I, Brandon J Thomas, hereby submit this original work as part of the requirements for the degree of Doctor of Philosophy in Psychology.

It is entitled: The Independence of Animal-Neutral and -Referential Environmental Properties

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The Independence of Animal-Neutral and -Referential Environmental Properties

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Abstract

Three experiments were conducted to test the relationship between environmental properties taken with reference to an animal and their action capabilities (e.g., affordances) and those that are independent of an animal (e.g., metric properties). In all three experiments, participants provided reports of the maximum height they could reach above their head with a stick(s) (reach-with-stick height) and the sticks’ length (stick length), a property that is constituent of reach-with-stick height. In Experiment 1 reach-with-stick height reports improved over trials whereas stick length reports remained constant. In Experiments 2a and 2b, feedback about maximum reach-with-stick height improved perception of this affordance, but such improvements did not transfer to perception of stick length in a pretest/practice task/posttest design. The results suggest that perceiving animal-referential and animal-neutral properties may require the detection of different information.
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CHAPTER 1

Introduction

The relationship between perceptual experiences of the environment is an important concern for perceptual scientists. Particularly of interest, is whether the perception of different environmental properties depend on each other. Assumptions about perceptual dependence are varied in the literature. Percept-percept coupling is the notion that successful perception of one property is sometimes dependent on the successful perception of another property (e.g., Epstein, 1982). Other theories about abstract knowledge structures and perception also assume that the perception of one property in the environment depends on the stored representations of other properties (e.g., Harnad, 1990; Mandler, 1984; Rumelhart, 1980). The ecological approach to perception-action (Gibson, 1966, 1979) broadly rejects percept-percept coupling, assuming instead that perception of a given property can be achieved independent of the perception of other properties. This hypothesis requires the assumption that properties of the animal-environment system are lawfully specified by information (patterns within energy arrays that relate unambiguously to properties of the animal-environment system). Specification obviates the need to invoke hypothetical computational-representational processes to perform the mediation necessary for coupling perceptions, even if perceived aspects of the environment are multidimensional or higher-order properties (Amazeen, 1999; Michaels & Carello, 1981; Stoffregen & Bardy, 2001). It is the assumption of specification that distinguishes Gibson’s direct perception approach from perceptual theories that could be labeled indirect perception (Michaels & Carello, 1981; Shaw, Turvey, & Mace, 1982).

The specific issue at stake in the present study is whether affordances—possibilities for action that reflect the fit between the animal and environment (Gibson, 1979)—are perceived as such—as higher-order properties that are independent of perception of the lower-order properties
of the animal or the environment that combine to define the affordances. Previous research has provided evidence broadly supporting this hypothesis, which is consistent with the ecological approach. For example, Mark (1987) found that participants whose ability to step and sit had been experimentally altered by wearing blocks on their feet improved in their ability to perceive maximum sitting and stepping heights over the course of the experiment. However, those participants did not improve in their ability to perceive the height of the blocks (the relevant dimension of the blocks for these affordances) over the same time frame. The independent trajectories of recalibration of affordance perception and perception of the lower-order property of relevance to this affordance suggest distinct informational bases for affordances and lower-order, action-neutral properties.

Similarly, Thomas and Riley (2014) created and tested a model that predicted the perceived maximum overhead reach-ability with a stick as a function of the remembered length of the stick plus the ability to reach without the stick. In other words, the study tested whether perceived reach-with-ability is reducible to the perceived length of the stick added to the perceived reach-ability without it. The same model was applied to perceived pass-through-able apertures while carrying an object that increases body width. The study found that neither perceived nor remembered maximum overhead reaching height with a stick, and neither perceived nor remembered minimum pass-through-able aperture width while holding a stick, could be predicted on the basis of remembered stick length. Furthermore, participants consistently overestimated the length of the stick and underestimated how much it increased overhead reach-with-ability.

Studies such as those suggest that the perception of affordances is largely independent of the perception of the isolated environmental properties or action capabilities that define them.
However, other studies suggest a relation between perceived animal-referential (i.e., affordances) and animal-neutral environmental properties. For instance, Day, Wagman, and Smith (2015) observed a transfer of calibration from perceived maximum leaping distance to perceived maximum stepping distance, but not vice versa. Day et al. concluded that stepping is likely a special case of leaping. There may be a similar relation between the perception of animal-referential and animal-neutral properties, in general. That is, perception of animal-neutral environmental properties may be a special case of perception of animal-referential properties. If so, calibration of perception of affordances might transfer to perception of action-neutral properties, but not vice versa. Investigating this possibility is one of the goals of the experiments reported here.

In addition, correlations exist among the various informational variables that can be detected by observers (see Jacobs, Michaels, & Runeson, 2001; McConnell, Muchisky, & Bingham, 1998; Thomas & Riley, 2015; Wagman & Van Norman, 2011; Withagen, 2004). For example, Thomas and Riley (2014) had participants perceive the length of rods and later asked them to remember the heaviness of those rods once they had been hidden. Participants could only accurately remember the heaviness of rods when their actual heaviness and length were correlated. These correlations further complicate idealized theoretical predictions about perceptual independence. First, if the informational variables that perceivers detect and utilize are correlated, then perceptual reports are also likely to be correlated, suggesting potential dependencies among perceived properties. Perhaps more problematic for resolving theoretical issues about whether percept-percept coupling occurs is that a perceiver may rely on a variable that merely correlates with (rather than specifies) the property that is meant to be perceived as long as that variable permits sufficient accuracy to satisfy the demands of the task—a situation
likely to hold when absolute perceptual accuracy is not required (i.e., in a laboratory experiment where the stakes are low and the task is potentially under-constrained). Moreover, those informational variables might also correlate to some degree with not just one but potentially several properties of the animal-environment system. To the extent that this occurs, perceptual reports of different properties may not always be independent of one another.

Ashby and Townsend (1986) offered a rigorous methodological and statistical approach to testing the independence of perceived properties (also see Ashby & Gott, 1988; Ashby & Lee, 1991). That strategy has been used to demonstrate perceptual independence of a number of properties perceived by dynamic or effortful touch (the haptic subsystem involving active wielding of hand-held objects; Amazeen & Turvey, 1996; Fitzpatrick, Carello, & Turvey, 1994; Gibson, 1966; Turvey, Burton, Pagano, Solomon, & Runeson, 1992). Such studies have revealed perceptual independence of an object’s length and center of percussion (Cooper, Carello, & Turvey, 1999), whole length, partial length, and hand position (Cooper, Carello, & Turvey, 2000; see also Santana, Hove, Riley, & Tollner, 2003), and size and weight (Amazeen 1999). While this approach has many advantages, it does place restrictions on experimental designs and procedures—for example, it requires that perceptual reports take the form of categorical responses and requires a factorial design that crosses an equal number of (categorical) levels of the properties that are being tested for perceptual independence.

My goal in the current study was to determine whether perceptual reports of animal-referential and -neutral (i.e., environmental) properties are independent by evaluating whether each contributes to the perceptual reports of the other. In Experiment 1 I attempted to replicate Mark’s (1987) findings investigating the evolution of the perception of an animal-referential and action-neutral properties with practice perceiving these properties. I used a different perceptual
task than in the Mark study (the present task involved overhead reaching height with a stick and reports of stick length), but similar to Mark’s task the present task required participants to provide perceptual reports of properties that were physically interdependent (overhead reaching height with a stick implies stick length, just as stepping height with blocks on feet implies the height of blocks).

In Experiment 2 I used the transfer of (re)calibration paradigm (cf. Rieser, Ashmead, Garing, & Pick, 1995) to investigate whether action-relevant and action-neutral properties share informational bases or if they are independent. Using this paradigm, the relation between two different perceived properties is determined by testing whether (re)calibration of perception of one property transfers to perception of another property. Calibration is the process of scaling actions or perceptual reports to information, and recalibration is the rescaling of this relation based on feedback or practice (Withagen & Michaels, 2007). The extent to which recalibration of a given perception-action task transfers to a different perception-action task can be used as an index of the degree to which those tasks are related or dependent on one another (i.e., whether they share an informational basis). The absence of a transfer of recalibration across tasks indicates that those actions or perceptions do not share informational bases, i.e., that perceivers are (correctly) attuned to different informational variables to perform those perceptual tasks.

Attunement and calibration are two different, though related, concepts. Attunement refers to the

1 A caveat must be mentioned here with regard to using recalibration and transfer to identify instances of perceptual independence. Carello et al. (1999) found that the length and center of percussion of a wielded object were perceptually independent, but Withagen and Michaels (2007) found that recalibration of perception of length transferred to perception of center of percussion. The former finding demonstrates that these two properties are perceptually independent, whereas the latter finding suggests that there is at least some relation between the perception of each property, be it causal or correlational. Nonetheless, an absence of the transfer of recalibration suggests that these two perceived properties are based on the detection of distinct informational variables.
information that is detected to perform a perception-action task, rather than the scaling of actions to information per se (see Wagman, Shockley, Riley, & Turvey, 2001). However, the transfer of recalibration from one task to another necessitates a shared informational basis, because the information that is scaled to action in one task must be consonant with the other task.

Rieser et al.’s (1995) influential investigation of the transfer of recalibration found that recalibration of the relations between optic flow transferred only to other actions that shared a common function. For instance, recalibration to changes in optic flow rate during walking transferred to other locomotor behaviors such as sidestepping and crawling (Withagen & Michaels, 2002) but not to other (non-locomotor) behaviors such as throwing or turning in place. Similarly, transfer of recalibration to the optical consequences of actions has been demonstrated between pointing at and tracking targets (Abeele & Bock, 2003), the direction of walking but not throwing or kicking (Bruggeman & Warren, 2010), and turning to face targets (Pick, Wagner, Rieser, & Garing, 1999). Furthermore, in the domain of perception by dynamic or effortful touch, recalibration of the perception of length of a wielded object transfers from one hand to the other (Withagen & Michaels, 2004), from hands to feet (Stephen & Hajnal, 2011), and from touch to audition (Wagman & Abney, 2012, 2013). Also, Witt, Proffitt, and Epstein (2004) found that increased effort led to greater perceived distance but only when the effort was associated with the intention of the perceiver. Greater effort to throw increased perceived distance when the perceiver expected to throw but not walk, and greater effort to walk increased perceived distance when the perceiver expected to walk but not throw. More relevant to the current investigations on transfer of calibration in perception of affordances, recalibration of the perception of maximum reaching height transfers from one means of reaching to another (Wagman, 2012; Wagman, Higuchi, Taheny, 2014).
By using this methodological strategy, I sought to understand the dependence of animal-neutral and animal-referential properties. Differential calibration of two perceived properties with repeated practice (Experiment 1) or on the basis of feedback about the accuracy of perceptual reports (Experiment 2) would provide evidence for the properties’ independence of one another, even if initial (pre-calibration) perceptual reports of those properties appear correlated. While the recalibration/transfer approach is perhaps less rigorous than the aforementioned statistical tests of perceptual independence, it is well suited to the verbal, continuous report procedures utilized in previous studies (Stephen & Hajnal, 2011; Wagman, 2012; Wagman & Abney, 2012, 2013; Wagman et al., 2014 Withagen & Michaels, 2004; Yasuda, Wagman, & Higuchi, 2014), thus providing a clearer link between those studies and the present project.
CHAPTER 2

Experiment 1

In Experiment 1 participants reported their perceived maximum reaching height if they were to reach with a hand-held implement (reach-with-ability) and also reported the perceived length of the implement (cf. Thomas & Riley, 2014). The former is an animal-referential and action-relevant property and the latter is an animal- and action-neutral property. Perceived reach-with-ability, at face value, seems to require that participants perceive the length of the stick, per se. Based on Mark’s (1987) findings, however, I hypothesized that these properties would be perceived independently, and accordingly expected that over four sets of trial blocks absolute error would decrease for (i.e., there would be improvement in) perceived reach-with-ability but would not change for (i.e., there would be no improvement in) perceived stick length. Those results would suggest that the properties of reach-with-ability and stick length are perceived independently even though one property implies the other.

Participants

Fifteen undergraduates (14 females and 1 male) from the University of Cincinnati participated for course credit. Written informed consent was obtained before data collection; all procedures were IRB-approved. Participants were required to be no taller than 173 cm due to the height constraints of the laboratory and apparatus, which precluded taller participants from performing the overhead reaching task. The average height of participants was 167.3 cm (SD =

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2 This sample size is consistent with that of Experiment 1 of Thomas and Riley (2014), and so should provide enough power to detect effects.
10.9 cm) and the average maximum overhead reaching height with the stick was 231.9 cm (SD = 8.2 cm).

Materials and Apparatus

Participants directed an experimenter to raise or lower a marker consisting of 11 stacked washers (total 11 g mass, 3 cm diameter, 2 cm tall) wrapped in red duct tape until the marker was at the perceived maximum overhead reaching height. The marker was tied to a pulley system that hung over the top of a planar surface (264 cm tall × 165 cm wide). Gray sheets covered the surface to create a uniform background for the marker. On the back of the vertical planar surface, a tape measure was attached so that the experimenter could measure perceptual reports. The tape measure was not visible to participants. The stick that was used in both conditions was a 38 cm long section of white PVC pipe (2.5 cm diameter). The first 10 cm of the PVC pipe was covered with red tape to designate the “handle” of the stick. The apparatus is depicted in Figure 1.

Figure 1. A depiction of the apparatus used in Experiments 1 and 2. Participants instructed an experimenter to raise and lower the marker. The rod was placed in front of the report apparatus while participants made their reports.
Design

Experiment 1 utilized a within-participants design. In the reach-with-stick height condition, participants were asked to report their maximum overhead reaching height if they were to reach with the stick. Maximum reaching height was defined as the maximum height at which the marker could be touched by the distal end of the stick, held in the preferred hand, with the arm fully extended above the head, without lifting either foot off the ground or standing on tiptoes. In the stick length condition, participants were asked to report the length of stick, not including the red handle. Both properties were reported by instructing the experimenter to adjust the marker to the respective height/length. Participants reported each property in separate blocks of trials that alternated within four block sets (sets consisted of the trial blocks for each property). The order of the blocks in which the respective properties were reported within each set was counterbalanced across participants but was consistent within each set for a given participant. Each property block consisted of six trials. This yielded a total of 48 trials in the experiment.

Procedure

Each participant stood 285 cm away from the vertical planar surface in a viewing area (50 × 50 cm) centered relative to the vertical surface. Each trial began with the marker set to its highest position (264 cm from the laboratory floor) or its lowest position (on the laboratory floor). Each condition consisted of three ascending trials (starting with the marker set to its lowest position and raising it) and three descending trials (starting with the marker set to its highest position and lowering it). Ascending and descending trials alternated for each of the 6 trials per condition.
In the reach-with-stick height condition, the stick was placed in a designated area in front of the vertical surface standing with the handle facing up. Participants envisioned walking over to the vertical surface, picking up the stick by the red handle with the bottom of the fist flush with the end of the proximal end of stick, and then using the distal end of stick to reach for the marker. Participants reported perceived maximum reaching height by directing the experimenter to raise or lower the marker until it was at the maximum height that they estimated they could reach with the distal end of the stick. The experimenter adjusted the height of the marker from behind the vertical surface and was not visible to the participant.

In the stick length condition, the stick was placed in the same designated area in front of the vertical surface and participants reported the length of the stick (not including the red handle). Participants were asked to report the length of the stick without considering the handle because the handle would be held in the fist and would not increase maximum reaching height, thereby making estimates of reaching height and stick length comparable (cf. Riley & Thomas, 2014). Participants instructed the experimenter to raise or lower the marker until its height off the laboratory floor was the same as the length of stick without the handle.

In both property conditions, participants were able to make changes to the position of the marker after their initial report until they felt satisfied with the marker’s position. Participants were instructed to close their eyes after each trial while the marker was positioned for the next trial.

After all trials were completed, the experimenter measured participants’ standing height and maximum reaching height when reaching with the stick. At no prior point in the experiment did any participant approach the vertical surface, pick up the stick, or attempt to reach for the marker.
Results & Discussion

Since I was interested in how practice affected the accuracy of perception regardless of whether each property was originally over- or underestimated, I converted the perceptual reports into absolute error measures for all analyses. Absolute error was calculated for each trial by taking the absolute value of the difference between the perceptual report and the actual reach-with-stick height or stick length, respectively.

The absolute errors were averaged within each block of trials and the values were submitted to a 2 (property: reach-with-stick height and stick length) × 4 (Block Set) within-subjects analysis of variance (ANOVA). There was a significant main effect of property, $F(1,13) = 124.45, p < .001, \eta_p^2 = .91$—absolute error was larger for reach-with-stick height ($M = 31.92$ cm) than for stick length ($M = 5.41$ cm). In addition, there was a significant main effect of Block Set, $F(3,39) = 6.68, p = .001, \eta_p^2 = .34$—overall, absolute error tended to decreases across sets.

However, both of those effects were superseded by a significant set × property interaction, $F(3,39) = 6.87, p = .001, \eta_p^2 = .35$ (see Figure 2). To specifically test my hypothesis, I used a series of post-hoc $t$-tests with Bonferroni corrections that compared absolute error over Block Sets for each property. For the reach-with-stick condition, absolute error marginally decreased from set 1 ($M = 38.12$ cm) to set 2 ($M = 32.53$ cm), $p = .063$, and then significantly decreased from set 2 to set 3 ($M = 30.84$ cm), $p = .031$. Absolute error for stick length decreased from set 1 ($M = 8.10$ cm) to set 2 ($M = 7.48$ cm), $p = .344$, and then decreased significantly from set 2 to set 3 ($M = 6.96$ cm), $p = .028$.

It is important to note that the error rate for stick length is in fact greater than reach-with-stick height when expressed as percentage of actual reach-with-stick height ($M$ error rate = 13.8%) and actual stick length ($M$ = 19.3%). Percentages of error were not used in the analysis below, however, since feedback was given by participants with the same reporting device and on the same absolute scale for both properties. Furthermore, running the analyses reported in the manuscript as percentage of absolute error did not substantially alter the pattern of results.
decreased from set 2 to set 3 ($M = 29.92$ cm) ($p = .041$) as well as from set 3 to set 4 ($M = 27.09$ cm) ($p = .019$). For the stick-length condition, absolute error did not change across any of the sets (all $p > .266$). Another series of simple-effects tests that compared absolute error for the two properties at each of the Block Sets found significant differences between the two property reports at each Block Set (all $p < .001$).

![Figure 2](image)

**Figure 2.** Mean absolute error of reports in the Reach-with-stick height and Stick length conditions across the four Block sets in Experiment 1. Error bars represent standard errors of the mean.

It is possible that there was no change in absolute error for stick length because absolute error values were so small for this property, which might implicate a floor effect in stick length report performance. To confirm that error in this condition was not at floor, I compared mean absolute error on perceived stick length to 0. Mean absolute error values ($M = 5.50$ cm) were, in fact, significantly different from 0, $t(14) = 7.83$, $p < .001$, suggesting that error was not at floor.

Consistent with the findings of Mark (1987), Experiment 1 found that animal-referential and animal-neutral properties evolved independently with continued practice at perceiving these respective properties. Perception of maximum reach-with-stick height improved over the four
sets of trials but perception of stick length did not. The findings thus provided preliminary evidence that perception of these two properties is independent and, perhaps, that the properties have independent informational bases. However, the results of this study do not provide conclusive evidence that the two properties are perceptually independent. Experiment 2 used a transfer of recalibration paradigm to more conclusively address the potential dependence of one property on the other.
CHAPTER 3

Experiment 2a

Experiment 2a was designed to further test the independence hypothesis with the use of a transfer of recalibration paradigm. The study implemented a pretest/practice task/posttest design. Participants practiced perceiving either maximum reach-with-stick height or stick length and were either provided with explicit feedback about that property or not provided with any explicit feedback. The primary questions were (1) whether such practice would serve to recalibrate perception of the practiced property and (2) whether such recalibration would transfer to the perception of the unpracticed property. Based on the results of Experiment 1 and the extant literature on affordance perception, I expected that recalibration of the practiced property would not transfer to the perception of the other property. This would suggest that perception of maximum reach-with-stick height and stick length merely correlate and do not share informational bases.

Participants

Fifty-two undergraduates from the University of Cincinnati participated in this study for course credit. Written informed consent was obtained before data collection. Given the height constraints of the laboratory and apparatus, participants were required to be no taller than 173 cm. The average height of the participants was 166.5 cm ($SD = 4.8$ cm) and their average maximum overhead reach with the stick was 233.9 cm ($SD = 7.4$ cm). The sample consisted of 47 females and 5 males.
Materials, Apparatus, and Design

The materials and apparatus were identical to Experiment 1. The experiment utilized a pretest/practice task/posttest design. All participants completed the pretest that consisted of reporting the two properties (reach-with-stick height and stick length) which were defined as and reported by the same procedure as Experiment 1. This was followed by the practice task (two blocks). During the practice task, half of participants practiced perceiving (i.e., made repeated perceptual estimates of) reach-with-stick height, and half practiced perceiving stick length. Within each of these groups, half of the participants received feedback on these perceptual reports, and half did not. All participants then completed the posttest, which was identical to the pretest. The order of the property conditions was counterbalanced across participants, but the same order was used for the pre- and posttests for a given participant. Each block consisted of six trials (three ascending and three descending), yielding a total of 48 trials. See Figure 3 for a schematic of the design.

Procedure

Before perceptual reports were obtained, participants were blindfolded and their actual reach-with-stick height was measured. This was obtained at the beginning of the experiment so that feedback could be provided during the reach-with-stick height practice task blocks. Participants were blindfolded so that they did not receive any a priori visual feedback about reach-with-ability. This procedure was performed for all participants regardless of practice task and feedback condition to control for potential confounding effects. The procedure for reporting reach-with-stick height and stick length were identical to Experiment 1.
In the two practice task blocks, half of the participants \( (n = 26) \) reported reach-with-stick height and half \( (n = 26) \) reported stick length, depending on practice task condition. These reports were given using the same procedure as the pretest. Within each of these groups, half of the participants \( (n = 13) \) were provided feedback on the property that they reported and half \( (n = 13) \) were not provided with any feedback. Feedback in the reach-with-stick height practice condition was provided by the experimenter adjusting the marker to participants’ actual reach-with-stick height after each report. Feedback in the stick length practice condition was provided by adjusting the marker to the actual length of the stick after each report. The participant was asked to close their eyes while the height of the marker was adjusted to the actual reach-with-stick height or stick length. Then, they opened their eyes, viewed the location of the marker for a few seconds, and closed their eyes again while the marker was readjusted to the start location for the next report trial.

*Figure 3.* A schematic of the experimental design and procedure for Experiment 2a.
In the posttest, all participants reported reach-with-stick height and stick length in separate blocks that were completed in the same order as the pretest. After all trials were completed, each participant’s standing height was recorded.

**Results & Discussion**

I calculated absolute error and averaged the trials of each block in the same way as Experiment 1. I compared absolute error in a 2 (Test: pretest vs. posttest) × 2 (Property: reach-with-stick height vs. stick length) × 2 (Practice task: reach-with-stick height vs. stick length) × 2 (Feedback: feedback or no feedback) mixed-design ANOVA. Test and Property were within-subjects factors, and Practice and Feedback were between-subjects factors. The four-way interaction was significant, $F(1, 48) = 9.23, p = .004, \eta^2_p = .16$ (see Figure 4). I conducted a set of follow-up tests to decompose this interaction.

First, two parallel 2 (Test: pretest vs. posttest) × 2 (Property: reach-with-stick height vs. stick length) × 2 (Feedback: feedback or no feedback) simple-effects ANOVAs were conducted separately in each practice task condition (i.e., reach-with-stick height practice and stick length practice). The three-way interaction was significant for the reach-with-stick height practice task, $F(1, 24) = 17.52, p < .001, \eta^2_p = .42$, but not for the stick length practice task, $F(1, 24) = 0.15, p = .702, \eta^2_p = .01$ (see Figure 4, compare top two panels to bottom two panels). Therefore, stick length practice data were not included in the subsequent follow-up analyses.
Next, two parallel 2 (Test) × 2 (Feedback) simple-effects ANOVAs were conducted separately for each reported property. For the property of reach-with-stick height there was a significant main effect of Test, $F(1, 24) = 25.63, p < .001, \eta^2_p = .52$—absolute error for reach-with-stick height decreased from the pretest ($M = 32.87$ cm) to the posttest ($M = 21.02$ cm). The main effect of Feedback was not significant, $F(1, 24) = 2.42, p = .113, \eta^2_p = .09$, but there was a significant Test × Feedback interaction, $F(1, 24) = 18.70, p < .001, \eta^2_p = .44$ (see Figure 4, top left panel). Post-hoc $t$-tests with Bonferroni corrections revealed that, in the pretest, there was no difference in absolute error in reach-with-stick height between the feedback ($M = 34.21$ cm) and no-feedback ($M = 31.52$ cm) conditions ($p = .604$). However, in the posttest, absolute error was
smaller in the feedback condition ($M = 12.24$ cm) than in the no-feedback condition ($M = 29.77$ cm) ($p = .004$). Moreover, post-hoc, Bonferroni-corrected $t$-tests also revealed that while absolute error decreased from pre- to posttest in the feedback condition ($p < .001$), there was no change in absolute error from pre- to posttest in the no-feedback condition, $p = .607$ (see Figure 4, top left panel). For the property of stick length, there were no significant effects (all $p > .10$) (see Figure 4, top right panel).

As in Experiment 1, I compared mean absolute error of perceived stick length to 0 in each of the four conditions to confirm that error in this condition was not at floor. One-sample $t$-tests showed that absolute errors significantly differed from 0 in each case (all $p < .05$). I also attempted to determine whether stick length reports were recalibrated from pre- to posttest by stick length feedback. When feedback was provided about stick length average absolute error decreased from pre-test ($M = 7.02$ cm) to post-test ($M = 3.08$ cm), $t(14) = 5.36, p < .001$, suggesting that stick length perception was recalibrated. However, this effect must be interpreted with caution since the omnibus three-way interaction that included stick length reports conducted in the set of simple effects reported above was not significant.

To summarize, there was evidence to suggest that both reach-with-stick height and stick length reports were recalibrated by explicit feedback about the respective property (though the evidence of this is not as strong for stick length), confirming my first hypothesis. I also found that recalibration did not transfer to the untrained property, confirming my second hypothesis and indicating that perception was recalibrated by feedback but not by practice, per se. These findings suggest that the two properties are independent and potentially perceived on the basis of different informational variables. Nonetheless, there are a few methodological issues with Experiment 2a. Particularly, there only one stick was used and perceptual reports of each
property were given on opposite sides of the report apparatus. These issues were addressed in Experiment 2b.
CHAPTER 4

Experiment 2b

Experiment 2a found that feedback given about actual reach-with-stick height and stick length during training recalibrated perception of each respective property, but recalibration did not transfer from the perception of one property to the other, consistent with my hypothesis. Nonetheless, there were a methodological issues with Experiment 2a that potentially require further attention. While participants’ stick length reports did significantly differ from perfect accuracy (the average absolute values in these conditions significantly differed from 0.0), the absolute magnitudes of those reports were disproportionately more accurate than reach-with-stick height reports (though it is important to note that again the percentage of error with respect to the average was not substantially different between the two properties). This disparity in reports for each property potentially reflects a difference in the difficulty of the two reporting procedures and might preclude their direct comparison. Because stick length reports were measured from the ground to where the handle met the white portion of the stick, all participants had to do was adjust the marker to the top of the handle (see Figure 1). This is perhaps a trivial reporting procedure. Also, reach-with-stick height reports were given with the marker near the top of the wall, which is opposite to the end of the wall that stick length reports were given (near the ground). This is another discontinuity in the reporting procedures of the two properties that requires attention.

Experiment 2b largely replicated Experiment 2a, except participants reported stick length by instructing the experimenter to adjust the marker to a spot on the wall in which the distance of the marker from the top of the wall was equal to the length of the stick. This change in the stick length reporting procedure not only made the task more difficult, but also insured that stick
length reports were given near the top of the wall along with the reach-with-stick height reports. Also, a single stick was used in Experiment 2a, so it is possible that feedback and practice caused participants to memorize a location on the report apparatus rather than recalibrate perception of the stick’s property. In Experiment 2b reports of both properties were made on three sticks of different lengths, making the aforementioned strategy more difficult and less likely.

Participants

Fifty-two undergraduates from the University of Cincinnati participated in this study for course credit. Written informed consent was obtained before data collection. Again, given the height constraints of the laboratory and apparatus, participants were required to be no taller than 173 cm. The average height of the participants was 163.7 cm (SD = 5.2 cm) and their average, maximum overhead reach (see materials and apparatus section) was 208.8 cm (SD = 9.3 cm) with stick 1, 223.5 cm (SD = 7.9 cm) with stick 2, and 238.0 cm (SD = 9.8 cm) with stick 3. The sample consisted of 46 females and 6 males.

Materials, Apparatus, & Design

The materials were identical to Experiment 2a, aside from the sticks that were employed. Three sections of white PVC pipe (2.5 cm diameter) were used. The first 10 cm of each PVC pipe was covered with red tape to designate the “handle” of the stick. Stick 1 was 15 cm long, stick 2 was 30 cm long, and stick 3 was 45 cm long.

The design was largely the same as Experiment 2a, aside from the use of three sticks that vary in length instead of one. Stick length manipulated in Experiment 2b as a within-subjects variable.

Procedure
The procedure was largely the same as in Experiment 2b. Participants reported both properties of the three sticks in each trial block (pretest, both practice task blocks, and posttest). Again, participants reported both properties in the pre- and posttest, and reported either the stick length or reach-with-stick height, depending on the practice task condition in the two practice task blocks. Within each trial block, participants reported on 3 sticks that varied in length. The order of the 3 sticks was randomized within each trial block. Participants completed 4 consecutive trials for each stick, and the marker was raised (ascending) and lowered (descending) twice on alternating trials. In every block, all three sticks were presented and reported on by participants, resulting in 72 total trials. Participants were blindfolded and their actual ability to reach for each stick was measured prior to explaining the instructions of the task for the same reasons as in Experiment 2a. Participants only viewed the sticks during the experiment when they were placed in the square in front of the vertical surface. Participants were asked to close their eyes while the sticks were swapped during the experiment.

The stick length report procedure also differed from Experiment 2a. Participants were asked to instruct the experimenter to adjust the marker to the point on the vertical surface where the distance of the marker from the top of the wall matched the length of the stick.

**Results and Discussion**
Figure 5. Experiment 2b results. Mean absolute error in the Test × Feedback conditions for Reach-with-stick height reports with Reach-with-stick practice (A1), Reach-with-stick height reports with Stick length practice (A2), Stick length reports with Reach-with-stick practice (B1), and Stick length reports with Stick length practice (B2). Error bars represent standard errors of the mean.

I calculated absolute error and averaged the trials of each block. I compared absolute error in a 2 (Test: pretest vs. posttest) × 2 (Property: reach-with-stick height vs. stick length) × 2 (Practice task: reach-with-stick height vs. stick length) × 2 (Feedback: feedback or no feedback) × 3 (Stick: stick 1, stick 2, stick 3) mixed-design ANOVA. Test, Stick, and Property were within-subjects factors, and Practice and Feedback were between-subjects factors. The five-way interaction was not significant, $F(2, 94) = .013, p = .987, \eta^2_p = .00$. The only significant four-way interaction was the Feedback × Practice task × Property × Test interaction, $F(1, 47) = 9.00, p = .004, \eta^2_p = .16$ (see Figure 5). No other four-way interactions were significant (all $p > .10$). Since
Stick did not significantly interact with the other variables, absolute errors of the perceptual reports were averaged across the different stick lengths for the remainder of the analyses. I conducted a set of follow-up tests to decompose the significant four-way interaction.

First, two parallel 2 (Test: pretest vs. posttest) × 2 (Property: reach-with-stick height vs. stick length) × 2 (Feedback: feedback or no feedback) simple-effects ANOVAs were conducted separately in each practice task condition (i.e., reach-with-stick height practice and stick length practice). The three-way interaction was significant for the reach-with-stick height practice task, $F(1, 24) = 11.25, p = .003, \eta^2_p = .32$, but not for the stick length practice task, $F(1, 23) = 2.37, p = .788, \eta^2_p = .01$ (see Figure 5, compare top two panels to bottom two panels). Therefore, stick length practice data were not included in subsequent analyses.

Next, two parallel 2 (Test) × 2 (Feedback) simple-effects ANOVAs were conducted separately for each reported property. For the property of reach-with-stick height there was a significant main effect of Test, $F(1, 24) = 5.67, p = .026, \eta^2_p = .19$—absolute error for reach-with-stick height decreased from the pretest ($M = 17.94$ cm) to the posttest ($M = 12.48$ cm). The main effect of Feedback was not significant, $F(1, 24) = 3.1, p = .095, \eta^2_p = .12$, but there was a significant Test × Feedback interaction, $F(1, 24) = 12.07, p = .002, \eta^2_p = .34$ (see Figure 5, top left panel). Post-hoc $t$-tests with Bonferroni corrections revealed that, in the pretest, there was no difference in absolute error in reach-with-stick height between the feedback ($M = 19.30$ cm) and no-feedback ($M = 16.58$ cm) conditions ($p = .463$). However, in the posttest, absolute error was smaller in the feedback condition ($M = 5.87$ cm) than in the no-feedback condition ($M = 19.09$ cm) ($p = .003$). Moreover, post-hoc $t$-tests with Bonferroni corrections revealed that while absolute error decreased from pre- to posttest in the feedback condition ($p < .001$), there was no
change in absolute error from pre- to posttest in the no-feedback condition, \( p = .447 \) (see Figure 5, top left panel). For the property of stick length, there were no significant effects (all \( p > .10 \)) (see Figure 5, top right panel).

I compared mean absolute error of perceived stick length to 0 in each of the four conditions to confirm that error in this condition was not at floor. One-sample \( t \)-tests showed that absolute errors significantly differed from 0 in each case (all \( p < .05 \)). As in Experiment 2a, I attempted to determine whether stick length reports were recalibrated from pre- to posttest by stick length feedback. When feedback was provided about stick length average absolute errors did not decrease from pre-test (\( M = 4.82 \) cm) to post-test (\( M = 4.56 \) cm), \( t(10) = 1.01, p < .017 \), suggesting that stick length perception was not recalibrated, unlike the same analysis conducted in Experiment 2a.

The results in Experiment 2b largely replicate those from Experiment 2a. The only difference was the aforementioned non-significant post-hoc comparison of stick length reports with feedback and stick length practice in the pre- and posttest, which was significant in Experiment 2a. Experiment 2b was conducted to address the potential floor effect in stick length reports from the Experiment 2b and the possibility that participants’ memorized the location of the marker on the report apparatus instead of recalibrating perception. Experiment 2b seemed to suffer from the same potential floor effect as Experiment 2a. However, this was again not the case when error was represented as percent absolute error.\(^4\) Experiment 2b did however, successfully address the potential methodological issues associated with using single stick and with reporting stick length relative to the laboratory floor. In sum, the results of Experiment 2b

\(^4\) The average percent absolute error for perceived stick length was 22.3% and 13.3% for perceived reach-with-stick height in Experiment 2a. In Experiment 2b, perceived stick length was 18.2% and perceived reach-with-stick height was 6.9%.
supported the hypothesis that perceived reach-with-ability is independent of perceived length. However, it is still not clear that perceived length was successfully recalibrated, since feedback about actual stick length did not significantly improve perceived stick length.
CHAPTER 5

General Discussion

Three experiments were conducted to investigate the relation between the perception of affordances (action-relevant environmental properties taken with reference to an animal) and action-neutral environmental properties that are independent of an animal (i.e., metric properties). Participants provided reports of the maximum height they could reach above their head with a stick (reach-with-stick height) and the length of the stick (stick length). The main question was whether perception of the affordance (reach-with-ability) was independent of perception of the lower-order environmental property (stick length) that partly determined the affordance in question as revealed by the patterns of calibration of perceptual reports of the respective properties.

Experiment 1 built on Mark’s (1987) findings that perception of maximum sitting height improves with repeated opportunities to perceive this affordance. The results were also consistent with those of Ramenzoni, Davis, Shockley, and Riley (2010), who found that the perception of reaching while jumping improved with repeated practice in the absence of feedback. In particular, I compared trajectories of errors in perception of reach-with-stick height and in perception of stick length with repeated experience perceiving these properties, in the absence of feedback about the accuracy of the reports. Based on Mark’s earlier findings, I predicted that absolute error in perception of reach-with-stick height would decrease with practice perceiving this property but that perception of stick length would not change with practice perceiving this property. That prediction was confirmed.

In Experiments 2a and 2b, I investigated (1) whether feedback about maximum reach-with-stick height and stick length would recalibrate perception of each of these properties,
respectively, and (2) whether such recalibration would transfer to perception of the other property. Based on previous research showing the independence of animal-referential and animal-neutral properties (e.g., Higuchi et al., 2011; Mark, 1987; Thomas & Riley, 2014; Yasuda et al., 2014), I predicted that feedback about a given property would improve perception of that property but that such improvements would not transfer from one property to the other. Consistent with my hypotheses, perception of reach-with-stick height improved with feedback, and such improvements did not transfer to perception of stick length (see Figure 5, top left panel).

However, improvements in perception of stick length with (or without) feedback were less evident (see Figure 5, right panels). As a result, investigating whether or not such improvements transferred to perception of reach-with-stick height was not as straightforward. A post-hoc test did find that stick length reports improved from pre- to posttest in Experiment 2a. However, since this effect was not evident in the omnibus test, it is possible that stick length perception was not recalibrated (possibly because the error in the reports was initially very low, allowing little room for improvement), a possibility which seems likely given that the same post-hoc comparison was not significant in Experiment 2b. Nonetheless, this potential improvement in perceived stick length from pretest to posttest with feedback coupled with the fact that absolute errors for stick length were significantly different from 0 in both experiments provides at least some evidence that error in this task was not at the floor and that improvements in perception of this property (and, in principle, transfer of such improvements) were possible. Furthermore, stick length reports expressed as percentage of absolute error were consistently greater than reach-with-stick height error.
No transfer of (re) calibration was observed in the current study between perception of reach-with-stick height and stick length. Therefore, the results of Experiments 2a and 2b suggest that perception of these animal-referential and -neutral properties do not depend on one another. Consequently, my results are consistent with the ecological approach to perception-action in which perception of higher-order affordances is direct rather than being inferred on the basis of perceived lower-order animal and environment properties (Gibson, 1966, 1979). From this perspective, properties of objects and events lawfully structure patterned energy distributions (e.g., the optic array). Different properties are specified by different patterns within a given energy distribution. Along these lines, the results of the experiments reported here suggest that despite the fact that the animal-referential property of reach-with-stick height and the animal-neutral property of stick length apparently imply each other, perception of each of these properties is likely specified by different informational variables. Considered in the context of other similar work (Higuchi, et al., 2011; Mark, 1987; Yasuda et al., 2014), the results suggest that this is likely the case for other animal-neutral and animal-referential properties as well.

As noted in the introduction, a rigorous methodological and statistical test of perceptual independence has been developed by Ashby and Townsend (1986). I did not use this method here for a number of reasons, including the constraints that this technique imposes on experimental methodology. However, even though the transfer of recalibration paradigm arguably lacks the methodological and statistical rigor of Ashby and Townsend’s method, it is a valuable complement to that method. Transfer of recalibration has been demonstrated for properties that were found to be independent using Ashby and Townsend’s method (e.g., length and center of percussion of an occluded welded rod), however. Future research should therefore
implement a stronger test of perceptual independence for animal-referential and -neutral properties.

Although I did not find evidence that perception of reach-with-stick height and stick length were perceptually dependent, it is possible that perception of other animal-referential and -neutral properties do, in fact, depend on one another (but perhaps in a different way than proposed by theories that posit the coupling of percepts). For instance, Shockley, Carello, and Turvey (2004) found that the perception of heaviness of a wielded object is based on the perception of maneuverability. Importantly, however, the argument being made by those authors was that perception of the animal-neutral property depends on perception of the animal-referential property and not the other way around. In other words, the colloquial descriptors such as “heavy” and “light” may simply be inappropriate for a principled understanding of perception by touch (Wagman, 2015). A similar argument might be made about perception in general—animal-referential, action-relevant properties (i.e., affordances) may be fundamental to perception, perhaps more fundamental than animal-independent (i.e., metric) properties (cf. Chemero, 2003, 2000; Witt & Riley, 2014; Stoffregen, 2003, 2000). It will be important for future research to address the informational constraints on the perception of animal-referential and -neutral properties of the environment.

There is also a large body of evidence that suggests that the perception of animal-neutral properties are influenced by action and embodied experience (see Proffitt & Linkenauger, 2013, and Witt, 2011, for reviews). Effort, intention, and action capabilities have been shown to influence the perception of putatively geometrical properties such as distance, slant, and size. It is possible that action-relevant properties are mapped onto the perception of action-neutral properties (cf. Shockley et al., 2004). It is likewise possible that these perceived properties are
dependent on animal-referential properties. In light of the current study and its findings, it is important for future research to determine whether embodied effects on the perception of action-neutral properties (e.g., perceived distance) are related to action-relevant properties (e.g., perceived effort to travel to distance).

Finally, the results of the current study are consistent with work showing that (improvements in) the ability to perceive affordances is highly context-specific. That is, the perceptual skill developed in perceiving affordances in a particular context does not (necessarily) transfer to a different context. For example, Adolph and colleagues have shown that infants who successfully differentiate safe and risky gaps from a (more stable) sitting posture do not necessarily do so from a (less stable) crawling posture (Adolph, 2000) and toddlers who successfully differentiate safe and unsafe drop offs while crawling do not necessarily do so while walking (Kretch & Adolph, 2013). Similarly, Higuchi and colleagues have shown that while American football players are more skilled at running through apertures than athletes in other sports, they show no advantages over such athletes in either walking through apertures or in perceiving the width of their own body (Higuchi et al., 2011). Similarly, Weast, Shockley, and Riley (2011) found that basketball players were better than non-basketball players at perceiving the basketball-relevant affordance of another person’s jump-reaching height, but their accuracy did not differ from non-basketball players when perceiving another person’s standing reaching height and sitting ability. The independence observed in the current study between perceived reach-with-ability and length might be consonantly due to the difference in context of the two tasks. In other words, the use of an object for reaching is a qualitatively different task than an attempt to gauge its length, and therefore a different perceptual context. It is an intriguing possibility that these contextual differences account for their perceptual independence.
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