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I, Luis H Favela Jr., hereby submit this original work as part of the requirements for the degree of Master of Arts in Psychology.

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Walking Through Apertures: Assessing Judgments Obtained from Multiple Modalities

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Walking Through Apertures: Assessing Judgments Obtained from Multiple Modalities

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Abstract

According to Gibson's ecological theory of perception-action, the proper objects of perception are affordances. Affordances are directly perceivable, environmental opportunities for behavior. The current study assessed affordance judgments, and the confidence ratings corresponding to those judgments, of aperture pass-through-ability based on three modes of perceiving. The modes were vision and two blindfolded conditions involving haptic perception via technological aids: A cane and the Enactive Torch (ET). The first hypothesis, that vision would provide judgments of the critical boundary most similar to the actual boundary, was not supported. The second hypothesis, that participants would perform better on pass-through-ability judgments using the ET than when using the cane, was supported. The third hypothesis, that across all three modalities participants’ ratings of confidence in the accuracy of their yes/no judgments would be lowest near the perceptual category boundary, was supported. Results suggest that in terms of making affordance judgments of aperture pass-through-ability, participants were more accurate with the haptic modalities than with vision. Results also suggest that participants were least confident with their more accurate modality, and most confident with their least accurate modality.
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Introduction

Theoretical Background

According to James J. Gibson's ecological theory of perception-action (1966/1983, 1979/1986; cf. Reed, 1996), the proper objects of perception are affordances. Although there are a number of competing definitions of the term ‘affordances’ (e.g., Chemero, 2009; Gibson, 1979/1986; Greeno, 1994; Jones, 2003; Stoffregen, 2003; Turvey, 1992; Warren, 1984), it is generally agreed among ecological psychologists that affordances are “directly perceivable, environmental opportunities for behavior” (Chemero, 2009, p. 23). These opportunities for behavior are based on properties of the environment and properties of the animal (Stoffregen, 2003). Stair climbing, for example, is based on the height of the stair relative to the animal’s leg length, as well as other properties of the animal such as strength and flexibility.

It is empirically well established that humans can perceive affordances. Examples of investigations of affordance perception include research on haptic perception of gap sizes using hand-held probes (Barac-Cikoja & Turvey, 1993), haptic perception of stand-on-ability of slopes (Fitzpatrick, Carello, Schmidt, & Corey, 1994), hammer-with-ability and poke-with-ability (Wagman & Carello, 2001; Wagman & Shockley, 2011), move-ability (Shockley, 2009; Shockley, Carello, & Turvey, 2004), catching moving objects (Oudejans, Michaels, Bakker, & Dolne, 1996), sit-on-ability (Mark, 1987; Mark, Balliet, Craver, Douglas, & Fox, 1990), and step-on-ability (Ramenzoni & Riley, 2005; Warren, 1984), just to name a few. Research on crossability-by-stepping over horizontally oriented apertures (Burton, 1992, 1994; Burton & Cyr, 2004) and the pass-through-ability of apertures in the frontal plane (Davis, Riley, Shockley, & Cummins-Sebree, 2010; Fath & Fajen, 2011; Higuchi, Takada, Matsuura, & Imanaka, 2004;
Wagman & Taylor, 2005; Warren & Whang, 1987) are the most pertinent for the current study and will be discussed in the next section.

**Pass-through-ability of Apertures**

Warren and Whang (1987) conducted one of the earliest studies on perception of whether apertures afford passage. As Warren and Whang noted, affordances are defined by relations between the dimensions of objects in the environment and the dimensions of observers. In this study, Warren and Whang focused their investigation on the *critical* points of visually guided walking through apertures in three experiments. As the authors state, a point is critical “where a phase transition to a new action occurs” (p. 371). With regard to apertures, a point is critical for an agent when she cannot walk through an aperture without hitting the sides of the opening with her shoulders, thus requiring her to change behavior, such as rotating the shoulders (or not) while walking through the aperture.

In Experiment 1, Warren and Whang (1987) quantified the affordance of pass-through-ability by means of the critical aperture-to-shoulder-width ratio ($A/S$, where $A$ is the width of the aperture and $S$ is the width of the shoulders at the broadest point). A critical value of $A/S = 1.30$ was experimentally discovered and marked the transition from passing through the aperture while walking normally to needing to rotate one’s shoulders to walk through. Warren and Whang needed to obtain this critical value, which was the actual boundary separating walk-through-able from not-walk-through-able, before they could address the questions asked in Experiment 2.

In Experiment 2, Warren and Whang asked if perception of the affordance boundary demonstrated in Experiment 1 is dependent on dynamic (“moving” in Warren & Whang, 1987) or static information. There were two groups (observers with small and large $S$) and each group provided pass-through-ability reports in a static condition and in a moving condition. In the static
condition, information about the aperture was obtained from a fixed point of observation. In the moving condition, information about the aperture was obtained while walking in a straight line toward the front of the aperture. The perceived critical point for the “small” group under the static condition was $A/S = 1.14$, and under the moving condition was $A/S = 1.15$. The perceived critical point for the “large” group under the static condition was $A/S = 1.17$, and under the moving condition was $A/S = 1.16$. There was no significant effect of subject size on $A/S$-scaled perceived critical points. This result is consistent with the actual difference in shoulder width between the groups in accordance with Warren and Whang’s hypothesis that people are perceptually sensitive to the critical point, which, in extrinsic, unscaled units was significantly greater for the larger than small group. These results support the idea that participants judge category boundaries between pass-through-able and not-pass-through-able apertures as a constant ratio of their body size and that static monocular information is sufficient for perceiving the affordance of pass-through-ability.

Other studies have confirmed and expanded on Warren and Whang’s (1987) finding that people can accurately perceive the affordance of pass-through-ability. For example, Higuchi et al. (2006) demonstrated that while approaching apertures of varying widths, participants who held horizontal bars that increased their effective body width rotated their shoulders to degrees proportional to the width added to their body dimensions by the bar. In another study, Fath and Fajen (2011) found that in addition to static eyeheight-scaled information, multiple kinds of dynamic information could also be used to inform perceptual judgments utilized to guide locomotion through apertures.

Whereas Warren and Whang (1987) examined apertures in the frontal plane, Burton and Cyr examined the perception of crossability-by-stepping over horizontally oriented apertures.
(Burton, 1992, 1994; Burton & Cyr, 2004). Burton and colleagues situated their hypothesis in the context of two boundaries. These boundaries were, first, between gaps that cannot be crossed and those that can, and, second, between gaps that can be crossed only with modification of the agent’s normal step cycle and those that can be crossed normally. Burton and colleagues, like Warren and Whang, were concerned with biomechanical aspects of the agent, such as their height, leg length, and eye height. One important distinction between the work of Burton and colleagues and that of Warren and Whang is that participants in the latter experiment involved visual perception, while participants in the former’s experiments involved dynamic touch perception. Dynamic touch perception occurs via deformations of muscles and tendons about joints involved in actively wielding hand-held objects, in this case, via probing gaps with hand-held rods. Although studies on sensory substitution in the form of haptic information utilized in situations that normally use visual information have demonstrated that blind cane users outperform sighted persons in various tasks (Lessard, Pare, Lepore, & Lassonde, 1998; Passini, Proulx, & Rainville, 1990; Schiff & Oldak, 1990), the work of Burton and colleagues (1992, 1994; Burton & Cyr, 2004) demonstrated that even experienced visually impaired cane users were unable to make accurate judgments under some conditions when compared with undergraduate volunteers who were blindfolded for the first time (Burton & Cyr, 2004).

In one experiment, Burton and Cyr (2004) tasked their participants with exploring gaps in the floor with rods to determine if the gap was crossable. Participants were asked to answer the following two questions: First, “could the gap be crossed at all while walking,” and second, “could the gap be crossed naturally, without changing the size of a normal step of stopping before crossing” (Burton & Cyr, 2004, p. 308)? Results from the first question suggested nearly identical performance by the sighted and the visually impaired participants (Burton & Cyr, 2004).
Burton and Cyr utilized a probit analysis to determine the 50% cutoff, or, the point of subjective equality (PSE). The PSE was the gap width that on 50% of trials elicits a “Yes, cross-able” response. The PSE corresponds to the threshold at which participants perceive they are able to carry out an intended action, such as stepping over a gap in the ground or passing through an aperture (Avraham, Nisky, Fernandes, Acuna, Kording, Loeb, & Karniel, 2012; Engen, 1971; Meese, 1995). The PSE for visually impaired participants was $1.12 \times \text{Leg Length}$ and for blindfolded participants was $1.10 \times \text{Leg Length}$. Burton and Cyr noted similar findings in regard to the second question (though they did not provide the actual findings). Reported results of regressions of the number of judgments of crossability as functions of gap size, leg length, and rod length revealed similar performance among both the visually impaired and sighted.

A number of issues in the affordance, aperture, and sensory substitution literature have not been experimentally addressed. One issue concerns affordance judgments of pass-through-ability of apertures in the frontal plane utilizing haptic information. Warren and Whang (1987) investigated affordance judgments of apertures in the frontal plane made with visual information. Burton and colleagues (1992, 1994; Burton & Cyr, 2004) investigated affordance judgments of crossability-by-stepping over of horizontal apertures made with haptic information obtained with a probe. Neither sets of experiments, or any other, have investigated haptic judgments of apertures in the frontal plane pass-through-ability. Moreover, and as noted above, although numerous experiments have confirmed and expanded Warren and Whang’s findings, there have been few investigations across multiple modalities within the same task (e.g., Wagman & Abney, 2012; Wagman & Taylor, 2005).
The current study assessed judgments of aperture pass-through-ability based on three modes of perceiving: Vision and two blindfolded conditions involving haptic perception via technological aids—a cane and the Enactive Torch (Froese, McGann, Bigge, Spiers, & Seth, 2012; Grespan, Froese, Di Paolo, Seth, Spiers, & Bigge, 2008; Schmidmaier, 2011). The Enactive Torch (Figure 1) is a handheld sensory substitution device. It measures distance using an infrared range finder and relays that information to the user via vibratory stimulation applied to the wrist.

Participants in the current study judged their ability to walk through an aperture without turning their shoulders, such as walking through a doorway or between people standing in a crowded room. As discussed above, there is a body of literature concerning the ability to make judgments about apertures of various sizes (e.g., Burton, 1992, 1994; Burton & Cyr, 2004; Davis et al., 2010; Fajen, Diaz, & Cramer, 2011; Fath & Fajen, 2011; Fujikake, Higuchi, Imanaka, & Maloney, 2011; Gordon & Rosenblum, 2004; Hackney & Cinelli, 2011; Higuchi, Murai, Kijima, Seya, Wagman, & Imanaka, 2011; Higuchi, Cinelli, & Patla, 2009; Wagman & Taylor, 2005; Warren & Whang, 1987; Wilmot & Barnett, 2011). Of particular relevance to the current study is the ability to utilize different sensory modalities, specifically, visual and haptic, to make affordance judgments (Barac-Cikoja & Turvey, 1991, 1993; Burton, 1992, 1994; Burton & Cyr, 2004; Davis et al., 2010).

Although there are many theoretical issues concerning sensory substitution (e.g., Bach-y-Rita & Kercel, 2003; Froese & Spiers, 2007) and the haptic and spatial perception of the visually impaired (Heller, 1991; Kennedy, Gabias, & Heller, 1992; Thinus-Blanc & Gaunet, 1997), the current study focused on the performance of sighted participants on an aperture pass-through-
ability task utilizing a cane and the Enactive Torch while wearing blindfolds, as well as in a condition in which full vision was available (participants wore earmuffs in all three conditions). The perceived critical boundaries separating pass-through-able from non-pass-through-able apertures were compared across the modalities and, within each modality, to each participant’s actual aperture pass-through-ability (without turning their shoulders) critical point.

I hypothesized that vision would provide judgments of the critical boundary most similar to the actual boundary; that is, vision would provide more accurate judgments than both the cane and Enactive Torch. This claim was motivated by previous studies that have demonstrated that, unlike visual performance, participants underestimate aperture width when using a probe while blindfolded (Barac-Cikoja & Turvey, 1991), and participants tend to be more conservative when making judgments about the crossability of gaps when using a probe while wearing a blindfold (Burton, 1992).

I also hypothesized that participants would perform better on pass-through-ability judgments using the Enactive Torch than when using the cane. There is no precedent for research involving the Enactive Torch, particularly as a tool for the visually impaired. Thus, my hypothesis is based on exploring the possibility that the Enactive Torch may provide more varying degrees of awareness than a cane. For example, the Enactive Torch may provide graded degrees of vibration corresponding to a large range of distances, whereas a cane provides awareness about the presence or absence of a surface in peripersonal space.

I further hypothesized that across all three modalities participants’ ratings of confidence in the accuracy of their yes/no judgments would be lowest near the perceptual category boundary. This claim was motivated by previous studies that have demonstrated that categorization
judgments and confidence ratings are most uncertain and converge at the perceptual category boundary (Warren, 1984).

This study was one of the first to utilize the Enactive Torch in an experimental setting. It was also the first to investigate pass-through-ability of apertures in the frontal plane using information obtained haptically. In addition, it is one of the few studies to directly compare affordance perception using multiple modalities (cf. Fitzpatrick et al., 1994).
Method

Participants

Twenty-seven undergraduate students (19 women and 8 men) from the University of Cincinnati participated in this study. This sample size is based upon similar past experiments involving visual aperture judgments (Warren & Whang, 1987) and aperture judgments made with the assistance of a rod for striking (Barac-Cikoja & Turvey, 1991; Hanley & Goff, 1974). Participants’ ages ranged from 18 to 42 years ($M = 22.31$, $SD = 6.17$ yrs.), and shoulder widths ranged from 37 to 50 cm ($M = 42.48$, $SD = 3.31$ cm). To maintain measurement consistency, shoulders were measured with a constructed vernier-like caliper from the heads of the left and right humeri, with measurements taken from the front of the participant (cf. Warren & Whang, 1987) and the back. All participants reported no history of movement disorders or considerable experience using a cane or other handheld mobility assistance device. All participants reported normal or corrected-to-normal vision (with contact lenses or eyeglasses), the ability to walk without assistance, and no other sensory deficits.

Materials & Apparatus

A two-paneled, sliding doorway attached to a platform was constructed (Figure 2). A standing wooden frame was constructed (height: 2.43 m; width: 2.6 m), with two panels (height: 2.43 m; width: 40.5 cm, each) inserted into the frame. The panels could be slid laterally across the frame to create aperture widths ranging from 101.6 cm to 190.5 cm. Two platforms (height: 8.9 cm; length: 1.23 m; 0.91 m width, each) were attached at the middle front and back of the frame. Due to the standing wooden frame, the visible area of the panels began at 8.9 cm from the ground. Thus, when attached to the aperture frame, the platform was 8.9 cm high so as to match the height of the visible area of the panels in the aperture openings.
Participants utilized devices in two of the three conditions: A “cane” and the Enactive Torch. The “cane” was a wooden dowel (length: 121.5 cm, diameter: 4 cm), the dimensions of which matched the specifications of those utilized in similar, previously published experiments (cf. Burton, 1992, 1994). A wooden dowel was utilized instead of a standard “white cane” for the visually impaired because standard white canes do not have uniform physical properties. Instead, they are made of plastic with collapsing sections of different diameters, and a rubber gripped handle. That there are sections of varying widths that move slightly when wielded is problematic because they can influence the information participants utilize when attempting to make judgments, such as the inertial dynamics (cf. Burton & Turvey, 1990).

The Enactive Torch is a haptic sensory substitution device (Froese et al., 2012; Grespan et al., 2008; Schmidmaier, 2011). It is a flashlight-sized device that is held with one hand and is connected by a wire to a wrist strap with a vibrational motor (Figure 1). It has an infrared range sensor on the front that, when pointed at objects, sends an output to the vibrational motor that delivers haptic stimuli on the wrist. During standard functioning, the haptic stimulus applied to the wrist is inversely proportional to the distance of the object measured by the infrared sensor. If it is very close to an object, then the vibration amplitude is high, and if far away the vibration amplitude is low to none.

Participants wore earmuffs in all three experimental conditions and a blindfold in the cane and Enactive Torch conditions.

**Procedure**

Before beginning the experiment, participants were told that the session would last approximately one hour. The three different tasks were then explained. Participants then provided informed consent after reading the Institutional Review Board approved study
procedures and consent document. Once participants granted consent, their demographic information was recorded: Sex, age, ethnicity/race, height, weight, and handedness. Participants were then screened for visual acuity by being placed at a distance of 6.1 m from a wall-mounted, standard Snellen chart and were asked to read the 8th row of letters. Participants unable to read this row were dismissed. Next, participants were screened for prior regular cane usage. “Prior regular cane usage” does not include playing with a cane one day with friends, but is intended to capture periods of time in which a participant may have utilized a cane or cane-like instrument long enough to learn the ability to make accurate perceptual judgments with it. Although there is no general consensus on how long it takes an individual to learn to successfully navigate with a cane or cane-like instrument, it is generally accepted that approximately three weeks of intensive training would be necessary (cf. Altman & Cutter, 2004; Bickford, 1993; Ludt & Goodrich, 2002). Thus, three weeks was the cutoff criteria.

After the screening, participants underwent a familiarization and training task. The goal of this was to instruct participants to make rudimentary judgments with the cane and Enactive Torch, and to familiarize them with the operation of the latter. This also provided an opportunity to screen participants who were simply unable to understand the operation of the Enactive Torch but no participants failed to understand how to use the device. Participants were blindfolded and wore earmuffs. Previous work by Gordon and Rosenblum (2004) has demonstrated that auditory information can affect perceptual judgments of aperture pass-through-ability. Thus, earmuffs were provided so as to minimize additional sources of information that participants may have utilized to inform their judgments. Participants were then placed at a distance of 76 cm from the outside edge of the aperture. With both the cane and Enactive Torch, participants were asked to use each tool to make contact (or virtual contact in the case of the Enactive Torch) with the beam
and then walk forward until they believed the beam was parallel to the shoulder of the hand with which they were using the tool. All participants were able to perform the familiarization and training task accurately.

Next, participants were placed in front of the aperture. Participants stood on the platform with the heels of their feet 76 cm from the aperture. It was made clear to participants that they would be at this same distance from the aperture for the entire experiment. This distance was standard across all participants and was based on the minimum distance at which the cane could be utilized to explore the openings of the widest presented aperture. Participants were presented each of the three modality conditions in blocks, and blocks were presented in random order across participants. The three modality conditions were: (1) vision, earmuffs, and no tool; (2) blindfolded, earmuffs, and cane; or (3) blindfolded, earmuffs, and Enactive Torch. For the vision condition, participants had their head centered with the aperture, and for the two tool conditions, participants had the shoulder of the arm utilizing the tool centered with the aperture.

For each condition, participants were presented 16 aperture widths of the following eight increments: 101.6, 114.3, 127, 139.7, 152.4, 165.1, 177.8, and 190.5 cm. Each of these eight widths were randomly presented once and then randomly presented again, for a total of 16 trials. Participants were not informed that any of the widths would repeat. Participants were asked to provide perceptual reports concerning their ability to pass through the aperture by walking without altering their natural body movement, such as turning their shoulders. They were asked to respond “yes” or “no” with regard to whether they could walk through the 16 various aperture widths for each condition. After providing their “yes” or “no” response, participants were asked to provide a confidence rating between one and seven (1: “Not confident in my judgment;” 7: “Very confident in my judgment”). Participants were asked to close their eyes between trials in
the vision condition, and they were asked to point the cane and Enactive Torch to the side between trials in those respective conditions. Participants were asked to sit down between each block.

Once all trials were completed, measurements were taken of the participants’ shoulder width (cm) and actual shoulder pass-through-ability (cm), that is, their ability to pass between apertures without altering their natural body movement, such as turning their shoulders. In order to obtain the latter, participants began at the edge of one platform, walked through to the edge of the other platform at the other side of the aperture (for a total distance of 2.54 m), and then walked back.
Results

The PSE was estimated by means of a logistic regression function that related the percentage of “Yes, pass-through-able” responses to aperture sizes (Figure 3a) scaled by the width each participant could actually pass through, with a PSE closer to 1.0 indicating greater accuracy. The main analysis consisted of a one-way, within-subjects analysis of variance (ANOVA) to compare the PSE obtained from judgments of pass-through-ability made with vision, cane, and Enactive Torch (Figure 4a). There was a significant main effect of modality, $F(2, 26) = 3.92, \, p = .03, \, \eta^2_p = 0.13$. PSE judgments ranged from 0.71 to 1.17 for vision ($M = 0.89, \, SD = 0.11$), from 0.63 to 1.34 for cane ($M = 0.95, \, SD = 0.16$), and from 0.77 to 1.34 for Enactive Torch ($M = 0.98, \, SD = 0.17$). Post-hoc tests indicated that Enactive Torch was significantly different from both the cane and vision conditions ($ps < .05$) and that the cane condition was significantly different from the vision condition ($p < .05$). In order to determine how accurate PSE values were, each of the PSE values was compared to 1.0 (perfect accuracy) using one-sample $t$-tests. The PSE values obtained for the Enactive Torch and cane conditions did not differ significantly from 1, indicating that on average participants accurately perceived the affordance boundary in those conditions. However, the PSE in the vision condition was significantly less than 1, $t(26) = -5.3, \, p < .05$, indicating less accurate perceptual performance in that condition.

In addition to comparing the judgments of pass-through-ability, the confidence ratings that participants provided (‘1’ indicating low confidence in judgment and ‘7’ indicating high confidence in judgment) were also analyzed. The analysis consisted of three one-way, within-subjects ANOVAs. The first ANOVA compared the magnitude of the minimum confidence
ratings made with vision, cane, and Enactive Torch. There was no significant main effect of modality $F(2, 26) = 1.3, p = .28, \eta_p^2 = 0.47$.

The second ANOVA compared the aperture widths corresponding to the participants’ lowest confidence ratings made with vision, cane, and Enactive Torch. The aperture widths were estimated by using a polynomial fit to the confidence data as a function of aperture width scaled to each participants’ actual pass-through-ability. This provided the intrinsically scaled aperture width corresponding to the minimum confidence for each participant. Consistent with the PSE analysis above, values less than 1.0 reflected confidence minima corresponding to narrower apertures than the actual pass-through-able aperture size, and values greater than 1.0 reflected minima corresponding to apertures that were wider than actual pass-through-able apertures sizes. The main effect of modality was marginal but not significant $F(2, 26) = 3.02, p = .057, \eta_p^2 = 0.1$.

The third ANOVA compared the magnitude of the confidence ratings made with vision, cane, and Enactive Torch that corresponded with the PSE. The confidence function for each modality for each participant was determined using a polynomial fit. Based on this function, the PSE determined above was used to identify the value of confidence corresponding to the PSE. There was a significant main effect of modality $F(2, 26) = 4.0, p = .02, \eta_p^2 = 0.13$, indicating that participants’ confidence in their judgments of pass-through-ability were affected by the modality utilized to make those judgments. Confidence ratings obtained from the polynomial fit ranged from 2.76 to 6.91 for vision ($M = 4.63, SD = 1.31$), from 2.56 to 7.07 for cane ($M = 4.2, SD = 0.99$), and from 1.34 to 7.08 for Enactive Torch ($M = 4.02, SD = 1.37$). Post-hoc tests indicated that vision was not significantly different from the cane condition ($p > .05$), the cane condition was not significantly different from the Enactive Torch condition ($p > .05$), and the Enactive Torch condition was significantly different from the vision condition ($p < .05$).
Discussion

The aim of the current study was to quantify and compare participants’ performance on judgment tasks to perceive affordances for pass-through-ability utilizing three different modalities: Vision, cane, and Enactive Torch. Three hypotheses were tested. The first hypothesis was that the vision modality would provide more accurate judgments of pass-through-ability than both the cane and Enactive Torch. This hypothesis was not supported. The second hypothesis was that participants would perform better on pass-through-ability judgments using the Enactive Torch than when using the cane. This hypothesis was supported. The third hypothesis was that across all three modalities confidence would be lowest near the perceptual category boundary. This hypothesis was supported.

Results of the current study are mostly consistent with a number of previous findings. First, the mean $A/S$ ratio of the actual pass-through-ability boundary of participants (1.36) was near that of Warren and Whang (1987) (1.30) and Davis et al. (2010) (1.22). However, the mean $A/S$ ratio of the perceived pass-through-ability boundary of participants (0.89) was under that of Warren and Whang’s (1987) static condition small $S$ group (1.14) and large $S$ group (1.17), and was lower than Davis et al. (2010) (1.14). Second, that participants made more accurate judgments with the two haptic modalities than vision is consistent with Burton and Cyr’s (2004) finding that visually impaired persons with experience using canes and sighted persons with no such experience had equivalent performances on gap crossability tasks utilizing canes of various lengths. Burton and Cyr noted that experience with haptic mobility assistance devices such as a cane was not necessary for “fairly high level” task performance (2004, p. 314). Although performance only among sighted persons was compared, the current study takes Burton and Cyr’s findings a step further and suggests that people can perform better with haptic than visual
information on tasks normally associated with visual information, such as passing through or over apertures. Third, consistent with Warren’s (1984) findings, participants’ confidence ratings were lowest near the perceptual category boundary.

Contrary to my hypothesis that vision would provide more accurate judgments of pass-through-ability than both the cane and Enactive Torch, participants demonstrated the least accurate perceptual performance with vision. Participants were more accurate at perceiving the affordance boundary for pass-through-ability with the cane and Enactive Torch than with vision. Perceptual judgments were affected by the different modalities utilized, with judgments of pass-through-ability with the Enactive Torch being significantly different from both the cane and vision conditions in terms of being more accurate, and judgments with the cane condition being significantly different from the vision condition in terms of being more accurate. When the perceptual reports scaled to actual action capabilities (less than 1 corresponding to underestimation; greater than 1 corresponding to overestimation) were compared to 1 (perfect accuracy) using one sample $t$-tests I found that participants were accurate when using the cane and Enactive Torch but underestimated the affordance boundary in the visual condition.

The second hypothesis, that participants would more accurately perceive pass-through-ability using the Enactive Torch than when using the cane, was upheld. Post-hoc tests demonstrated that the Enactive Torch differed significantly from the cane, and, because Enactive Torch values were closer to 1.0, it can be concluded that the Enactive Torch was more accurate than the other two conditions.

The third hypothesis, that across all three modalities confidence would be lowest near the perceptual category boundary, was upheld. Results also indicated that there was a significant main effect of modality when comparing confidence ratings corresponding to participants’ PSE,
such that participants were least confident with their Enactive Torch judgments, followed by the cane, and most confident with their vision judgments.

In the ecological theory of affordances, many of the properties of the animal and environment are dynamic properties. Examples of dynamic properties include time-to-contact (Lee, 1976) and those properties of hand-held objects obtained by dynamic touch (Bingham, Schmidt, & Rosenblum, 1989; Turvey & Carello, 2011). Many such properties can only be accurately perceived by an active observer. It could have been the case in this study that the two haptic modalities were more accurate than vision because they involved a greater degree of information-generating or exploratory perceiver motion than did the vision condition. In the vision condition, participants opened their eyes, looked at the aperture, and then made a judgment, which was done with little movement by the participant other than postural sway. In the haptic conditions, participants moved their arms and shoulders as they wielded the cane and Enactive Torch in order to make contact with the aperture. This is not to suggest that participants did not produce any information-generating exploratory motion in the vision condition. No matter how still an animal attempts to be, there is always movement occurring, such as postural sway and eye saccades. What is being suggested is that participants were more accurately attuned to the properties of their body and the properties of the aperture in the haptic conditions because they moved a great deal more than in the vision condition. If correct, then these results would further bolster the theory of affordances, in part by highlighting the necessity of rejecting the perception-action divide. Instead, perception and action ought to be treated as two aspects of a single cycle in which both parts are functionally entailed by the other (cf. Turvey, 2004).

A question that emerges from the results regards the discrepancy across modalities between the accuracy of participants’ yes/no pass-through-able judgments and their confidence
ratings. Participants were most accurate in judging the perceptual boundary with the Enactive Torch and least with vision, but were more confident in their visual judgments than they were with the Enactive Torch. One way to frame this phenomenon is in terms of Thurstonian and Brunswikian modes of uncertainty (Juslin & Olsson, 1997; Runeson, Juslin, & Olsson, 2000). Confidence tends to be low when there is not an overtly cognitive awareness of the informational basis of the percept and high when there is an overtly cognitive awareness of the informational basis (Runeson et al., 2000). From the Gibsonian ecological perspective, a failure to detect adequate information can be viewed as a “Brunswikian category of errors,” and errors that still occur despite the detection of adequate information can be viewed as “Thurstonian in nature” (p. 532). Juslin and Olsson (1997) claimed that for direct perception, with its commitment to the idea that “more complex perceptual tasks involve the pickup of high-order invariants that specify distal variables with perfect validity” (p. 345), the dominant mode of uncertainty is Thurstonian.

From that perspective an interpretation of the results of the vision condition is as follows: Judgments made with vision were less accurate than the other modalities, but had high confidence ratings, because participants’ visual capabilities were miscalibrated for an environment with specifying information, and they were not aware of the shortcomings of their perceptual capabilities. In the Enactive Torch condition judgments were most accurate but least confident because participants’ haptic perceptual capabilities were calibrated for an environment with specifying information, but they were not aware of the strength of their haptic perceptual capabilities. Given these interpretations, and consistent with Juslin and colleagues (Juslin & Olsson, 1997; Runeson, Juslin, & Olsson, 2000), a Thurstonian account of the results is most compelling. However, this study was not designed to specifically address the question of Brunswikian versus Thurstonian accounts of perceptual uncertainty. In order to investigate this
question, experiments need to be designed to evaluate how perception and confidence ratings track the manipulation of informational variables. In such a study, if participants’ perception tracks specifying informational variables, then that would suggest a Thurstonian interpretation. If not, then that would suggest a Brunswikian interpretation.

Impaired vision is a major health issue in the United States (Eichenbaum, 2012; Frick, 2012; Hilber, 2011; Kaye, Kang, & LaPlante, 2000; Ko, Vitale, Chou, Cotch, Saaddine, & Friedman, 2012; Musch & Gardner, 2012; Pelletier, Thomas, & Shaw, 2009). Many visually impaired persons navigate the world with the assistance of canes. Canes are inexpensive and relatively easy to learn to use. However, they have limitations, which include navigating living areas located above ground floor or with multiple levels and utilizing public transportation (Kaye et al., 2000). Additionally, some users experience negative emotions concerning their cane use. Users, particularly children, can experience perceived social stigma due to the use of a mobility device that they perceive to make them standout in a negative way (Jacobson, 1993). A less conspicuous device may help alleviate this worry. Given that many forms of visual impairment are chronic and incurable, visually impaired individuals who wish to maintain independence will continue to utilize some sort of aid. It is a worthwhile endeavor to study alternatives to canes as aids for the visually impaired. It is especially worthwhile if that alternative has the potential to overcome the shortcomings of canes. Given that results of the current study indicate that the Enactive Torch is more accurate than the cane, it has the potential to be applicable in a wider range of environments than a cane and, given its relatively small size, is more inconspicuous than a cane. Additional research focusing on the Enactive Torch and cane in various experimental conditions would need to be conducted in order to better demonstrate the capabilities of one versus the other. Another area of Enactive Torch research worth pursuing
concerns its role as a sensory substitution device and how such a role affects, or not, the perception of affordances. Research with other kinds of haptic sensory substitution devices has suggested that users are aware of vibrotactile flow with their devices, and that such “vibrotactile flow is analogous to optic flow, but within the haptic domain” (Cancar, Diaz, Barrientos, Travieso, & Jacobs, 2013). Such claims are reminiscent of questions pertaining to the assumption that perception is divided into separate domains (sight, sound, touch, taste, and smell) and that information is specified in ambient energy arrays (cf. Stoffregen & Bardy, 2001). Perhaps sensory substitution devices such as the Enactive Torch can begin to make issues pertaining to such ideas as the global array more empirically tractable. To do so could have major implications for our understanding of perception-action.
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Figure 1. The Enactive Torch, version 5. This model was utilized in the experiment. The infrared range sensors are at the front. It connects via a cord to the vibrational motor, which is attached by a Velcro strap to the user’s wrist. (Retrieved January 30, 2014 from http://enactivetorch.files.wordpress.com/2008/01/et5.jpg)
Figure 2. Aperture (height: 2.43 m; width: 2.6 m) with two sliding panels (height: 2.43 m; width: 40.5 cm, each). Panels slid laterally across the frame to create aperture widths ranging from 101.6 cm to 190.5 cm.
Figure 3. (a) Mean percentage “yes, pass-through-able” responses, in raw units (cm). (b) Mean confidence ratings per aperture width, also in raw units (cm), with 1 being lowest confidence and
7 being highest confidence. In each graph the error bars correspond to one standard error. The vertical dashed line in the middle of each graph represents the point of subjective equality, which is the threshold at which participants perceive they are able to carry out an intended action, such as passing through an aperture.
Figure 4. (a) Mean point of subjective equality values for each modality, with values less than 1.0 reflecting an underestimation and values greater than 1.0 an overestimation ($N = 27$). The point of subjective equality is scaled by actual pass-through-ability. The horizontal dashed line in the middle represents the point of subjective equality, which is the threshold at which
participants perceive they are able to carry out an intended action, such as passing through an aperture. (b) Mean confidence ratings associated with the point of subjective equality for each modality, with 1 being lowest confidence and 7 being highest confidence ($N = 27$). All error bars correspond to one standard error.