.

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1992; Joh et al. 2007; Regia-Corte and Wagman 2008). Is all perception of affordances equivalent, or do the specific action characteristics matter? Without testing a range of actions, we cannot know. The current studies redressed this deficiency by assessing perception of affordances for crossing expanses using very different action systems: leaping and stepping with the legs, swinging with the arms, reaching with the arms and torso, and crawling using both arms and legs.

Factors affecting affordances

Body size affects affordances. Taller people take larger walking steps and can step over a wider expanse than shorter people (Mark et al. 1999). Longer-armed participants can reach farther over an expanse than shorter-armed participants (Carello et al. 1989). More slender people can squeeze through narrower doorways (Franchak et al. 2010; Comalli et al. 2012). Similarly, wider shoulders necessitate shoulder rotation for larger doorways compared with narrower shoulders (Warren and Whang 1987). The body-environment relation also holds true for infants. For example, infants with longer legs can step down larger drop-offs (Kretch and Adolph 2013).

Experience could also be an important factor for determining the limits of people's abilities. Previous studies show that the duration of infants' walking experience predicts the size of their walking steps on flat ground (Bril and Breniere 1989; Adolph et al. 2003). And over weeks of walking experience, infants can walk up and down steeper slopes (Adolph 1997), and they can step over larger drop-offs (Kretch and Adolph 2013), higher barriers (Schmuckler 1996), larger gaps (Zwart et al. 2005), and narrower bridges (Kretch and Adolph, in press).

However, affordances depend on more than body size and experience: A variety of dynamic factors alter the limits of motor abilities—and by extension, affordances. Stronger people can jump higher (Bruhn et al. 2004) and farther (Castro-Piñero et al. 2010). Compressibility is a better predictor of people's ability to squeeze through doorways than body dimensions or weight (Comalli et al. 2012). Balance, not body size, predicts infants' and adults' ability to walk over a narrow ledge (Comalli et al. 2012; Franchak and Adolph 2012b). How an action is performed can also change motor capabilities. For example, swinging the arms during a standing long jump can increase the distance covered by over 20 % compared to jumping with no arm movement (Ashby and Heegaard 2002). Likewise, some people squeezed through smaller openings while in motion—twisting and torqueing themselves through the doorway—than when pressed into the doorway while standing still (Franchak et al. 2009, July). Although Gibson (1979) and others (Fajen et al. 2008) have acknowledged that dynamic and performance factors affect affordances, such factors have not been systematically addressed in the affordance literature.

Factors affecting perception of affordances

Because action and perception are inherently intertwined (Gibson 1979), the same factors that affect possibilities for action—such as body size and experience—should affect people's perception of what they can do. The previous research shows that people take their body dimensions into account when judging affordances for a variety of actions. For example, judgments about sitting on chairs, climbing stairs (Mark 1987), stepping over an expanse (Mark et al. 1999), and squeezing through doorways (Warren and Whang 1987; Franchak et al. 2010) are all scaled to standing height.

For infants, experience is a critical factor in perceiving affordances. Without several weeks of experience with a new action system, infants do not scale actions to their body capabilities. The same infants who avoid risky slopes in a familiar crawling posture march straight down impossibly steep slopes when tested moments later in their new inexperienced walking posture (Adolph 1997), requiring rescue by an experimenter. Furthermore, infants seem unable to take advantage of brief experiences performing an action to immediately increase their accuracy (Joh and Adolph 2006; Adolph et al. 2010). Ignoring their failures on previous trials, novice walkers attempt to walk over the brink of impossibly high 90-cm drop-offs (Kretch and Adolph 2013), down impossibly steep 50° slopes (Adolph et al. 2008), and into gaps wider than the length of their bodies (Adolph et al. 2011).

The role of experience in adults' perception of affordances is less clear. Previous work indicates that adults rapidly account for abrupt changes in body dimensions, making accurate decisions about sitting and walking under doorways in platform shoes (Mark et al. 1990; Stefanucci and Geuss 2010) or high hats (Stefanucci and Geuss 2010), and about fitting through narrow apertures while wearing shoulder pads (Higuchi et al. 2006) or a "pregnancy pack" (Franchak and Adolph 2012a); prior experience with the altered body dimensions does not seem necessary for accurate perception. However, these manipulations represent relatively minor changes to familiar, well-practiced perception–action systems. The only studies to test adults' perception of truly novel affordances show mixed results: Just two minutes of experience moving in a wheelchair allowed participants to accurately judge the minimum height they could pass beneath in a wheelchair (Stoffregen et al. 2009), yet 8 days was insufficient to correctly judge the minimum width needed to pass through an aperture in a wheelchair (Higuchi et al. 2004). Likewise, some studies find trial-to-trial improvements in perceptual accuracy

(Mark et al. 1990; Stoffregen et al. 2005; Yu et al. 2011), while others find no such improvement (Stoffregen et al. 2009). Thus, it is unclear how much, if any, experience is required for accurate perception in adults.

In addition to obscuring the role of experience in adults' perception of affordances, the limited range of actions used in the affordance literature has a second negative effect. By focusing on situational variations on the same set of actions, it is impossible to know how specific action characteristics affect perception. Some researchers have drawn a convenient distinction between body scaled affordances, where body size is the limiting factor in determining what actions are possible, and action-scaled affordances, where the mechanics of action are the limiting factor (e.g., Fajen et al. 2008). But these same researchers largely agree that both body size and action are always a consideration. Action scaling simply has not been the focus of most previous work, in part because the previous work has relied on tasks where body size alone largely determines success or failure. Thus it is unclear whether or how different action mechanics affect the perception of affordances. Consistent reports of accurate perception of affordances might indicate that the adult perceptual system can accurately account for a range of factors that affect motor abilities. Alternatively, this consistent accuracy could simply be an artifact of reliance on a restricted set of movement types—ones where affordances are largely determined by body size. Without expanding the range of action systems tested, it is impossible to know.

In two experiments, we addressed this omission by asking participants to judge affordances for a range of actions (leaping over an expanse, swinging from the arms across "monkey bars," and so on), assessing their actual abilities in the same tasks, and then reassessing perceptual judgments after brief practice with the actions. Each action involved a different set of effectors, degree of familiarity, and movement dynamics. By measuring participants' perceived abilities prior to performing the actions in the laboratory, we asked whether adults are equally accurate when judging affordances for a wider range of actions. By assessing perceptual accuracy again after participants performed the actions, we were able to ask whether brief practice was sufficient to aid perceptual accuracy, as some previous work would suggest (Franchak et al. 2010).

Experiment 1

In Experiment 1, participants gave verbal judgments of the limit of their abilities before and after performing each of three actions: leaping, arm-swinging, and crawling. We expected participants to be most accurate judging affordances for leaping because locomoting on two legs is a highly practiced action system in adults. Arm-swinging is an unpracticed form of locomotion and involves effectors not typically used for locomotion. Quadrupedal crawling is unique because it is disused (after infancy, few people crawl for long distances) and crawling has enhanced stability from using four, rather than two, limbs for support. We anticipated that the different nature of the actions would affect maximum abilities; however, we could not predict whether participants would accurately perceive affordances for either crawling or arm-swinging—actions that are more unusual.

Method

Participants

Participants were 24 college-aged adults (12 men, 12 women) from the New York City area who volunteered or participated in partial fulfillment of a course requirement. All were informed that the study was physically strenuous and were instructed to wear loose-fitting, comfortable clothes to ensure freedom of movement. None had physical injuries that would interfere with their participation, and all had normal or corrected to normal vision. Prior to inclusion, all participants gave informed consent. All procedures reported were approved by the local ethics committee.

Apparatus

The apparatus for the leaping condition was a 297 cm long × 96 cm wide × 5 cm thick foam mat covered with nubby carpet (Fig. 1a). The landing target was a plastic strip (12 cm long × 96 cm wide) that could be moved along the walkway in 1-mm increments. A video camera attached to the landing target recorded the size of the expanse. A second camera recorded a front view of the participant at the starting position, and a third camera recorded the participant's legs across the entire expanse from a side view.

An adjustable monkey bar apparatus was constructed for the arm-swinging condition (Fig. 1b): The placement of the horizontal ladder was adjusted relative to each participant's height to maintain the participant's feet at 18 cm above the floor. The landing bar was also adjustable to provide a continuous range of distances in 1-mm increments. A video camera clipped to the landing bar recorded the size of the expanse. Two additional cameras recorded front and side views of the participant's entire body and movements during the task.

For the crawling condition, two high-density foam mats (96 cm long × 96 cm wide × 5 cm thick) were placed over the same walkway used in the leaping condition; the starting mat was laid flush against where the walkway

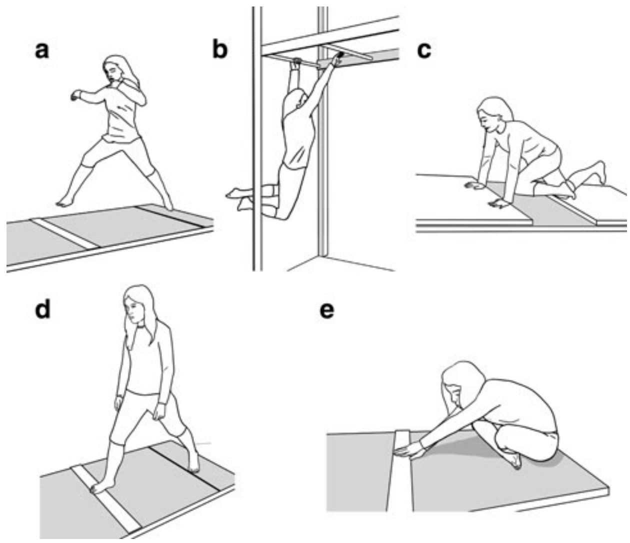

Fig. 1 Line drawings of testing apparatus and actions used in both experiments. Experiment 1: **a** leaping, **b** arm-swinging, and **c** crawling. Experiment 2: **d** stepping and **e** reaching

began and the landing mat was adjusted in 1-mm increments (Fig. 1c). A video camera attached to the side of the landing mat recorded the size of the expanse, and two additional cameras captured front and side views of the participant, respectively.

Procedure

Before starting the experiment, we told participants that we were interested in the limits of people's abilities for different actions (leaping with the legs, arm-swinging from monkey bars, and crawling on all fours) and how accurately people could perceive those limits. We told participants that they would make judgments about each action, then perform each action. The experimenter briefly demonstrated all three actions before participants gave informed consent in accordance with New York University's IRB. Participants then judged and performed all three actions in one of the six orders, counterbalanced for gender. Before each condition, the experimenter explained the action to be performed in detail, demonstrating correct performance and acting out errors that would constitute a failure.

Because arm-swinging on monkey bars had unique criteria for success (there was no opportunity for additional steps forward or back, and participants had to land both limbs on the far bar), we specifically designed the other two actions to be parallel. When leaping, participants had to land on the target strip with both feet, without taking additional steps before or after leaping. A successful leap was described verbally and modeled by the experimenter. The experimenter also explained and modeled errors that would constitute failures: Taking additional steps after landing to regain balance, grabbing the experimenter for support, and not getting at least the balls of both feet onto the target. A wall behind participants prevented them from taking a step back prior to leaping. When arm-swinging, participants had to get both hands to the landing monkey bar. The platform beneath participants' feet was removed at the start of each trial to ensure that they did not kick off the platform. When crawling, participants had to get both hands and one knee onto the landing mat without touching the floor between the mats. To ensure that participants did not propel themselves forward by pushing against the mat with their feet, they were told to keep their toes pointed back.

Once participants indicated they understood the action to be performed, we collected an initial set of perceptual judgments. The experimenter asked participants to judge the farthest distance they could go in the modeled action. Using the method of adjustment as in the previous work (Mark et al. 1990; Mondschein et al. 2000; Joh et al. 2007; Stoffregen et al. 2009), an experimenter moved the landing target (leaping), monkey bar (arm-swinging), or landing mat (crawling) along the increments, alternating the starting point of the target between easily traversable distances close to the participant and impossibly far distances several feet away from the participant, for a total of four trials per condition. Participants reported when the landing targets were at the farthest expanse they could traverse. All judgments were made from the starting posture of the action being tested: standing with the toes behind the starting line (leaping), on hands and knees with the hands behind the front edge of the mat (crawling), and standing with both hands on the starting bar with toes just barely touching a supporting platform (arm-swinging). The average of the four trials was taken as the farthest expanse participants judged crossable.

Then the experimenter told participants that they should perform the action. We used a modified psychophysical staircase procedure (Adolph 1995; Franchak et al. 2010) to estimate the farthest expanse participants could actually cross. Trials began with the average expanse participants had verbally reported they could cross. The distance was increased by 8 cm each time participants successfully crossed the expanse and decreased by 4 cm each time they failed until converging on their affordance threshold—the largest expanse they could cross, to within 4 cm. These staircase increments allowed us to estimate ability in a minimum number of trials.

Participants were encouraged to attempt all expanses, even if they thought they would fail, to provide measures of motor abilities even when participants perceptually underestimated. An experimenter stood by to ensure their safety. After each trial, participants turned away from the apparatus while the landing target was readjusted. Following the action task, a second set of verbal judgments were obtained using the same method of adjustment procedure. Success and failure were initially coded in real time by the experimenter. The codes were later verified from frame-by-frame coding from captured videos of each session using the video-coding software OpenSHAPA (www.openshapa.org).

Results and discussion

Affordance thresholds

Affordance thresholds—the largest increment participants were able to successfully cross—varied widely within and between conditions. Participants travelled the farthest distances while leaping. Thresholds for leaping ranged from 121 to 212 cm; the range for arm-swinging was 48–130 cm; and the range for crawling was 59–108 cm. Crawling thresholds were most tightly clustered. A three (condition) by two (gender) repeated-measures ANOVA confirmed differences between conditions, $F(2, 42) = 150.46$, $p < .01$. Post hoc comparisons (Sidak corrected) indicated that participants crossed larger gaps when leaping ($M = 157.54$ cm, SD = 26.61) compared with arm-swinging ($M = 84.65$ cm, SD = 26.86) and crawling ($M = 82.88$ cm, SD = 12.07), $p < .001$; crawling and arm-swinging did not differ, $p > .05$.

Larger people crossed larger expanses and men crossed larger expanses than women, corroborating that the staircase method gave accurate estimates of the limits of participants' abilities. The ANOVA confirmed a main effect of gender, $F(1, 21) = 22.48$, $p < .001$; the interaction between gender and condition was not significant, $F(2, 42) = 2.22$, $p = .12$. Height was correlated with thresholds for all three conditions, $rs > .52$, $ps < .03$. Weight was correlated with thresholds for leaping and crawling, $rs > .47$, $ps < .01$, but not arm-swinging $r = .33$, $p = .12$. Ten people swung farther than expected based on their height (thresholds larger than arm's length). Examination of the video recordings indicated that these unexpectedly proficient arm-swingers accomplished this feat by inducing pendular motion as they dangled from the bar to propel themselves further forward. Blind to participants' thresholds, two raters scored each video recording of arm-swinging and categorized each participant as either a "swinger" or a "hanger"; the raters agreed 100 %. Hangers dangled directly below the starting bar and quickly grabbed the landing bar. Swingers bent their bodies back and forth, building up momentum like pumping a swing, before releasing the starting bar at the height of the swing and allowing the momentum to carry them to the landing bar. Participants who induced pendular swing had larger arm-swinging thresholds than hangers, $t = 7.10$, $p < .001$. In this way, all of the nine swingers were able to reach landing bars placed beyond arms' length; only one hanger was able to reach bars more than arm's length away by flailing wildly until her hand made contact.

Perceptual judgments

Participants' judgments were roughly scaled to their abilities. People who crossed larger expanses in the affordance task predicted they could cross correspondingly larger distances in the pre- and posttest judgment tasks for each action (Fig. 2). At the initial pretest, judgments and affordance thresholds were correlated for all three actions, $rs > .58$, $ps < .01$. After performing the actions, judgments and thresholds remained highly correlated at posttest: leaping ($r = .92$), arm-swinging ($r = .94$), and crawling ($r = .74$), $ps < .01$. To a lesser extent, both pretest and posttest judgments were correlated with participants' body size. Judgments and height were correlated for leaping ($rs = .51$ and $.62$), arm-swinging ($rs = .58$ and $.52$), and crawling ($rs = .62$ and $.59$) for pre- and posttest, respectively, $ps < .05$.

However, we also found evidence of startling inaccuracies in participants' initial judgments. Although judgments were roughly scaled to abilities, participants often drastically underestimated their abilities. Of the 24 participants, 92 % underestimated their abilities for leaping at pretest (data points below the diagonal line on Fig. 2), 83 % for arm-swinging, and 71 % for crawling. On average, participants underestimated by 29.9 cm for leaping—despite its greater familiarity—and by 12.0 cm when arm-swinging and 8.8 cm when crawling. These inaccuracies were substantial, particularly for leaping. As seen in Fig. 3, pretest errors were as large as 87.8 cm in leaping—nearly a full meter discrepancy between perceived and actual abilities. For all three actions, errors were significantly greater than zero, $ts > 3.49$, $ps < .002$.

Although judgment error (motor ability minus perceptual judgment) was uncorrelated with motor ability for two of the three actions (r's $< -.37$, p's $> .08$ for leaping and crawling; see below for arm-swinging), it was conceivable that the larger distances possible in some actions could affect the accuracy of participants' judgments. Pretest judgment error was therefore analyzed using a linear mixed-effects model with all participants' affordance thresholds entered as a within-subjects covariate to adjust for the differences in ability between the actions. Even when adjusting for the larger distances covered in leaping, the model confirmed a significant main effect of condition in pretest judgment error, $F(2,45.96) = 10.02$, $p < .001$. As seen in Fig. 3, participants were significantly less accurate about leaping as compared to both crawling and

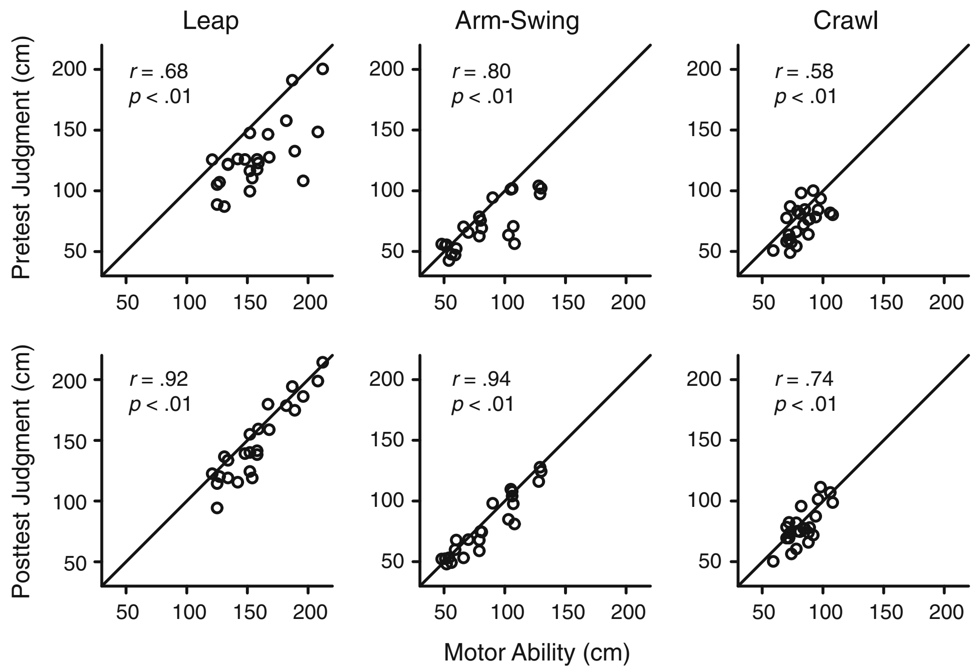

Fig. 2 Scatter plots of participants' judgments and motor abilities at both pretest (*top row*) and posttest (*bottom row*). The *diagonal line* represents perfect agreement between perceived ability and actual ability

arm-swinging, Sidak-corrected pairwise comparisons $ps < .01$. Crawling and arm-swinging did not differ from each other, $p = .89$.

Why would participants so drastically underestimate their abilities for locomoting on two legs, a highly practiced and familiar action system? The nine participants who performed arm-swinging as a launching action provide a suggestion. Although launching themselves allowed them to cross larger expanses, they incurred a penalty in terms of perceptual error: Compared to those who did not induce pendular motion, swingers were much less accurate in the arm-swinging task during the pretest, by an average of 13.4 cm (see Fig. 3). This simultaneous increase in distance travelled and perceptual error when arm-swinging was performed as a launching action caused pretest judgment error and motor ability to be correlated for arm-swinging when swingers and hangers are combined, $r = -.64$, $p = .001$. Participants' individual motor ability was therefore retained as a covariate to statistically adjust for differences in the maximum distance possible.

A mixed model consisting of condition, hanger/swinger status, and individual motor ability as a covariate confirmed the difference between launching and non-launching forms of arm-swinging, with a significant interaction between condition and arm-swinging strategy, $F(2,41.58) = 3.37$, $p = .04$; the main effect of condition remained, $F(2,41.58) = 9.83$, $p < .001$. Hangers made large errors only for leaping, ($p = .02$ compared to crawling and $p = .001$ compared to arm-swinging); crawling and arm-swinging were roughly equivalent ($p = .63$). Swingers, however, made substantial errors in both arm-swinging and leaping (Fig. 3). For swingers, judgments about both arm-swinging and leaping were less accurate than judgments about crawling ($p = .007$ and $p = .06$); arm-swinging and leaping did not differ, $p = .77$. Put simply, when performed as a launching action, judgments about arm-swinging look similar to judgments about leaping, another launching action. It would seem that for adults, experience may not be the key factor determining perceptual accuracy. Participants were inaccurate about a familiar action (leaping) and under some circumstances were accurate with a novel one (arm-swinging). Instead, whether or not the action requires participants to launch their body through the air matters more.

In contrast, brief experience performing the actions did allow participants to make more accurate judgments at posttest, particularly about leaping. Whereas 67 % of participants became more accurate in crawling and 67 % did so in arm-swinging, 87.5 % of people (all but 3) gave more accurate judgments about leaping after performing the

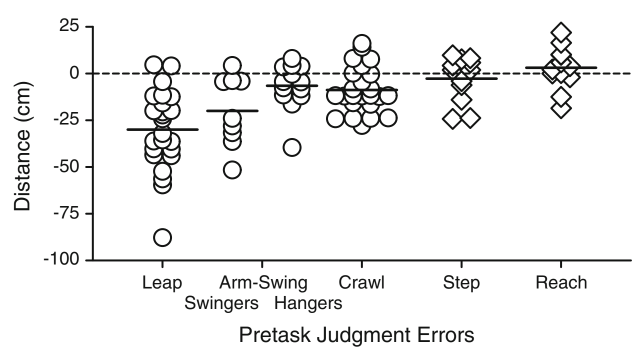

Fig. 3 Pretest error (difference between judgment and ability) by condition in Experiment 1 (*circles*) and Experiment 2 (*diamonds*). Errors less than zero are underestimation

action. This increased accuracy can be seen by comparing the scatterplots in the first column of Fig. 2. Initially, judgments for leaping underestimated actual abilities (data points below the diagonal line); at posttest, all judgments were tightly grouped around the diagonal, indicating a high correlation between perceived and actual abilities. Although participants updated slightly for all tasks (bottom row of Fig. 2), a three (condition) by two (hanger/swinger) repeated-measures ANOVA on the change in error from pre- to posttest (absolute value of error at pretest minus absolute value of error at posttest) confirmed a main effect of condition, $F(2, 40.85) = 6.79$, $p < .01$. Judgments improved the most in the leaping condition, $ps < .05$; no difference was found between the arm-swinging and crawling conditions, $p = .78$. Neither the main effect of swinging strategy nor the interaction between swinging strategy and condition were significant, $ps > .2$; the condition effect remained unchanged. However, swingers' judgments about arm-swinging were on average 10.85 cm more accurate at posttest, compared to an improvement of just 3.78 cm in the hangers. Although participants do not readily perceive affordances for launching actions accurately, with even brief experience they can partially correct their initial underestimation.

Experiment 2

In Experiment 1, we had expected participants to be most accurate about leaping because locomoting on two legs is a highly familiar and practiced task. Instead, participants underestimated their abilities when making judgments about launching actions. To confirm that this inaccuracy was a function of the launching nature of leaping (and "swingers" arm-swinging), we ran a second sample of participants using non-launching actions. Participants made judgments about their ability to step to a target—without leaping—and their ability to reach to a target from a sitting position. Stepping is very similar to the leaping condition of Experiment 1, but this time, instructions forbade participants from transitioning into leaping (i.e., at least one foot had to be in contact with the ground at all times). Reaching forward to a target involves the arms—as did crawling and arm-swinging—but involves no launching actions and no locomotion.

Methods

Participants were 12 college-aged adults (6 men, 6 women) from the New York City area who either volunteered or fulfilled a course requirement. The apparatus for both stepping and reaching conditions was the same walkway and landing target used in the leaping condition in Experiment 1 (Fig. 1d, e). Video cameras recorded the size of the expanse, the front view of the participant at the starting position, and the participant's limbs across the entire expanse from a side view.

Participants stepped and reached according to the same procedures as in Experiment 1. Before and after performing the actions, they verbally judged the farthest expanses they thought they could cross using the same method of adjustment. The limits of participants' abilities in each action were again determined by a modified staircase procedure, as described in Experiment 1. A successful stepping trial was defined as getting at least the balls of both feet securely onto the landing target without leaping or holding onto anything for support (Fig. 1d). When reaching, participants had to touch the landing target with the fingertips of both hands while sitting crossed-legged without letting their bottoms rise off the floor (Fig. 1e).

Following the action task, a second set of verbal judgments were obtained. Success and failure were initially coded in real time by the experimenter. The codes were later verified by frame-by-frame coding from captured videos of each session using the video-coding software OpenSHAPA.

Results and discussion

Although individual ability varied within conditions, affordance thresholds for stepping and reaching were not significantly different, $F(1,10) = .62$, $p = .45$. Stepping abilities ranged from 89 to 153 cm ($M = 121.83$); reaching abilities ranged from 97 to 147 cm ($M = 117.52$). For both actions, abilities were related to height, $rs > .62$, $ps < .03$, and weight, $rs > .59$, $ps < .04$. Neither the main effect of gender nor the interaction between gender and condition were significant, $ps > .55$. This was to be expected given that stepping and reaching require less strength than the actions tested in Experiment 1.

As in Experiment 1, participants' pretest judgments were roughly scaled to their abilities for both actions, $r = .81$, $p = .001$ for stepping and $r = .65$, $p = .02$ for reaching. Posttest judgments were also correlated with abilities, $r = .78$, $p = .003$ for stepping and $r = .87$, $p < .001$ for reaching. However, we found no evidence of the drastic underestimation seen in Experiment 1. Only 42 % of the 12 participants underestimated their abilities for stepping (compared to 92 % when leaping), and just 25 % underestimated for reaching. More importantly, errors were small: On average, participants tended to underestimate their abilities for stepping by 2.72 cm (SD = 12.04), but overestimate their abilities for reaching by 3.16 cm (SD = 11.27), Fig. 3. Errors for both actions were not significantly different from zero, $ps > .05$. Adjusting for any differences in abilities between the two actions, errors in reaching and stepping were not significantly different from each other, $F(1,11) = 1.23$, $p = .29$.

As seen in Fig. 3, errors for both stepping and reaching were substantially lower than those seen for leaping in Experiment 1. Instead, the distribution of errors for stepping and reaching looks very similar to that of errors in crawling—the most stable, non-launching action tested in Experiment 1. Although drawn from different samples, leaping and stepping were tested using the exact same procedure, allowing us to contrast the two as a between-subjects comparison. Even when adjusting for the larger distances that could be crossed in leaping by including actual abilities as a within-subjects covariate, errors were significantly higher for leaping, $F(2,33) = 17.79$, $p < .001$. Stepping and leaping are highly similar; both are locomotion on two legs and might have been expected to be part of the same perception–action system. Yet participants are fairly accurate at perceiving affordances for stepping and strongly underestimate their abilities for leaping.

Having been highly accurate judging their abilities to step and reach at pretest, participants had little room for improvement at posttest. Only 33 % of participants became more accurate judging stepping at posttest, and 42 % became more accurate when judging reaching. Moreover, participants updated their judgments by extremely small amounts: on average, stepping judgments were less accurate by 1.8 cm, whereas judgments about reaching improved by 2.9 cm. Accordingly, there was no effect of condition in the change in error measure, $t(11) = .03$, $p = .98$.

General discussion

This study is the first to compare perception of affordances across a range of actions with different dynamics and levels of familiarity. Broadening the range of observed actions provided new insight: Action characteristics affect people's ability to perceive affordances. Specifically, launching actions extend people's motor ability, but also lead to a deficit in perceptual accuracy. Participants grossly underestimated their abilities when asked to judge launching actions. This finding held when comparing across action systems (leaping vs. crawling), within action systems (leaping vs. stepping) and even within tasks (swingers vs. hangers during arm-swinging).

What is special about launching?

Why would participants underestimate their abilities for presumably familiar actions like leaping? Several possibilities can be ruled out. Fear of injury is an unlikely culprit. Leaping—the action with the greatest underestimation—was tested on flat ground on the same apparatus used in stepping and posed little risk to participants. The errors we observed are also not merely a result of uncertainty due to high motor variability. Launching actions by definition enlarge the problem space—a greater number of potential expanses are possible when launching than when constrained by body size—and are inherently more variable (e.g., Meylan et al. 2009). However, if variable performance across a large problem space alone were to blame, it would have led either to variable, inconsistent judgments, or to judgments that were just below the zone of uncertainty. In contrast, our participants gave judgments that were consistently far below actual abilities—they succeeded again and again at distances beyond what they judged to be the limit of their abilities. Furthermore, even young children can accurately take the variability of their own motor system into account (Snapp-Childs and Bingham 2009). Likewise, adults' judgments about the passability of horizontal and vertical openings accurately account for the greater variability seen in horizontal gait modifications (Franchak et al. 2012). Compression at far distances (Loomis and Beall 1998) can also be ruled out because we statistically controlled for distance in our analyses and participants' judgments still correlated well with individual abilities.

Instead, we propose that it is the launching nature of the action itself that leads to underestimation. Launching actions require the perceptual system to integrate body information with additional factors such as the ability to generate explosive force (either via a burst of muscle activity or by building up pendular momentum), the forward and upward aiming of that force, and the precise timing of the release of force. Based on the current data, the perceptual system seems unable to successfully integrate these additional factors to form accurate affordance judgments without practicing the action just prior to judging. This idea is supported by findings from the few other affordance studies to have included launching actions: Participants are accurate to within 2–3 cm when judging their maximum vertical reach, but underestimate their abilities by 10–16 cm when asked to judge the highest they can reach while jumping (Pepping and Li 2005; Ramenzoni et al. 2008, 2010). Just as in the current study, participants in these studies were highly accurate about a familiar, non-launching action but underestimated their abilities when performing a similar launching action.

One possible reason for this deficit is a lack of direct perceptual information about explosive force. Stored knowledge of potential force is impractical and unreliable because explosive force is highly variable and dependent on transient factors such as motivation and level of fatigue. Furthermore, most people rarely experience the fullest extent of their ability to generate explosive force, making stored knowledge about abilities unlikely. Alternatively, it is possible that the perceptual system does have access to information about explosive force, but does not initially know how to use that information to form accurate judgments. Lack of experience with the full limit of one's ability to generate explosive force might further contribute to difficulty using perceptual information.

Whether due to poor information, the inability to use information, or both, our results suggest that the perceptual system simply does not a priori take explosive force capacity into account. Instead, it bases judgments on the information it does have and does know what to do with—such as body dimensions—leading to judgments that are correlated with individual abilities, but do not reflect the extra distance that launching actions permit. Initial judgments about launching actions were gross underestimations because they did not sufficiently include the additional distance afforded by launching.

What is the role of experience?

Difficulty in obtaining and integrating information about explosive force helps to explain a seeming contradiction in our data regarding the role of experience: Participants were in some cases able to give accurate judgments about novel actions (arm-swinging), but were highly inaccurate about a familiar action (leaping) due to the launching nature of the actions. However, another seeming contradiction remains: Whereas participants' accumulated experience locomoting on two legs was insufficient for accurate perception of leaping at pretest, a few brief trials in the laboratory were enough to accurately perceive affordances for leaping at posttest. At pretest, our participants already had much of the information necessary to accurately perceive their abilities, but failed to integrate information about explosive force. Only a few brief trials of practice in the laboratory were needed to allow them to take this additional information into account. This rapid increase in accuracy is similar to those reported when adults are given additional information about an already familiar action system through practice (Franchak et al. 2010), rather than an infant learning about a new perception–action system over the course of months of locomotor experience (Adolph and Joh 2009).

It would be interesting to see how accurately subjects who routinely engage in launching forms of action—such as gibbons or parkour experts—would perceive affordances. Although the participants in our study were unable to accurately judge affordances for launching actions before performing them in the laboratory, both gibbons and parkour practitioners have extensive experience with explosive force and launching. Moreover, a gibbon swinging through the treetops or a parkour expert leaping from building to building would pay a high penalty for perceptual errors. They might therefore by necessity have become better calibrated for explosive force and be able to include this information in their perceptual judgments. It is also possible, however, that launching actions are more difficult to accurately judge regardless of one's long-term experience.

The fact that participants were able to give moderately accurate judgments that correlated with individual abilities for unfamiliar actions was also a surprise. Although abilities for crawling and non-launching arm-swinging were significantly underestimated at pretest, errors were only around 10 cm for both actions. This is likely due to adults' lifetime of experience moving the body in a variety of ways. When not performed as launching actions, crawling and arm-swinging are largely constrained by body dimensions and require no dramatic feats of coordination. Participants know or have perceptual access to their relevant body dimensions. And even if they are not familiar with the exact movements of crawling and arm-swinging, they have had extensive experience with the basic limits of what the body can do. Accordingly, they were able to make reasonably accurate—though still imperfect—judgments about these actions. Interestingly, however, the average error of 10 cm found for these two actions—while substantially less than that seen for leaping—is still larger than the 2–3 cm errors reported for highly familiar, non-launching actions both in the current studies (stepping and reaching in Experiment 2) and in previous work (Franchak et al. 2010). In fact, errors for stepping and reaching were not significantly different from zero. Participants were thus highly accurate when judging familiar, non-launching actions (stepping and reaching), slightly inaccurate when judging unfamiliar, non-launching actions (crawling and hanging arm-swinging) and severely inaccurate for judging launching actions, regardless of their familiarity (leaping and swinging arm-swinging). We therefore find evidence supporting the influence of both familiarity and launching on perceptual accuracy: Familiarity with the action helps when judging non-launching actions, but the difficulties of judging launching may override familiarity.

Conclusions

Accurate affordance judgments have to take into account a host of factors—body size, strength, coordination, and skill at the particular action—but these factors have typically been studied en masse. Adult work has focused on a range of tasks that are familiar and not challenging to motor control, leaving body size as the best predictor of abilities. Although research with infants has used tasks that are challenging (slopes, cliffs, gaps, barriers, ledges), infant's nascent skills are poor and the effects of experience dominate. Such work has demonstrated that the perceptual system can accurately account for these factors, but neither literature has allowed us to see whether different action characteristics affect perception. By adding explosive force to the equation, we have shown that adults are not equally skillful at integrating all types of information to form perceptual judgments. However, even brief experience was sufficient to recalibrate and take additional information about explosive force into account, demonstrating the immense flexibility of the perceptual-motor system.

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