Kinetic potential influences visual and remote haptic perception of affordances for standing on an inclined surface

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The ability of a perceiver–actor to perform a particular behaviour depends on their ability to generate and control the muscular forces required to perform that behaviour. If an intended behaviour is to be successful, perception must be relative to this ability. We investigated whether perceiver–actors were sensitive to how changes in their mass distribution influenced their ability to stand on an inclined surface. Participants reported whether they would be able to stand on an inclined surface while wearing a weighted backpack on their back, while wearing a weighted backpack on their front, and while not wearing a weighted backpack. In addition, participants performed this task by either viewing the surface or exploring it with a hand-held rod (while blindfolded). The results showed that perception of affordances for standing on the inclined surface depended on how the backpack influenced the ability of the participant to stand on the surface. Specifically, perceptual boundaries occurred at steeper inclinations when participants wore the backpack on their front than when they wore it on their back. Moreover, this pattern occurred regardless of the perceptual modality by which the participants explored the inclined surface.

Keywords: Perception–action; Affordances; Visual perception; Haptic perception.

In order to successfully engage in an intended behaviour (e.g., grasping an object or stepping on an elevated surface), perceiver–actors must be able to perceive (and behave with respect to) opportunities for behaviour (e.g., whether the object is within reach or whether the surface can be stepped on). Such opportunities for behaviour have been termed affordances (Gibson, 1979). Affordances are determined by the “fit” between properties of the environment and the action capabilities of a perceiver–actor (Chemero, 2003; Turvey, 1992). If intended behaviours are to occur successfully, perception must be relative to these action capabilities. That is, perception must be “action-scaled” (see Proffitt, 2006a, 2006b).

In part, action capabilities are determined by the geometric properties of the perceiver–actor (e.g., height, leg length, shoulder width, etc.). Whether stairs afford climbing by a particular person is determined, in part, by the person’s leg
length. Along these lines, Warren (1984) found that perception of this affordance was constrained by this property of the perceiver–actor. The boundary between stairs that were perceived to afford climbing and those that were not occurred at a lower riser height for participants with short legs than for those with long legs but occurred at the same ratio of riser height to leg length for each group of participants. Similarly, perception of whether a doorway affords passing through is constrained by the shoulder width of the perceiver–actor (Warren & Whang, 1987), and perception of whether a doorway can be passed through in a wheelchair is constrained by the width of the wheelchair (Higuchi, Takada, Matsuura, & Imanaka, 2004).

Action capabilities are also determined, in part, by the kinetic potential of the perceiver–actor—the ability to generate and control the muscular forces required to perform a particular behaviour (see Oudejans, Michaels, Bakker, & Dolné, 1996; Wagman & Malek, 2007). Whether stairs afford climbing by a particular person also depends on the strength and flexibility of that person’s legs. Along these lines, Konczak, Meeuwsen, and Cress (1992) found that the boundary between stairs that were perceived to afford climbing and those that were not occurred at a lower riser height (and a lower ratio of riser height to leg length) for older participants (mean age \( = 71.5 \) years) than for younger participants (mean age \( = 23.5 \) years). This difference in perception was due to differences in the kinetic potential between the two groups—the older participants were less able to generate and control the muscular forces required for climbing stairs (Konczak et al., 1992). Similarly, perception of whether rock-climbing holds can be reached depends on one’s level of fatigue while climbing (Pijpers, Oudejans, & Bakker, 2007).

**Kinetic potential and perception of geographic properties**

Research by Proffitt and colleagues (Bhalla & Proffitt, 1999; Proffitt, Bhalla, Gossweiler, & Midgett, 1995; Proffitt, Stefanucci, Banton, & Epstein, 2003; see Proffitt, 2006a, 2006b, for a review) has shown that the perception of geographic properties (e.g., geographic slant or egocentric distance) is also influenced by a perceiver’s kinetic potential. For example, perception of geographic slant is influenced by both the angle of inclination and the ability of the perceiver to generate and control the muscular forces required to traverse the slope. Hills appear steeper to participants who were fatigued (as a result of running a long distance) than to participants who were not fatigued, and hills appear steeper to elderly participants than to younger participants (Bhalla & Proffitt, 1999). Such differences in perception between the groups of participants are probably due to differences in their kinetic potential. It is more difficult for fatigued or elderly perceiver–actors to generate the muscular forces required for walking or standing on an inclined surface. As a result, the hills appeared steeper to them than to the nonfatigued or younger participants.

**Attachments to the body and changes in kinetic potential**

Bhalla and Proffitt (1999) also found that hills appear steeper to participants who were wearing a weighted backpack than to participants who were not wearing a weighted backpack. Similarly, such differences in perception are probably due to differences in the ability to generate and control the muscular forces required for walking or standing on an inclined surface. Wearing a weighted backpack changes this ability in at least two ways. It not only increases the amount of muscular force required (by increasing the mass of the perceiver–actor), it changes the directions in which those forces are required (by changing the mass distribution of the perceiver–actor).

Wearing a weighted backpack on the back of the body raises one’s centre of mass (i.e., makes one “top-heavy”) and shifts the centre of mass away from the inclined surface (i.e., it makes one “back-heavy”). Such a shift in centre of mass will tend to pull the participant off of the inclined surface. Standing on an inclined surface in this
scenario requires generating muscular forces required to overcome the effects of the inclined surface plus the effects of the weighted backpack. Therefore, wearing a weighted backpack on the back should make it more difficult to stand on an inclined surface. In contrast, wearing a weighted backpack on the front of the body raises the centre of mass and shifts it towards the inclined surface. Such a shift in centre of mass will tend to hold the participant on the inclined surface. Standing on the inclined surface in this scenario requires generating muscular forces required to overcome the effects of the inclined surface minus the effects of the weighted backpack. Therefore, wearing a backpack on the front should make it easier to stand on the inclined surface.

Thus, the influence of a weighted backpack on the ability to stand on an inclined surface should differ depending on how the backpack changes the mass distribution of the person-plus-object system (i.e., whether it is worn on the front or the back). The present study investigated this possibility and, more importantly, whether perception of affordances for standing on an inclined surface is influenced by these changes in kinetic potential.

Structured energy arrays and perception of affordances

Proffitt and colleagues have shown that changes in kinetic potential brought on by a weighted backpack influences perception of geographic properties (see Proffitt, 2006a, 2006b, for a review). Presumably, this perceptual experience has adaptive value to the extent that it influences decisions about whether (and how) to perform a particular behaviour (i.e., that it influences perception of affordances). If intended behaviours are to be successful, perception must be relative to the action capabilities of the perceiver–actor. From the ecological approach to perception–action, the stimulation patterns that support perception of affordances can be found in structured ambient energy arrays (Gibson, 1979). Perception will be relative to the action capabilities of the perceiver–actor if (a) the structure in a given energy array is sufficient to support perception of the affordance and (b) if the perceiver–actor is capable of detecting this structure (Turvey & Shaw, 1999).

Perception of whether an inclined surface affords standing on should be relative to the ability of the perceiver–actor to generate the muscular forces required to stand on that surface. From the ecological perspective on perception–action, so long as the above conditions (a and b) are met, perception of this affordance should be relative to such action capabilities regardless of the modality by which such structured energy is detected (see Carello, Wagman, & Turvey, 2005). However, this does not necessarily mean that the perceptual modalities are equally efficient at influencing decisions about behaviours. For example, due to many years of experience in performing visually guided actions, (sighted) perceiver–actors are likely to be less aware of (and less confident in) their ability to detect such structured energy by perceptual modalities other than vision.

Fitzpatrick, Carello, Schmidt, and Corey (1994) investigated these hypotheses. Participants reported (yes or no) whether they would be able to stand on an inclined surface both (a) while viewing the surface and (b) while exploring (i.e., probing, tapping) it with a hand-held rod while blindfolded (i.e., exploring it by means of remote haptic perception). Although the perceptual reports varied as function of angle of inclination, there was no difference in perceptual reports in the two modality conditions. Moreover, the boundary between inclinations that were perceived to afford standing on and those that were not occurred at the same angle of inclination in each case, and this value was within a few degrees of the actual (behavioural) boundary for this behaviour (an inclination of approximately 30°; see also Klevberg & Anderson, 2002).

That is, Fitzpatrick et al. (1994) found that perception of whether an inclined surface afforded standing on was relative to the perceiver–actor’s action capabilities regardless of whether they viewed the surface or probed it with a hand-held rod. Participants were less confident in their
perceptual responses when they explored the surface haptically than when they did so visually. However, in both conditions, minimum confidence occurred within a range of surface inclinations that included the perceptual boundary (i.e., when more fine-grained distinctions were required; Fitzpatrick et al., 1994).

A weighted backpack is likely to alter the ability of a perceiver–actor to stand on an inclined surface, and perception of whether an inclined surface affords standing on should be relative to these altered action capabilities. However, such a change in action capabilities is unlikely to alter either (a) whether structure in any given energy array is sufficient to support perception of this affordance or (b) the ability of the perceiver–actor to detect such structure. Thus, such a change should not differentially affect the ability to detect such structure by means of different perceptual modalities. Therefore, perception of whether an inclined surface affords standing on while wearing a weighted backpack should be relative to these altered action capabilities regardless of the perceptual modality by which such structure is detected (i.e., regardless of whether the surface is explored visually or by means of a hand-held rod). The present study investigates this hypothesis.

The present study

The present study builds on the work of Proffitt and colleagues (e.g., Bhalla & Proffitt, 1999) and on that of Fitzpatrick and colleagues (Fitzpatrick et al., 1994) in several ways.

First, we investigated whether changes in kinetic potential brought on by wearing a weighted backpack influence perception of affordances for standing on an inclined surface. Second, we investigated whether perception of this affordance is influenced in different ways depending on how the changes in a perceiver–actor’s mass distribution influence their kinetic potential for this behaviour (i.e., whether the weighted backpack is worn on the back or on the front). Third, we investigated whether perception of this affordance is influenced by such changes in kinetic potential regardless of whether the inclined surfaced is viewed or explored with a hand-held rod.

We had several specific hypotheses. First, we expected that wearing a weighted backpack would influence perception of whether an inclined surface affords standing on and that it would do so in different ways depending on how the changes in mass distribution affect the ability to stand on that surface. Specifically, we expect that (a) perceiver–actors will report that they would be able to stand on the inclined surface less often when wearing the backpack on their back than when wearing it on their front, (b) perceiver–actors would exhibit perceptual boundaries at smaller angles of inclination when wearing the backpack on their back than when wearing the backpack on their front, and (c) perceiver–actors would exhibit behavioural boundaries at smaller angles of inclination when wearing the backpack on their back than when wearing it on their front.

Second, although we expected that (d) perceiver–actors would be more confident in their perceptual responses when the inclined surface was explored visually than when it was explored haptically (see Fitzpatrick et al., 1994; Klevberg & Anderson, 2002), we expected that (e) perception of this affordance would be influenced by (the changes in) kinetic potential in each case (and would therefore be relative to action capabilities in each case).

Method

Design

The experiment used a 2 (perceptual modality: vision vs. remote haptic) × 3 (mass placement: backpack worn on back vs. backpack worn on front vs. no backpack) mixed design with perceptual modality as a between-participants variable and mass placement as a within-participants variable.

Participants

A total of 40 undergraduate students (15 men and 25 women) at Illinois State University participated in this experiment in fulfilment of an extra credit
option in their psychology courses. A total of 20 participants were included in each perceptual modality condition; 8 men and 12 women participated in the vision condition; 7 men and 13 women participated in the remote haptic condition. The two groups of participants differed neither in their heights (vision, 172.5 cm; remote haptic, 169.4 cm) nor in their weights (vision, 65.7 kg; remote haptic, 69.1 kg, \( p > .25 \)). The procedure required that participants (a) wear a weighted backpack in two of the three mass placement conditions and (b) attempt to stand on the inclined surface at the end of the experiment. Therefore, in the interest of participant safety, participants were deemed inappropriate for the study (prior to data collection) if they weighed more than 91 kg (200 lbs), if they wore shoes with heels that were greater than 5 cm in length, or if they reported that the amount of weight in the backpack caused them discomfort.

**Materials and apparatus**

The apparatus consisted of a wooden surface \((152 \mathrm{~cm} \times 76 \mathrm{~cm})\) that was reinforced with metal braces so that it was strong enough to support a participant (and backpack) up to 105 kg. One end of the surface was hinged to a wooden frame \((91 \mathrm{~cm} \times 76 \mathrm{~cm})\) so that the angle of inclination of the surface could be adjusted. The other end of the surface was supported by a metal dowel resting on hooks that were screwed into the back of wooden studs \((122 \mathrm{~cm} \text{ tall, one on each side of the platform})\). The hooks were placed at seven different heights \((40 \mathrm{~cm}, 45.5 \mathrm{~cm}, 56 \mathrm{~cm}, 65.5 \mathrm{~cm}, 74.5 \mathrm{~cm}, 86 \mathrm{~cm}, \text{ and } 100 \mathrm{~cm} \text{ from the ground})\) so that the surface could be set at seven different angles of inclination, ranging from \(15^\circ\) to \(45^\circ\) in increments of \(5^\circ\) (see Figure 1). The front of each wooden stud (the side facing the participant) was covered with cardboard so that the hooks were not visible to the participant. Prior to the experiment, a scale was used to measure participants’ body weight.

In two of the three mass placement conditions, exercise free weights in 2.3 kg (5 lb) and 4.6 kg (10 lb) increments were placed in an ordinary backpack. For a given participant, the amount of weight in the backpack was approximately equal to 15% of his or her body weight. This proportion of additional weight has been shown to influence (a) perception of geographic properties (Bhalla & Proffitt, 1999; Proffitt et al., 2003; see Proffitt, 2006a, 2006b, for a review) and (b) whether infants attempt to descend slopes (Adolph & Avolio, 2000). In the remote haptic condition, participants wore a pair of blackened occlusion goggles (so that they were unable to see the surface or the surrounding environment) and used a wooden dowel \((1 \mathrm{~m} \text{ in length, } 1 \mathrm{~cm} \text{ in diameter})\) to explore the surface. A support railing was provided for participant safety.

**Procedure**

**Perceptual task.** Participants stood on the scale, and their body weight was recorded. They stepped...
down from the scale on to the laboratory floor and stood facing the surface in a designated area (60 cm wide × 45 cm deep) that was approximately 1 m from the surface. Prior to each trial, the experimenter adjusted the angle of the surface (by raising and lowering the metal dowel that supported the surface). Participants then provided two responses. First, they reported (“yes” or “no”) whether they would be able to stand on the surface at that angle while maintaining “normal upright posture” (i.e., by flexing their ankles to align their body with the gravitational vector but without making postural adjustments such as going up on the toes or bending at the waist or knees; see Fitzpatrick et al., 1994). Second, they provided their confidence in that report on a scale of 1 to 7 (where 1 indicated “not at all confident”, and 7 indicated “extremely confident”). Participants kept their shoes on during the experiment and were given as much time as necessary to provide each response.

Participants performed this task in each of three mass placement conditions. In the back-weighted condition, participants wore the weighted backpack on their back (i.e., as one would normally wear a backpack). In the front-weighted condition, participants wore the weighted backpack on their front. The backpack hung at the same height on the participant in each of these conditions. In the unweighted condition, participants did not wear a backpack.

Participants performed this task by exploring the surface by one of two perceptual modalities. In the vision condition, participants closed their eyes until the angle of the surface was adjusted for a given trial. The experimenter then stepped behind an occlusion screen (so that he was not visible to the participant during the trial) and indicated to the participant to begin the trial. Participants opened their eyes, viewed the surface, and provided each response (the yes or no response and the confidence rating). After the pair of responses was provided, participants returned their arms to their sides, and the angle of the surface was adjusted for the next trial. No restrictions were placed on how the participant explored the surface with the dowel, and no measures were taken to prevent the participant from hearing the contact between the rod and the surface.

Each participant completed one of the modality conditions and all three of the mass placement conditions. Modality conditions were counterbalanced across participants. Mass placement conditions were blocked, and the order of these conditions was counterbalanced across participants. Each angle was presented three times within each mass placement condition, and the order in which angles of inclination were presented was completely randomized within a block of trials. Participants completed a total of 63 trials in the perceptual task (3 conditions × 7 angles × 3 trials per angle per condition). Participants did not approach the inclined surface or attempt to stand on the surface until all trials of the perceptual task were completed.

Behavioural task. After the perceptual task had been completed, the behavioural boundary (i.e., the largest angle of inclination at which participants could actually stand on the surface while maintaining normal upright posture) was measured. Three different boundaries were measured for each participant—one while wearing the weighted backpack on the back, another while wearing the backpack on the front, and a third without wearing the backpack. The order in which these measurements were taken was counterbalanced across participants. For each measurement, the wooden dowel was placed in their right hand. They placed their arms at their sides so that the other end of the dowel was in contact with the floor while the angle of the surface was adjusted for a given trial. The experimenter then indicated to the participant to begin the trial. The participant explored the surface with the wooden dowel (by probing, scraping, or tapping it) and provided each response (the yes or no response and the confidence rating). After the pair of responses was provided, participants returned their arms to their sides, and the angle of the surface was adjusted for the next trial. No restrictions were placed on how the participant explored the surface with the dowel, and no measures were taken to prevent the participant from hearing the contact between the rod and the surface.
wooden surface was initially set at the smallest angle of inclination (15°).

Each participant then attempted to stand on the surface for five seconds while maintaining normal upright posture (as defined above). If the participant was able to do so, then he or she stepped down from the surface, and it was raised to the next highest angle of inclination. This procedure was repeated until the participant was unable to stand on the surface while maintaining normal upright posture (i.e., until they were unable to stand on the surface without going up on the toes, bending at the knees or waist, or grabbing the support railing). During the behavioural task, the experimenter stood on the floor behind the participant to “spot” them in case they fell backwards while attempting to stand on the surface.

Results

Behavioural task

Behavioural boundaries (i.e., the largest “stand-on-able” angle) in each of the mass placement conditions were compared to determine whether the ability to maintain upright posture on the inclined surface was influenced by the placement of the weighted backpack. A 2 (participant group) × 3 (mass placement) repeated measures analysis of variance (ANOVA) revealed a significant effect of mass placement, $F(2, 76) = 10.11$, $MSE = 9.65$, $p < .01$. A series of paired-sample $t$ tests (using a Bonferroni correction) revealed that (a) behavioural boundaries occurred at a larger angle (i.e., participants could stand on a surface with a steeper angle of inclination) when the backpack was worn on the front ($M = 30.2°$, $SD = 5.9$) than when it was worn on the back ($M = 27.2°$, $SD = 5.8$), $t(39) = 4.22$, $p < .01$; (b) behavioural boundaries occurred at a larger angle when the backpack was worn on the front than when the backpack was not worn ($M = 28.0°$, $SD = 5.8$), $t(39) = 3.49$, $p < .01$; and (c) there was no difference in behavioural boundaries when the backpack was worn on the back and when no backpack was worn, $t(39) = 1.06$, $p = .30$. There were no other significant effects (all other $p$s > .23).

Such results show that the weighted backpack influenced the ability to stand on the inclined surface depending on how the backpack changed the mass distribution of the perceiver–actor. Specifically, the ability to perform this behaviour is enhanced when the weighted backpack was worn on the front relative to when it was worn on the back. The results also show that the ability to stand on the inclined surface did not differ for the (different) participants in the two perceptual modality conditions. Respectively, these results allow for a more meaningful investigation of (a) whether perception of affordances for standing on an inclined surface is influenced in different ways depending on how the changes in a perceiver–actor’s mass distribution influence their kinetic potential for this behaviour and (b) whether perception of this affordance is influenced by such changes regardless of whether the inclined surface was explored visually or by means of a hand-held rod.

Perceptual task

Probability data. The percentage of yes responses for each angle of inclination in each condition was compared in a 2 (modality) × 3 (mass placement) × 7 (angle of inclination) repeated measures ANOVA. A main effect of angle of inclination showed that the percentage of yes responses decreased as the angle of the surface increased (see Figures 2 and 3), $F(6, 228) = 209.5$, $MSE = 988.08$, $p < .01$.

A main effect of mass placement showed that the percentage of yes responses differed depending on whether (and how) the backpack was worn, $F(2, 76) = 8.77$, $MSE = 335.35$, $p < .01$. Overall, the percentage of yes responses was highest in the front-weighted condition ($M = 47.1%$, $SD = 15.7$) and lowest in the back-weighted condition ($M = 15.1%$, $SD = 15.1$). However, an interaction of mass placement and angle of inclination showed that the effect of mass placement occurred only at particular angles of inclination, $F(12, 456) = 1.92$, $MSE = 261.04$, $p < .01$. Inspection of Figure 3 reveals that this difference between mass placement conditions was most pronounced at intermediate
angles, particularly at an inclination of 30°. A series of follow-up paired-sample t tests (using a Bonferroni correction) revealed that at this angle, (a) the percentage of yes responses was greater in the front-weighted condition (M = 40.8%) than in the back-weighted condition (M = 20.8%), t(39) = 3.18, p < .01; (b) the percentage of yes responses was greater in the unweighted condition (M = 35.8%) than in the back-weighted condition, t(39) = 3.05, p < .01; and (c) there was no difference between the percentage of yes responses in the front-weighted condition and in the unweighted condition, t(39) = 0.846, p = .40. The ANOVA revealed no other significant effects.

Perceptual boundaries (individual participant data). To determine whether the differences in the percentage of yes responses would lead to differences in perceptual boundaries, we compared perceptual boundaries in each of the conditions derived both at the level of the individual participants and at the level of the aggregate data. At the level of the individual participants, the perceptual boundary for each participant in a given condition was the largest angle of inclination that received a yes response on at least half of the trials (i.e., on at least two of three trials) in that condition (see Burton, 1992; Wagman & Malek, 2007; Warren, 1984). To ensure that perceptual boundaries were systematic, it was required that all angles of inclination smaller than the perceptual boundary in a given condition were perceived as affording upright posture (i.e., it was required that these angles also received a yes response on at least half of the trials; see Gordon & Rosenblum, 2004).

A 2 (modality) × 3 (mass placement) repeated measures ANOVA was conducted on the perceptual boundaries derived at the level of the individual participants. A significant main effect for mass placement showed that the perceptual boundaries
differed depending on whether (and how) the backpack was worn, \(F(2, 76) = 10.13, MSE = 8.58, p < .01\). A series of follow-up paired sample \(t\) tests (using a Bonferroni correction) revealed that (a) perceptual boundaries occurred at larger angles in the front-weighted condition (\(M = 26.8°\), \(SD = 5.9\)) than in the back-weighted condition (\(M = 23.9°\), \(SD = 5.3\)), \(t(39) = 4.31, p < .01\); (b) perceptual boundaries occurred at larger angles in the unweighted condition (\(M = 25.9°\), \(SD = 5.3\)) than in the back-weighted condition, \(t(39) = 3.12, p < .01\); and (c) perceptual boundaries did not differ in the front-weighted condition and in the unweighted condition, \(t(39) = 1.36, p = .181\). There was no main effect of perceptual modality, \(F(1, 38) = 0.276, MSE = 25.14, p = .60\). Thus, there was no difference between the perceptual boundaries in the vision condition (25.1°, \(SD = 4.2\)) and those in the remote haptic condition (25.9°, \(SD = 5.7\)). The ANOVA revealed no other significant effects.

**Perceptual boundaries (aggregate data).** At the level of the aggregate data, probit analysis (Finney, 1971) was used to determine the angle of inclination that would have resulted in a yes response 50% of the time in each condition. This angle can be taken as the perceptual boundary at the level of the aggregate data (see Burton, 1992; Fitzpatrick et al., 1994; Klevberg & Anderson, 2002; Wagman & Malek, 2007; Wagman & Taylor, 2005b). Given that previous analyses revealed no effect of perceptual modality either in the percentage of yes responses or in the perceptual boundaries at the level of the individual participants, the data from the two modality conditions were combined prior to conducting the probit analysis. Probit analysis revealed that (a) the perceptual boundary in the back-weighted condition occurred at 26.8° (with lower and upper fiducial limits of 25.3° and 28.2°, respectively); (b) the perceptual boundary in the front-weighted condition occurred at 29.1° (with lower and upper fiducial limits of 28.3° and 29.8°, respectively); and (c) the perceptual boundary in the unweighted condition occurred at 28.2° (with lower and upper fiducial limits of 27.4° and 28.9°, respectively). The nonoverlapping fiducial limits in the back-weighted and front-weighted conditions suggest that the perceptual boundary occurred at a significantly larger angle when participants wore the backpack on their front than when they wore it on their back (\(p < .05\); see Figures 2 and 3).

Both at the level of the individual participants and at the level of the aggregate data, perceptual boundaries occurred at larger angles in the front-weighted condition than in the back-weighted condition. Furthermore, the perceptual boundaries in the unweighted condition are consistent with those from previous research investigating perception of affordances for standing or walking on inclined surfaces (Fitzpatrick et al., 1994; Kinsella-Shaw, Shaw, & Turvey, 1992).

**Comparison of perceptual boundaries to behavioural boundaries.** A series of paired-sample \(t\) tests (using a Bonferroni correction) was performed to compare perceptual boundaries (derived at the level of the individual participants) to behavioural boundaries in each mass condition. When the backpack was worn (either on the back or on the front), perceptual boundaries occurred at smaller angles of inclination than the respective behavioural boundaries: back-weighted condition, \(t(39) = 2.8, p < .01\); front-weighted condition, \(t(39) = 2.81, p < .01\). In contrast, there was no difference between perceptual boundaries and behavioural boundaries in the unweighted condition, \(t(39) = 1.63, p = .11\). That is, participants accurately assessed their ability to stand on an inclined surface when not encumbered with a heavy backpack, but they underestimated their ability to do so when wearing a weighted backpack (regardless of whether it was worn on the front or the back of their body).

**Confidence data**

The confidence ratings in each condition were compared in a 2 (modality) × 3 (mass placement) × 7 (angle of inclination) ANOVA. There was a main effect of angle of inclination, \(F(6, 228) = 30.18, MSE = 2.39, p < .01\). Inspection of Figure 4...
reveals that confidence ratings were generally lowest at intermediate angles (between 20° and 30°). Consistent with previous research (e.g., Fitzpatrick et al., 1994; Wagman & Malek, 2007; Warren, 1984), this range contains the perceptual boundaries for each of the three mass placement conditions (compare Figure 2 to Figure 4). As expected, a main effect for perceptual modality showed that participants were less confident in the remote haptic condition \((M = 5.57, SD = 0.46)\) than in the vision condition \((M = 5.96, SD = 0.40)\), \(F(1, 38) = 8.16, MSE = 0.185, p < .01\). There was a marginal interaction of perceptual modality and mass placement, \(F(2, 76) = 2.88, MSE = 0.53, p = .06\), but there were no other significant effects.

**GENERAL DISCUSSION**

Previous research has shown that perception of geographic properties is influenced by a perceiver’s potential for generating the muscular forces required to perform a particular behaviour (see Proffitt, 2006a, 2006b, for a review). In particular, Bhalla and Proffitt (1999) found that slopes appeared steeper to perceiver–actors wearing weighted backpacks (on their backs) than to those not wearing weighted backpacks. Such perceptual experience has adaptive value to the extent that it influences decisions about whether (and how) to perform a particular behaviour (i.e., to the extent that it influences perception of affordances; see Turvey, 2004). The current experiment expands on this previous work by showing that (a) a manipulation that influences perceived geographic slant (i.e., wearing a weighted backpack) also influences perception of affordances for standing on a slanted surface (see also Adolph & Avolio, 2000) and (b) how this manipulation influences perception of this affordance depends on how the backpack influences the kinetic potential of the perceiver–actor. Perceiver–actors exhibited perceptual boundaries at smaller angles when the backpack served to increase the muscular forces required to stand on the inclined surface (i.e., when it is worn on the back) than when the backpack served to decrease the muscular forces required to stand on the inclined surface (i.e., when it is worn on the front). A reciprocal pattern of results would be expected in perception of whether a declined surface affords standing on. This may be a topic of future research.

A number of experiments have shown that in many cases perception of surface layout by audition or touch is comparable to that by vision (see Carello et al., 2005). Specifically, Fitzpatrick et al. (1994) found that perception of whether an inclined surface affords standing on is relative to the action capabilities of the perceiver–actor regardless of whether the surface is explored by means of vision or by means of a hand-held rod (i.e., there was no difference in the perceptual boundary on this behaviour in each case). The results of the current experiment are consistent
with those of Fitzpatrick et al. (1994). However, the current experiment expands on this previous work by showing that when a perceiver–actor's action capabilities are altered by means of a weighted backpack, perception of affordances of an environmental surface is relative to these (altered) action capabilities regardless of whether the surface is explored by vision or by means of a hand-held rod. This indicates that such a change in action capabilities did not alter the ability of the perceiver–actor to detect the structure that supports perception of this affordance in either case. In addition, perceiver–actors were more confident in their ability to detect such structure by means of vision than by means of a hand-held rod.

Some researchers have proposed that the stimulation patterns that support perception of affordances are multimodal, necessarily extending across energy arrays (Stoffregen & Bardy, 2001). However, although our experiment was not necessarily designed to test the predictions of this characterization of perception, we believe that our results are (more) consistent with the proposal that the particular energy array detected (e.g., the optic array, the acoustic array, etc.) may be irrelevant so long as (a) the structure in each array is sufficient to support perception of the affordance, and (b) the perceiver–actor is capable of detecting such structure (see Carello et al., 2005; Gordon & Rosenblum, 2004; Rosenblum & Gordon, 2001; Wagman & Malek, 2007; Wagman & Taylor, 2005b).

**Embodied perception and attachments to the body**

Objects attached to the body create an integrated person-plus-object system with perception–action capabilities that may be entirely different from those of the person-without-object system (Smitsman, 1997). First, objects attached to the body (e.g., the backpack) change a perceiver–actor's action capabilities and therefore change the affordances available to that person. If intended behaviours are to occur successfully, perceiver–actors must be sensitive to how such objects change their action capabilities. The current experiment demonstrates that perceiver–actors are sensitive to how a weighted backpack changes their ability to stand on an inclined surface. Such results add to a body of research showing that when an object is attached to the body, perception is relative to the integrated person-plus-object system (Bhalla & Proffitt, 1999; Bongers, Michaels, & Smitsman, 2004; Higuchi, Cinelli, Greig, & Patla, 2006; Higuchi et al., 2004; Wagman & Taylor, 2005b).

Second, attachments to the body (e.g., the hand-held rod) can change a person's perceptual capabilities and therefore change the affordances that can be perceived by that person. If intended behaviours are to occur successfully, perceiver–actors must be able to exploit such objects as perceptual tools. The current experiment adds to a growing body of research showing that perceiver–actors are able to exploit a hand-held rod to perceive behaviour-relevant properties of environmental surfaces (Burton, 1992, 1993; Fitzpatrick et al., 1994; Patla, Davies, & Niechwiej, 2004; Wagman & Taylor, 2005a).

The fact that perceiver–actors show sensitivity to the ways in which objects attached to their body change their perception–action capabilities (even with relatively little exposure to the attached object) suggests that objects attached to the body are generally experienced as extensions of the body (Ackroyd, Riddoch, Humphreys, Nightingale, & Townsend, 2002; Berti & Frassinetti, 2000; Yamamoto, Moizumi, & Kitazawa, 2005; see Hirose, 2002).

**Attunement to attachments to the body**

Despite a general sensitivity to how an attachment to the body changes action capabilities even with relatively minimal exposure to the object attached to the body (see Higuchi et al., 2004; Wagman & Taylor, 2005b), it may take some extended exposure to the perception–action dynamics of the objects attached to the body for the perceiver–actor to become highly attuned to the behavioural boundaries of the person-plus-object system (Higuchi et al., 2004; Hirose & Nishio,
In the current study, perceiver–actors accurately assessed their ability to stand on the surface when not wearing a backpack (i.e., in this condition, there was no difference between perceptual boundaries and behavioural boundaries), they underestimated their ability to do so while wearing a backpack (i.e., both in the front-weighted and in the back-weighted conditions, perceptual boundaries occurred at a smaller angle of inclination than did behavioural boundaries). It is possible that such underestimation shows an increased “margin of safety” when action capabilities have been experimentally altered. Moreover, it is likely that with extended exposure to the perception–action dynamics of the weighted backpack, perceiver–actors would become more highly attuned to how the backpack places limits on their ability to stand on the inclined surface, and as a result the perceptual boundaries would more closely match the behavioural boundaries (see Higuchi et al., 2004; Hirose & Nishio, 2001). Along the same lines, perceiver–actors are likely to become more aware of (and more confident in) their ability to perceive affordances by exploring a surface with a hand-held rod with extended practice in such perceptual tasks. These possibilities could be explored in future research.

Mass distribution and attachments to the body

In many cases, objects attached to the body change the action capabilities of the perceiver–actor because they change the geometric properties of the perceiver–actor. Wheelchairs and certain carried objects extend the widest horizontal body dimension and therefore limit the ability of the perceiver to pass through narrow spaces (Higuchi et al., 2004; Wagman & Taylor, 2005b). In other cases, objects attached to the body change the action capabilities of the perceiver–actor because they change the kinetic potential of the perceiver–actor. Wheelchairs and carried objects also change the ability of the perceiver–actor to generate and control the forces required to perform certain behaviours (see Adolph & Avolio, 2000; Bhalla & Proffitt, 1999; Higuchi et al., 2006).

In the current experiment, an object attached to the body (i.e., a weighted backpack) changed the kinetic potential of the perceiver–actor by changing their mass distribution. Whether an environmental surface was perceived to afford standing on depended on how the mass distribution of the person–plus–object system influenced the ability to generate and control the muscular forces required for this behaviour. A large body of research has shown a similar role of mass distribution in the perception of hand-held wielded objects. Whether a hand-held object is perceived to afford use in a particular task depends on how the mass distribution of that object influences the ability to generate the muscular forces required for that task (Wagman & Carello, 2001, 2003; see Carello & Turvey, 2004, for a review).

CONCLUDING COMMENTS

The current experiment revealed that (a) perception of affordances for standing on an inclined surface is influenced by the changes in kinetic potential brought on by an attachment to the body (i.e., a weighted backpack); (b) perception of this affordance is influenced in different ways depending on how an attachment to the body changes the ability to stand on the surface (whether it increases or decreases the muscular forces required to stand on the surface); and (c) perception of this affordance is influenced by such changes in kinetic potential regardless of whether the surface is perceived by vision or by remote haptic perception. These results highlight the role of attachments to the body and the mass distribution of the perceiver–actor in the perception of affordances.

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