It doesn't add up: Nested affordances for reaching are perceived as a complex particular

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Abstract

In the Ecological Approach to Perception and Action, affordances are emergent, higher-order relationships in an animal-environment system. In addition, perceivers should perceive such relationships directly, rather than by combining lower-order constituents of the affordance, such as non-affordance properties of the animal or the environment. In the present study, we investigated whether this latter claim applied to perception of superordinate affordances – affordances that emerge from relations between lower-order affordances. We asked whether perception of a superordinate affordance for reaching by different means would be reducible to a combination of lower-order constituents of that affordance. Participants reported the maximum height that they would be able to reach with their arm alone versus with a hand-held tool. In both cases, reported judgments of maximum reaching height differed from an additive model in which values were computed from a combination of perceived lower-order constituents of the affordance. The results are consistent with the ecological claim that affordances are perceived, “as such,” rather than being computed or inferred from constituent properties, even when those constituent properties are, themselves, affordances.

Keywords Affordances · Reaching · Tool use

Introduction

Affordances are available behaviors emerging from higher-order relations between (and among) properties of animals and their environment (Gibson, 1979/2015). A large body of research has shown that people can perceive a variety of affordances for themselves, for others, and for groups, and that perception of such affordances generally reflects this fit (see Wagman, 2020 for a review, but see Cordovil & Barreiros, 2011). For example, perception of whether a surface can be stepped onto depends upon the fit between the height of the surface, and the length, strength, and flexibility of the leg as well as overall balance and coordination ability (Konczak, Meeuwssen, & Cress, 1992; Mark, 1987; Pufall & Dunbar, 1992; Warren, 1984).

Representational and ecological perspectives on perception of affordances

There are (at least) two perspectives on how affordances are perceived. In what can be generally termed *representation-based perspectives*, perception of affordances is an inferential (or computational) process, in which (representations of) properties of the self and representations of properties of the environment are combined or compared (for discussion, see Creem-Regher, Gagnon, Geuss, & Steffanucci, 2013; Ramenzoni, Riley, Shockley, & Davis, 2008). These include, but are not limited to, perspectives in which object properties, bodily properties, or action capabilities are represented, simulated, derived, or stored in the service of perception (e.g., Longo & Haggard, 2010; Garbarini & Adenzato, 2004). In such perspectives, perceiving an affordance (for the self, for others, or for a group) would seem to depend (in some form or other) upon current or prior knowledge of lower-order constituents of the affordance, such as non-affordance properties of the animal and of the environment. For example, perceiving whether an object can be reached might require perceiving the egocentric distance of the object, perceiving (or knowing) the length of the arm, and (some form of) an internal process comparing these two values.

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James Gibson's Ecological Approach (Gibson, 1979/2015) offered a qualitatively different account of affordance perception. In this view, the animal-environment relations that constitute affordances lawfully structure energy arrays such that this structure is specific to (relates unambiguously to) these relations. In this perspective, animals perceive affordances by detecting the information about a particular animal environment fit, without any need to combine perceptions of lower-order constituents of that affordance (i.e., non-affordance properties of the animal or the environment). That is, perceivers ought to have direct perceptual sensitivity to affordances as higher-order relationships rather than having indirect perceptual sensitivity to affordances achieved by combining lower-order constituents of the affordance, such as non-affordance properties of the animal or the environment. Consequently, the higher-order animal-environment relations that define affordances ought to be perceived as a *complex particular* – a singular but multifaceted and multileveled higher-order relationship (Turvey, 2015) – and ought not to be reducible to a combination of perceived lower-order constituents of that affordance. In other words, in this perspective affordances are not derived from any internal process. Rather, they are the immediate objects of perception.

Research has provided support for Gibson's perspective by showing that perception of affordances does not seem to depend upon separate, prior or simultaneous perception of properties of the animal and environment that are constituent of that affordance. Mark (1987) asked observers to judge their maximum sitting height while wearing wooden blocks on the feet, which served to increase actual maximum sitting height. Over a series of repeated trials, perceived maximum sitting height came to reflect the new actual maximum sitting height, but perceived block height remained relatively unchanged. In addition, Higuchi et al. (2011) asked participants with experience playing American football and control-group athletes with experience in other sports (e.g., baseball, tennis, track) to run through narrow apertures and to report their own shoulder width (on separate sets of trials). They found that the football players made more efficient shoulder rotations when running through the apertures than the non-football players, indicating that they were more finely attuned to affordances for this particular behavior. However, football players were no better at perceiving (or knowing) their own shoulder width than the control group athletes (see also Yasuda, Wagman, & Higuchi, 2014). Such findings support the hypothesis that affordances are perceived as higher-order relationships, and are not inferred or computed from separate sensitivities to lower-order constituents of that affordance (i.e., non-affordance properties of the animal or the environment).

Nested affordances

Animals have many properties and environments have many properties. Consequently, in any situation, there are multiple affordances for any given animal; that is, multiple behaviors are available. It might be the case that these multiple affordances exist independently of one another. However, it seems more likely that affordances are related in a way that reflects the relationship among the many properties of animals and the relationship among the many properties of environments, respectively. Animals and environments are each highly nested entities, with components and processes simultaneously existing at many different spatial and temporal scales (Gibson, 1979/2015; see also Franchak, 2020; Gottlieb, 1999; Ingold, 2013; Lewontin, 2002; Nonaka, 2020a, b; Oyama, 2000; Van Orden, Holden, & Turvey, 2003; Wagman & Miller, 2003). For both animals and environments, all components and processes are more or less nested in the context of other components and processes, and no components or processes exist in isolation. Therefore, it is likely the case that any *relations between* the many properties of animals and the many properties of the environment are nested as well. By this account, all affordances are nested in the context of other affordances, and no affordances are perceived in isolation (Rietveld & Kiverstein, 2014; Wagman, Caputo, & Stoffregen, 2016). Therefore, perception of affordances should reflect these nesting relationships.

Consistent with this idea, research has shown that perception of whether an object can be reached depends not only on the fit between arm length and object location but also on the nested context in which that reaching occurs. For example, perception of maximum horizontal reaching distance additionally depends on the posture from which reaching would be performed and the stability of the support surface (Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989; Mark et al., 1997), and perception of maximum vertical reaching distance additionally depends on the means by which reaching would be performed (Wagman, Cialdella, & Stoffregen, 2019; Wagman & Morgan, 2010).

The idea that affordances can be nested within one another implies that an individual affordance may be superordinate to other affordances and, therefore, that some affordances will be subordinate to others. That is, while some affordances will arise from relations between (non-affordance) properties of the animal and the environment, other affordances will arise from relations between other (subordinate) affordances. Thus, affordances both exist in the context of other affordances and can comprise other superordinate affordances. Hence, perception of a given affordance ought not to depend on or imply prior or simultaneous perception of lower-order properties constituent of that affordance regardless of the degree to which that affordance is nested. In other words, superordinate affordances ought to be perceived as a “complex particular”

(Turvey, 2015) and ought not to be reducible to a combination of perceived lower-order constituent components of that affordance.

Thomas and Riley (2014) found preliminary support for this hypothesis using the *remembered affordance paradigm* (see Wagman, Thomas, McBride, & Day, 2013). They argued that in representation-based perspectives, both perceiving and remembering require the use of representations. Therefore, they proposed that remembered affordances for a given behavior can be used to evaluate whether representations of properties of the self and of the environment are combined or compared in *perceiving* affordances for that behavior. In their study, participants performed a sequence of tasks. First, they reported the maximum height to which they could reach with a visible hand-held implement (a stick). Then, after the stick had been removed from view, participants reported the maximum height to which they could reach using their arm only, the remembered length of the stick, and the remembered height to which they could reach using the stick. Thomas and Riley (2014) found that the remembered maximum reaching height with the stick was not merely an additive combination of perceived maximum reaching height with the arm only plus remembered (or perceived) stick length. That is, they found that a remembered nested affordance was not merely an additive combination of perceived and remembered lower-order constituent components of that affordance. They concluded that perceiving affordances for a given behavior does not necessitate the storing, manipulating, and retrieving of representations of object properties.

The current experiment

The study by Thomas and Riley (2014) provided evidence that perception of nested affordances for reaching was not reducible to a combination of perceived lower-order constituent components of the affordances – either non-affordance properties of the animal or environment or lower-order affordances (see also Thomas, Hawkins, & Nalepka, 2018; Thomas, Wagman, Hawkins, Havens, & Riley, 2017). In the present study, we attempted to provide stronger support for this hypothesis, by making two important and novel modifications to their experimental design.

First, their conclusions were dependent upon the degree to which perceived affordances are continuous with remembered affordances. There are good reasons to expect that this could be true (see Thomas & Riley, 2014; Wagman et al., 2013; Wagman, Thomas, & McBride, 2019). However, stronger evidence would be provided if such conclusions were not dependent on any particular relations between perceived and remembered affordances (i.e., between perceiving and remembering). That is, stronger evidence would be provided if, for example, it

could be shown that *perceived* affordances for reaching with an implement (rather than remembered affordances for this behavior) were not an additive combination of perceived lower-order constituent components of that affordance.

Second, in Thomas and Riley's (2014) study, the degree of nesting between superordinate and subordinate affordances was implicit. That is, in their study, participants were asked to perceive their ability to reach by one particular means (i.e., with an implement). Stronger evidence would be provided if the degree of nesting between superordinate and subordinate affordances was explicitly manipulated. That is, stronger evidence would be provided if it could be shown, for example, that perceived affordances for reaching *by different means* (i.e., with vs. without an implement) were each not additive combinations of perceived lower-order constituent components of those affordances.

In the present experiment, we implemented both of these innovations. Our goal was to ascertain whether the claim that an affordance is perceived as an emergent higher-order relationship (and not as a combination of lower-order constituents of that affordance) applies to perception of *superordinate affordances* – affordances that emerge from relations between lower-order affordances, rather than from non-affordance properties of the animal and of its environment. Specifically, we asked whether perception of an affordance for reaching by different means would be reducible to (a combination of) perceived lower-order constituents of the affordance, or instead whether nested (i.e., both superordinate and subordinate) affordances for reaching would be perceived as a complex particular.

We asked perceivers to report the maximum height that they could reach by two different means – with their arm alone versus with a hand-held tool. In *Gibson's ecological approach* the animal-environment relations that define affordances ought to be perceived as a complex particular (Turvey, 2015), and this ought to be the case regardless of the degree to which those relations are nested. Therefore, we expected that participants would be sensitive to superordinate affordances as an emergent higher-order relationship, and that nested affordances for reaching would not be reducible to a combination of lower-order constituent components of that affordance, including non-affordance properties of animal and environment (Predictions 1 and 2) and lower-order affordances (Prediction 3). We tested three specific hypotheses, as outlined below.

First, we predicted that perceived maximum reaching height with the arm (RHA_P) would differ from an additive model in which this value was computed from a combination of perceived shoulder height (SH_P) and perceived arm length (AL_P):

$$RHA_P \neq SH_P + AL_P \text{ (Prediction 1)}$$

Second, we predicted that perceived maximum reaching height with the tool (RHT_P) would differ from an additive model in which this value was computed from a combination of perceived shoulder height (SH_P) and perceived arm-plus-tool length $[(A+T)L_P]$:

$$RHT_P \neq SH_P + [(A + T)L_P] \quad (\text{Prediction 2})$$

Third, we predicted that perceived maximum reaching height with the tool would differ from an additive model in which this value was computed from a combination of perceived maximum reaching height with the arm (RHA_P) and perceived tool length (TL_P):

$$RHT_P \neq RHA_P + TL_P \quad (\text{Prediction 3})$$

Analogously, we also predicted that ratios of perceived perceived-to-actual maximum reaching ability with the arm and with the tool would differ from ratios generated using perceived maximum reaching ability values generated additive models (Thomas et al., 2017; see also Chang, Wade, & Stoffregen, 2009).

Method

Participants

Twenty-four undergraduate women from Illinois State University participated in exchange for course credit. Data from two participants were excluded due to failure to follow or understand experimenter instructions, leaving a final sample size of 22 participants. We did not necessarily seek a single-sex sample. Rather, the height of the laboratory ceiling mandated that participants be no taller than 173 cm (68 in.). This constraint may account for the fact that only women (who generally are shorter in stature, and have shorter arms than men) chose to sign up to participate. We had no reason to expect that there would be an effect of gender on performance in this task above and beyond the effects of sex-specific anthropometrics. Participants' mean standing height was 158.1 cm ($SD = 5.4$ cm). All participants gave written informed consent prior to taking part in the experiment. The protocol was approved in advance by the Illinois State University Institutional Review Board in accordance with the Declaration of Helsinki.

We conducted an *a priori* power analysis with the G*Power program (Faul, Erdfelder, Lang, & Buchner, 2007) using a standardized effect size of $d_z = .73$ (from Wagman et al., 2019). This analysis suggested that a minimum sample size of $n = 16$ would be required to detect this effect with statistical power of $p = .80$ in a two-tailed t-test with alpha level set to 0.05.

Materials and apparatus

Participants reported maximum reaching height by instructing the experimenter to adjust the height of an object (a white plastic cylinder, 82 g, 4 cm in length, 5 cm in diameter) suspended by a pulley system from the top of a vertical surface (250 cm tall $\times$ 120 cm wide); (Fig. 1a). The surface and the laboratory walls were covered in black fabric to create a uniform background and thus reduce optical information (e.g., visible landmarks) for such reports. The experimenter adjusted the height of the object while seated behind the surface and was not visible to the participant. Participants stood in a viewing area (50 cm $\times$ 50 cm) that was 285 cm from (and centered with) the vertical surface. A reaching location (50 cm $\times$ 50 cm) was marked with tape 15 cm in front of (and centered with) the vertical surface. A tape measure was attached to the back of the vertical surface so that the experimenter could measure the height of the object. A hand-held trigger-handle “Reacher Grabber” Tool (45 cm, 158.8 g, Duro-Med Industries) was used in the Tool condition (Fig. 1b). The trigger-handle of the tool was wrapped with a rubber band to secure the pincer tips of the tool in the “closed” position.

Procedure

Perceived reaching height task To assess perceived reaching ability, we used a version of the method of adjustment (e.g., Mark, 1987). The participant stood in the viewing area with her arms at her sides and closed her eyes. The object was then set to its highest (250 cm) or lowest (50 cm) position on the vertical surface depending on whether the trial was an ascending or a descending trial (see below). When signaled by the experimenter, the participant opened her eyes. The participant then instructed the experimenter to adjust the height of the object so that the bottom of the object was at the maximum height that she would be able to touch if she were to walk to and stand in the marked reaching location with both feet flat on the floor and reach up with the specified end-effector (hand or tool, depending on condition).

In the *Hand* condition, the participant reported the maximum height at which she would be able to touch (i.e., come into contact with) the bottom of the object with the thumb and the index finger of closed fist made with the preferred hand. In the *Tool* condition, the participant reported the maximum height at which she would be able to touch the bottom of the object with the closed pincer tips of the tool if she were to hold the tool by the handle with her preferred hand. There was no time limit on a given trial, and the participant could fine-tune her response until she was satisfied. After each trial, the participant closed her eyes while the object height was set for the next trial.

Each participant completed both end-effector conditions. End-effector conditions were blocked, and the order of these

Fig. 1 **a** Judgment apparatus, seen from the participant's viewpoint. **b** The Reacher Grabber Tool that was used in the Tool condition

conditions was counterbalanced across participants. There were six trials in each end-effector condition. Ascending trials (in which the object height was initially set at 50 cm) and descending trials (in which the object height was initially set at 250 cm) were alternated over the course of the experiment. Alternate participants began the experiment with ascending or descending trials.

Perceived properties task Once the 12 trials of the *perceived reaching height task* were completed, the participant stood with her arms at her sides and was asked to imagine holding the tool by the handle in the fist of her preferred hand so that the pincer tips pointed toward the floor. The participant then instructed the experimenter to adjust the height of the object so that the bottom of the object would be even with three different landmarks – the top of the shoulder of her preferred arm (perceived shoulder height : SH_P), the thumb and the index finger of her preferred hand (perceived fist height : FH_P), and the distal tip of the closed pincer tips of the tool (perceived tool height : TH_P). As in the preceding task, there was no time limit on a given trial, and the participant could fine-tune her response until she was satisfied. Landmarks were blocked, and the order of landmarks was randomized across participants. There were six trials for each landmark. Ascending trials and descending trials were alternated following the order established in the *perceived reaching height task*.

At no point during either the *perceived reaching height task* or the *perceived properties task* did the participant approach the surface or perform any of the behaviors. After completing both tasks, the experimenter measured the maximum height at which the participant actually could (1) touch (contact) the bottom of the object with the thumb and finger of a fist made with the preferred hand, and (2) touch the bottom

of the object with the closed pincer tips of the tool held in the preferred hand. The participant then held the tool by the handle in her preferred fist with her arm at her side so that the pincers pointed toward the floor. The experimenter measured (3) the height of the thumb and forefinger from the floor, and (4) the height of the distal tip of the pincer tool from the floor.

Results

Evaluation of additive models in terms of perceived maximum reaching height

We evaluated whether mean perceived maximum reaching height with the hand (RHA_P) and mean perceived maximum reaching height with the tool (RTA_P) in the perceived reaching height task described above differed from the predictions of the additive models as described in Predictions 1, 2, and 3.

First, for each participant, we derived perceived arm length (AL_P), perceived tool length (TL_P), and perceived arm-plus-tool length $[(A+T)L_P]$ using values obtained in the perceived properties task described above. Specifically, we derived perceived arm length by subtracting perceived fist height from perceived shoulder height ($AL_P = SH_P - FH_P$), perceived tool length by subtracting perceived tool height from perceived fist height ($TL_P = FH_P - TH_P$), and perceived arm-plus-tool length by subtracting perceived tool height from perceived shoulder height $[(A+T)L_P] = SH_P - TH_P$. Next, for each participant, we used these values to calculate perceived maximum reaching height with the arm and perceived maximum reaching height with the tool via the addition operations specified in the right half of Predictions 1, 2, and 3.

We then evaluated each of the hypotheses described in Predictions 1, 2 and 3 using a two-tailed *t*-test. We applied Bonferroni corrections for multiple comparisons. The first *t*-test evaluated the hypothesis described in Prediction 1. It revealed that perceived maximum reaching height with the arm (RHA_p : $M = 178.1$ cm, $SD = 12.4$ cm) differed from an additive combination of perceived shoulder height and perceived arm length (Prediction 1; $SH_p + AL_p$: $M = 192.62$ cm, $SD = 18.9$ cm) ($t(21) = 3.57$, $p < .01$, Cohen's $d_z = 0.76$) (see Fig. 2, left).

The second *t*-test evaluated the hypothesis described in Prediction 2. It revealed that perceived maximum reaching height with the tool (RHT_p : $M = 194.56$ cm, $SD = 15.0$ cm) differed from an additive combination of perceived shoulder height and perceived arm-plus-tool length (Prediction 2: $SH_p + [(A+T)L_p]$: $M = 219.1$ cm, $SD = 17.2$ cm) ($t(21) = 5.87$ $p < .001$, Cohen's $d_z = 1.25$) (see Fig. 2, right).

The third *t*-test evaluated the hypothesis described in Prediction 3. It revealed that perceived maximum reaching height with the tool (RHT_p : $M = 194.56$ cm, $SD = 15.0$ cm) also differed from an additive combination of perceived maximum reaching height with the arm and perceived tool length (Prediction 3: $RHA_p + TL_p$: $M = 204.5$ cm, $SD = 3.5$ cm) ($t(21) = 4.77$ $p < .001$, Cohen's $d_z = 0.85$) (see Fig. 2, right).

Evaluation of additive models in terms of perceived-to-actual maximum reaching height

Next, we compared whether ratios of perceived-to-actual maximum reaching ability differed from ratios generated using perceived maximum reaching heights computed by each of the additive models in Predictions 1, 2, and 3.

For each participant, we created ratios of perceived-to-actual reaching ability by dividing perceived maximum reaching height with the arm and with the tool by actual maximum reaching height with the arm and tool (i.e., RHA_p/RHA_A and RHT_p/RHT_A , respectively). We also created ratios

of perceived-to-actual reaching ability using the values perceived maximum reaching heights obtained from each of the additive models. Specifically, we divided values of perceived maximum reaching height with the arm computed via Prediction 1 by actual maximum reaching height with the arm [$(SH_p + AL_p)/RHA_A$]. We also divided the values of perceived maximum reaching height with the tool computed via Prediction 2 and Prediction 3 by actual maximum reaching height with the tool ($SH_p + [(A+T)L_p]/RHT_A$) and $(RHA_p + TL_p)/RHT_A$, respectively.

Again, we evaluated each of the hypotheses described in Predictions 1, 2, and 3 using a two-tailed *t*-test, applying Bonferroni corrections for multiple comparisons. The first *t*-test revealed that the ratio of perceived-to-actual reaching ability with the arm (RHA_p/RHA_A : $M = 0.93$, $SD = 0.10$) differed from the ratio generated using values from Prediction 1: ($M = 1.01$ cm, $SD = 0.13$), $t(21) = 3.60$ $p < .01$, Cohen's $d_z = 0.76$ (see Fig. 3, left).

The second *t*-test revealed that the ratio of perceived-to-actual reaching ability with the tool (RHT_p / RHT_A : $M = 0.85$, $SD = 0.05$) differed from the ratio generated using values from Prediction 2 ($M = 0.96$ cm, $SD = .08$ cm), $t(21) = 5.82$ $p < 0.001$, Cohen's $d_z = 1.2$ (see Fig. 3, right). The third *t*-test revealed that the ratio of perceived-to-actual reaching ability with the tool (RHT_p / RHT_A : $M = 0.84$, $SD = 0.05$) also differed from the ratio generated using values from Prediction 3 ($M = .89$ cm, $SD = .06$ cm), $t(21) = 4.02$ $p < .001$, Cohen's $d_z = 0.85$) (see Fig. 3, right).

General discussion

Affordances emerge out of relations between properties of an animal and properties of its environment. Like other emergent relationships or properties, affordances differ logically, and often qualitatively, from their constituent properties (see Camazine et al., 2003; Friedenberg, 2009). Nonetheless,

Fig. 2 (Left) Mean values of RHA_p and $SH_p + AL_p$. The means differ, confirming our Prediction 1. (Right) Mean values of RHT_p , $SH_p + [(A+T)L_p]$, and $RHA_p + TL_p$. The mean for RHT_p differed from the mean SH_p

+ $[(A+T)L_p]$, confirming our Prediction 2. The mean for RHT_p also differed from the mean for $RHA_p + TL_p$, confirming our Prediction 3. Error bars indicate standard error of the mean

Fig. 3 (Left) Mean values of RHA_p/RHA_A and $(SH_p + AL_p)/RHA_p$. The means differ, confirming our Prediction 1. (Right) Mean values of RHT_p/RHT_A , $(SH_p + [(A + T)L_p])/RHT_A$, and $(RHA_p + TL_p)/RHT_A$. The mean for RHT_p/RHT_A differed from the mean $(SH_p + [(A + T)L_p])/$

$/RHT_A$, confirming our Prediction 2. The mean for RHT_p/RHT_A also differed from the mean for $(RHA_p + TL_p)/RHT_A$, confirming our Prediction 3. Error bars indicate standard error of the mean

Gibson argued that affordances directly constrain behavior; that the success or failure of behavior is directly influenced by affordances, and is not directly constrained by the constituent properties of the animal, or of the environment. Affordances are the immediate objects of perception; they are the primary realities for perceivers (Turvey, 2015). Therefore, Gibson argued that affordances ought to be perceived “as such” – as emergent higher-order relationships in an animal environment system. That is, that perceivers ought to have direct perceptual sensitivity to emergent, higher-order relationships in the animal-environment system (Stoffregen, 2003; Thomas & Riley, 2014; Thomas et al., 2017). This claim has motivated the empirical prediction that affordance judgments should be a function of these higher-order relational properties rather than a function of lower-order constituents of the affordance, including non-affordance properties of the animal or of the environment as well as lower-order affordances. Accordingly, tests of this prediction have been an important part of experimental research on affordance perception from the inception of this field (e.g., Mark, 1987; Thomas & Riley, 2014).

Importantly, though, affordances do not exist in isolation; that is, it is never the case that only one affordance exists in any animal-environment system. Rather, multiple affordances always exist, and are nested in the context of other affordances. Some affordances are superordinate to other affordances, arising from relations between subordinate (lower-order) affordances. In the present study, our primary aim was to investigate whether such superordinate affordances are perceived as emergent higher-order relationships, and not as a combination of lower-order (constituent) affordances. Specifically, we asked whether perception of an affordance for reaching by different means would be reducible to (a combination of) perceived lower-order constituents of the affordance, or instead whether nested (i.e., both superordinate and subordinate) affordances for reaching would be perceived as a complex particular.

Participants reported the maximum height that they would be able to reach by two different means – with their arm alone versus with a hand-held tool. Our general prediction was that, in each case, perception of maximum reaching height would differ from an additive model in which such values were computed from a combination of perceived lower-order constituents of the affordance (including non-affordance properties of the animal or the environment or lower-order affordances). Specifically, we predicted that perceived maximum reaching height with the arm would differ from an additive combination of perceived shoulder height and perceived arm length (Prediction 1). We also predicted that perceived maximum reaching height with the tool would differ from both an additive combination of perceived shoulder height and perceived arm-plus-tool length (Prediction 2) and an additive combination of perceived maximum reaching height with the arm and perceived tool length (Prediction 3).

All three hypotheses were supported when perceptual reports were considered independently of the participant reaching ability (when perceived maximum reaching heights were measured in cm) and when such reports (and predictions of the additive models) were scaled in terms of the participant reaching ability (ratios of perceived-to-actual maximum reaching heights) (see Figs. 2 and 3). The results are inconsistent with representation-based accounts of perception of affordances in which a perceiver combines or compares representations of properties of the self and representations of properties of the environment such as those that claim that perceiving affordances for reaching with a tool require incorporating (perception of) metric properties of the tool into an internal body schema (see Cardinali et al., 2009; Maravita & Iriki, 2004; Sposito, Bolognini, Vallar, & Maravita, 2012). Nonetheless, it is clear that whatever means by which participants were perceiving superordinate affordances in the current study, it was more nuanced than a linear combination of discrete values (either perceptions or representations) of constituent lower-order properties. Thus, the results are consistent with Gibson’s account, in which affordances are perceived as

emergent higher-order relationships – that is, as complex particulars (Thomas, Riley, & Wagman, 2020; Turvey, 2015; see van Rooij, Bongers, & Haselager, 2002).

Detection of information and affordances

Two essential claims of the theory of affordances (Gibson, 1979/2015) are that: (1) the animal–environment relations that define affordances lawfully structure energy arrays such that this structure provides information about this fit, and (2) affordances are perceived as a consequence of detecting such information (see Wagman, 2020; Thomas et al., 2020). In Gibson’s account, affordances (nested or otherwise) are perceived by detecting patterns in ambient energy arrays that specify a particular animal–environment relation. Thus, affordances are perceived by detecting the information about a particular animal–environment relation and not by combining perceptions of lower-order constituents of that affordance. It should be noted that we did not explicitly analyze, measure, or manipulate information about affordances for reaching in this study. That is, we did not address the patterns in ambient arrays that participants might have detected. Analysis of the information supporting affordance perception is an important topic for future research. Hence, our results are consistent with but are not a definitive evaluation of Gibson’s proposal.

When perceptual reports and predictions of the additive models were scaled in terms of actual reaching ability, the ratios produced by the additive models were closer to 1.0 than those produced using the perceived maximum reaching height values (see Fig. 3). The fact that perceptual reports of maximum reaching height were less accurate than the additive models might be taken as evidence that participants were not (necessarily) detecting information about this affordance, thereby weakening our conclusions. However, there are at least two reasons to doubt such an interpretation. First, confirmation of our predictions – that is, demonstrating that perception of superordinate affordances for a given behavior are not reducible to a combination of lower-order constituents of that affordance merely requires that perceived maximum reaching height *differ* from the predictions of each of the additive models. The *direction* of such differences is of no particular consequence (see Thomas & Riley, 2014; Thomas et al., 2017). Second, detection of information about an affordance guarantees that perception of the ability to perform a given behavior will be scaled to (i.e., lawfully constrained by) the ability to perform that behavior. However, it does not guarantee that perception will be *perfectly* scaled to the ability to perform that behavior. A large literature has demonstrated that perception of affordances for a given behavior increasingly reflects the ability to perform that behavior when

participants have the opportunity to engage in exploratory movement such as body sway (e.g., Mark, Balliett, Craver, Douglas, & Fox, 1990; Stoffregen, Yang, & Bardy, 2005; Yu, Bardy, & Stoffregen, 2011) or locomotion (Stoffregen, Yang, Giveans, Flanagan, & Bardy, 2009) or when they have the opportunity to practice performing the to-be-judged behavior (i.e., when there is feedback about performance, see Franchak, Celano, & Adolph, 2012; Higuchi, Cinelli, Greig, & Patla, 2006; Wagman, 2012; Wagman, Taheny, & Higuchi, 2014). In the present study, participants did not have the opportunity to locomote or practice reaching with or without the tool. Under such circumstances, participants generally underestimated perception of maximum vertical reaching distance with or without a tool (Wagman, 2012; Wagman & Morgan, 2010; Wagman et al., 2013). However, while repeated experience perceiving maximum reaching height with a tool (i.e., a series of repeated judgments of the affordance) or feedback about judgment accuracy were sufficient to improve perception of maximum reaching height affordance, neither type of experience was sufficient to improve perception of tool length (Thomas et al., 2017). More generally, feedback about performance improves perception of superordinate affordances but does not improve perception of subordinate affordances or properties constituent of that affordance (Higuchi et al., 2011; Mark, 1987; Yasuda et al., 2014). These findings are both consistent with our hypothesis that superordinate affordances are (or can be) perceived as such (without necessitating perception of subordinate affordances or properties), and suggest that it is unlikely that experience or feedback would bring perception of a given affordance into closer correspondence with an additive model. Nonetheless, this latter possibility is an important topic for future research.

Conclusion

In Gibson’s ecological approach the animal–environment relations that define affordances should be perceived as a complex particular, and this ought to be the case regardless of the degree to which those relations are nested. We predicted that perception of affordances for reaching by different means (i.e., with vs. without an implement) would not be reducible to a combination of lower-order constituent components of that affordance, including non-affordance properties of animal and of the environment as well as lower-order affordances. Our results supported this hypothesis and were consistent with Gibson’s proposal that animals perceive affordances by detecting the information about a particular animal environment relation.

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Open practices statement The experiment reported here was not preregistered. The data are available upon request.

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