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Heads up! Dynamic Similitude for Perception with an Object Wielded by Head or Hand

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Abstract

Possibilities for behavior (i.e., affordances) can be perceived with units spanning anatomical components and external objects. For example, affordances for standing on an inclined surface can be perceived with an object held in the hand or attached to the head. We investigated whether these two person-plus-object perceptual systems exhibit the same pattern of nonlinear phase transitions in perception of this affordance. Blindfolded participants explored an inclined surface with a rod held in the hand or attached to the head and reported whether they could stand on that surface. Inclinations were presented in ascending or descending sequences. In both conditions, responses exhibited negative hysteresis — perceptual boundaries occurred at steeper angles for descending than for ascending sequences. The generalization of this pattern across components that differ in physiology, sensitivity, and experience is consistent with both the soft assembly of perceptual devices and with a dynamical systems perspective on perception of affordances.

Heads up! Dynamic similitude for perception with an object wielded by head or hand

Affordances are possibilities for behavior emerging from the fit between action capabilities and environmental properties (Gibson, 2014). Research on perception of affordances has shown that, in large part, perceivers are sensitive to the boundaries at which they must transition from one mode of performing a given behavior to different mode of doing so. For example, perceivers are sensitive to the distance at which they would no longer be able to reach an object merely by extending their arm and would instead need to transition to another means of reaching for that object such as bending at the torso (Carello, Grosofsky, Reichel, Solomon, & Turvey, 1989). In addition, perceivers are sensitive to the angle of inclination at which they would no longer be able to stand on a given surface and would need to transition to different means of postural support such as bending at the waist or squatting (Fitzpatrick, Carello, Schmidt, & Corey, 1994; Regia-Corte & Wagman 2008; Wagman & Hajnal, 2014).

Affordances and dynamical systems theory

Over the past several decades, researchers have investigated perception of affordances from the perspective of dynamical systems theory—a perspective in which the emergence of stable states in complex systems is the result of lawful and nonlinear interactions among a (small) set of key variables (known as control parameters) (e.g., Fitzpatrick et al., 1994; Richardson, Marsh, & Baron, 2007; Warren, 1984; see Harrison, Turvey, & Frank, 2016).

There are a number reasons for this, but perhaps the most important one is that there are deep and fundamental similarities between (perception of) affordances and the nonlinear phase transitions that are the signature of self-organizing physical, biological, or chemical systems (see Camazine 2003; Kelso, 1995; Wagman, 2010). In particular, the spontaneous, abrupt, and nonlinear transitions between distinct stable behavioral (or perceptual) states with continuous adjustment of the relevant environmental property are analogous to the spontaneous, abrupt, and nonlinear transitions between distinct stable physical, biological, or chemical states with continuous adjustment of the relevant control parameter. In short, both phenomena can be described as nonlinear phase transitions between stable states occurring at a critical value of a continuous parameter.

Importantly, however, in both kinds of phenomena, the critical value at which the transition occurs can differ depending on whether the relevant parameter is being systematically increased or decreased (Fitzpatrick et al., 1994; Friedenberg, 2009; Kelso, 1995; Richardson, et al., 2007). A phenomenon known as (*positive*) *hysteresis* occurs when such a transition occurs at a smaller value of a given parameter when that parameter is systematically decreased (i.e., presented in a descending sequence) than when it is systematically increased (i.e., presented in an ascending sequence). In (positive) hysteresis, the behavior of the system "lags behind" the changes in the parameter that drives the behavior of the system. In other words, the system's present behavior is being influenced by the history of that system.

A phenomenon known as *negative hysteresis (or enhanced contrast*) occurs when such a transition occurs at a larger value of a given parameter when the values of that parameter are systematically decreased (i.e., presented in a descending sequence) than when such values are systematically increased (i.e., presented in an ascending sequence). In negative hysteresis, the behavior of the system is "out in front of" the changes in the parameter that drives the behavior of the system. In other words, the system's present behavior is being influenced by the future states of that system (see Richardson, et al., 2007).

Research has shown that (positive) hysteresis is generally exhibited in *behavioral* tasks in which participants are asked to perform one of two different modes of performing a given behavior. For example, the transition from one-handed to two-handed grasping occurs at a larger object size when objects are presented in ascending sequence than then they are presented in descending sequence (Lopresti-Goodman, Richardson, Baron, Carello, Marsh, 2009; Lopresti-Goodman, Turvey, & Frank, 2011; Richardson et al., 2007).

Alternatively, negative hysteresis is generally exhibited in *perceptual* tasks in which participants are asked to verbally report which of two different modes of performing a given behavior would be possible (or which they would choose to perform). For example, perception of the maximum surface inclination that affords standing on occurs at a steeper angle of inclination when surface inclinations are presented in a descending sequence than when they are presented in an ascending sequence (Fitzpatrick et al., 1994; Regia-Corte & Wagman, 2008; Richardson et al., 2007).

Soft assembly in perception of affordances

Perceivers are not only sensitive to the boundaries at which they must transition between two different modes of performing a particular behavior given their action capabilities, they are sensitive to that boundary across variety of contexts and by a variety of different means (e.g., Regia-Corte & Wagman, 2008; Wagman & Day, 2014). In other words, to a large extent, perception of a given affordance exhibits both task specificity and anatomical independence (Wagman & Hajnal, 2014). In other words, perception of a particular boundary generally reflects the fit between action capabilities and environmental properties and is generally unaffected by the anatomical components or perceptual modality used to explore the surface properties of relevance to that affordance. For example, perceivers are sensitive to the minimum aperture width through which they (or a part of their body) could pass regardless of whether they view that aperture, explore that aperture with the hands, or listen to sounds projected through that aperture (Gordon & Rosenblum, 2004; Ishak, Adolph, & Lin, 2008; Warren & Whang, 1987). In addition, perceivers are sensitive to the distance reachable with a given object regardless of whether that object is wielded with one hand, two hands, one hand and one knee, the foot, the torso, or the head (Carello, Fitzpatrick, Domaniewicz, Chan, & Turvey, 1992; Hajnal, Fonseca, Harrison, Kinsella-Shaw, & Carello, 2007; Palatinus, Carello, & Turvey, 2011; Wagman, Langley, & Higuchi, 2016).

Such research has suggested that the various components brought to bear in perceiving a given affordance are softly assembled. That is, they are flexibly, spontaneously, and temporarily recruited for the purposes of a particular perceptual task (Carello et al., 1992; see Kugler & Turvey, 1987). Importantly, such soft assembly is not limited to anatomical components per se. Rather, inert objects can be also flexibly, spontaneously, and temporarily used as tools that change a person's perceptual capabilities, creating a unique person-plus-object-perceptual system (Wagman & Hajnal, 2016). For example, blindfolded participants are sensitive to the maximum surface inclination on which they could stand when they probe that surface with a wooden rod. Moreover, perception of this affordance reflects the fit between action capabilities and environmental properties regardless of whether that object is wielded with one hand or the other, both hands, one foot or the other, or even the head (Fitzpatrick et al., 1994; Wagman & Hajnal, 2016, 2014). Notably, this occurred despite (a) differences between the (inert, homogeneous, rigid) rod and the (organic, flexible, heterogeneous) limb to which it was attached (b) the physical, physiological, and functional differences between (the organizations of) anatomical components and (c) the novelty of the perceptual tasks.

These results suggest that there exists a similitude for perception of a given affordance not only across disparate anatomical components but also across the body and an inert object used as a perceptual tool. Importantly, the soft assembly of such components into a person-plus-object perceptual tool is *also* consistent with a dynamical systems perspective of perception of affordances. This is so because one of the underlying principles of dynamical systems theory is that the same principles lawfully constrain behavior of many different systems across many different levels, regardless of the specifics of the components that comprise those systems (see Chemero, 2009; Kelso, 1995; Kugler & Turvey, 2007; Wagman, 2010).

The experiment reported here explicitly investigated the hypothesis that there exists a dynamic similitude for perception of a given affordance across two different person-plus-object perceptual systems, each consisting of different anatomical components. In particular, we compared perception of the maximum surface inclination that could be stood on when that surface was probed with a wooden rod wielded by two different anatomical components. To provide a strong test of this hypothesis, we chose anatomical components that differ markedly in sensitivity, dexterity, and functionality—the hand and the head (see Wagman & Hajnal, 2016).

Our main hypothesis was that perceptual reports in both conditions would exhibit negative hysteresis despite (a) differences between the (inert, homogeneous, rigid) rod and the (organic, flexible, heterogeneous) limb to which it was attached, (b) the physical, physiological, and functional differences between (the organizations of) anatomical components and, (c) the novelty of the perceptual tasks (cf. Fitzpatrick et al., 1994; Regia-Corte & Wagman, 2007; Richardson et al., 2007). That is, for both person-plus-object perceptual systems, we expected that the maximum inclination perceived to afford standing on would occur a steeper angle when inclinations are presented in a descending sequence than when they are presented in an ascending sequence.

Method

Participants. Twenty-two undergraduate students (7 men; 15 women, average weight = 58.9 kg, *SD* = 7.9 kg) participated in fulfillment of an extra credit option in their psychology courses. This sample size was based on previous research on perception of affordances for standing on an inclined surface probed with a perceptual tool (cf. Wagman & Hajnal, 2014, 2016). Two participants were left handed, and twenty were right handed as determined by the handedness portion of the Lateral Preference Inventory (Coren, 1993). Given that the experimental procedure required standing on inclined surface, in the interest of participant safety, it was required that participants weigh less than 91 kg and wear appropriate footwear (e.g., athletic shoes with a rubber sole and no heel). Written informed consent was obtained from each participant. All procedures performed in this study were in accordance with the ethical standards of the Illinois State University IRB and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

Materials and Apparatus. A wooden surface (152 cm × 76 cm) was reinforced with metal braces so that it was strong enough to support a participant up to 105 kg. One end of the surface was hinged to a wooden frame (91 cm × 76 cm). The other end of the surface was supported by a metal dowel resting on metal hooks that were screwed into vertical wooden studs (122 cm tall) attached to each side of the frame such that the surface could be adjusted to nine different angles of inclination, ranging from 10º to 50º in increments of 5º (see Figure 1). Participants wore a disposable shower cap, a plastic hard hat (ERB19762 Americana Cap Style, Woodstock, Georgia, USA) secured with an elastic chinstrap, and a fabric blindfold. A plastic cylinder (5 cm outer diameter, 1.3 cm inner diameter, 7.5 cm length, 167 g mass) was attached to the right side of the helmet (just above the right ear) so that it was parallel to the helmet brim. In the Head Condition, a 153 cm wooden dowel (1.3 cm in diameter, 95 g mass) was secured in the cylinder such that one end was flush with the back of the cylinder and the other extended in front of the participant (see Figure 1, top). In the Hand condition, the same dowel was held in the participant's preferred hand (see Figure 1, bottom). A digital scale was used to measure body weight. Portions of the Lateral Preference Inventory (Coren 1993) were used to measure participant handedness.

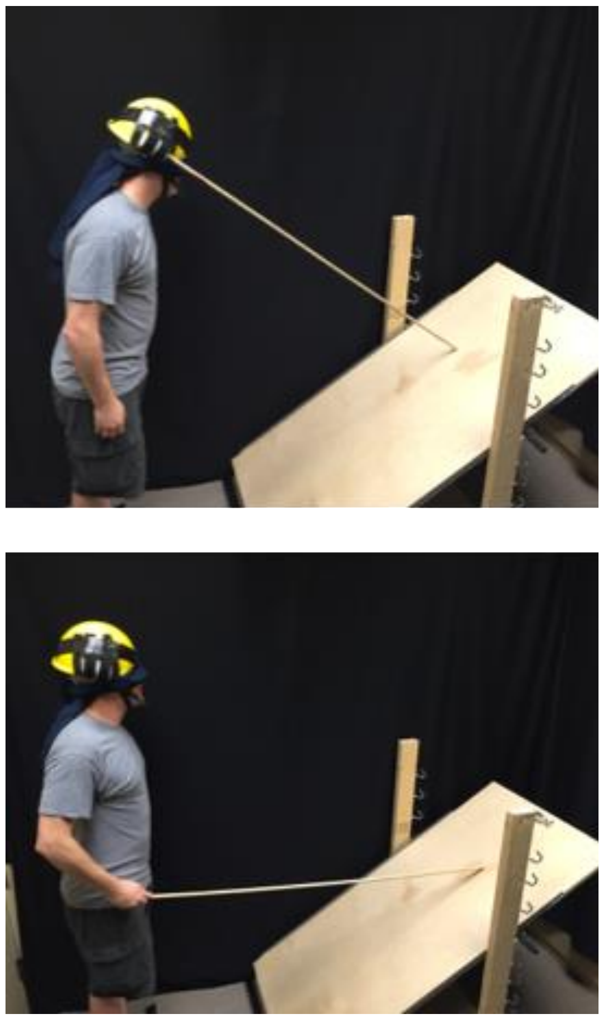

Figure 1. The Head (top) and Hand (bottom) conditions.

Procedure. *Perceptual task*. Body weight and handedness of each participant was recorded. The participant stood approximately 1 m from the surface (set at 45° before the participant arrived), and put on the shower cap, helmet, and blindfold.

In the Head Condition, the experimenter secured the dowel in the cylinder, and the participant stood upright such that the dowel extended in front of him or her and was roughly parallel to the floor. In the Hand Condition, the participant grasped the dowel with the preferred hand and placed the distal tip of the dowel on the floor next to the surface. In each condition, the participant returned to these respective postures after every trial.

The experimenter then adjusted the angle of the surface to either 10º or 50º, depending on whether angles of inclination were to be presented in an ascending or descending sequence (see below). The participant explored the surface with the dowel (see Figure 1) and reported (yes or no) whether he or she would be able to stand on the surface without bending at the knees or waist, going up on the toes or grasping a support railing (cf. Fitzpatrick et al., 1994; Wagman & Hajnal, 2014; 2016). For ascending sequences of presentation, the angle of inclination was increased (from 10º to 50°) by 5º. For descending sequences of presentation, the angle of inclination was decreased (from 50°) by 5°. The participant again explored the surface with the dowel and provided the yes or no answer. Ascending or descending presentation of surface angles continued until the participant response changed from yes to no, or vice versa.

No restrictions were placed on how (or how long) the participant explored the surface with the dowel, and no measures were taken to prevent the participant from hearing contact between dowel and surface. Each participant performed this task in both component conditions in blocked fashion. The order of component conditions was counterbalanced across participants. For each component, each participant performed this task for two ascending and two descending series of trials. Ascending and descending directions alternated within each component condition, and order of directions was counterbalanced across participants. Participants did not attempt to step or stand on the surface until all trials were completed.

Behavioral task. After the perceptual task was completed, the participant removed the blindfold, and the surface was set to 10º. The participant then attempted to stand on the surface in the manner described above (i.e., without bending at the knees or waist, going up on the toes or grasping a support railing) for 5 s. If the participant was able to do so successfully, he or she stepped down, the surface was set at the next steepest angle, and the participant again attempted to perform this task. Surfaces were presented in ascending sequence (in increments of 5°) until the participant was unable to perform this task. The steepest surface angle that could be stood on was the behavioral boundary for that participant.

For a written copy of participant instructions, see Electronic Supplementary Material 1. For raw data, see Electronic Supplementary Material 2.

Results and Discussion

Individual participant data. We derived mean perceptual boundaries— the steepest angle of inclination that received a 'yes' response— for each participant in each condition (averaged across the two ascending sequences and two descending sequences within the Head and Hand conditions, respectively). A 2 (Component: Head vs. Hand) × 2 (Sequence: Ascending vs. Descending) Analysis of Variance was conducted on these values. A main effect of Sequence, $F(1,21) = 19.79$, $p < .001$, $\eta_p^2 = 0.49$, revealed that perceptual boundaries occurred at steeper angles for Descending (M= 28.5º, 95% CI = 26.1° - 30.9°) than for Ascending (M= 24.0º, 95% CI = 21.7° - 26.3°) sequences (see Figure 2, top). Neither the main effect of Component (Head: M= 25.1º, 95% CI = 22.5° - 27.73°; Hand: M= 27.4°, 95% CI = 24.9° - 30.0°), $F(1,21) = 2.35$, p

= .14, η_p^2 = .11 nor the interaction of Component × Sequence was significant, $F(1,21) = 3.24$, $p = .08$, η_p^2 = .13 (see Figure 2, top). A post hoc power analysis was conducted on the non-significant main effect of Component. Assuming a medium effect size, power was estimated to be approximately 0.80 (Faul, Erdfelder, Lang, & Buchner, 2007). In neither Component condition was the mean perceptual boundary different from the mean behavioral boundary (M = 26.7°, 95% CI = 25.0° - 28.4°) (Head: $t(20) = .83$, $p = .42$, Cohen's d = 0.24 ; Hand: $t(20) = .68$, $p = .51$, Cohen's $d = .12$).

Wilcoxon signed-ranks tests confirmed that, in both Component conditions, the number of participants for whom perceptual boundaries occurred at steeper angles for descending than ascending sequences (i.e., showing negative hysteresis) (Head = 17; Hand = 13) was greater than the number of participants for whom perceptual boundaries occurred at steeper angles for descending than ascending sequences (i.e., showing positive hysteresis) (Head = 4; Hand = 5) and the number participants for whom perceptual boundaries occurred at the same value in each case (Head = 1; Hand = 4) (Head: $z = 2.89$, $p < .01$; Hand: $z = 2.51$, $p < .05$).

Aggregate data. At the level of the aggregate data, probit analysis (Finney, 1971) was used to determine the angle that would have resulted in a 'yes' response on 50% of the trials in each condition. In the Head condition, the perceptual boundary was 25.3º for ascending sequences (95% CI = 22.4º- 28.0º) and 30.3º for descending trials (95% CI = 28.6º - 31.8º). In the hand condition, the perceptual boundary was 28.4º for ascending sequences (95% CI = 27.0º-29.8º) and 31.4º for descending sequences (95% CI = 30.1º - 32.6º). The pattern of overlapping and non-overlapping confidence intervals shows significant differences between the ascending and descending sequences in each Component condition, respectively, and thus corroborates the findings at the level of the individual participants (see Figure 2, bottom).

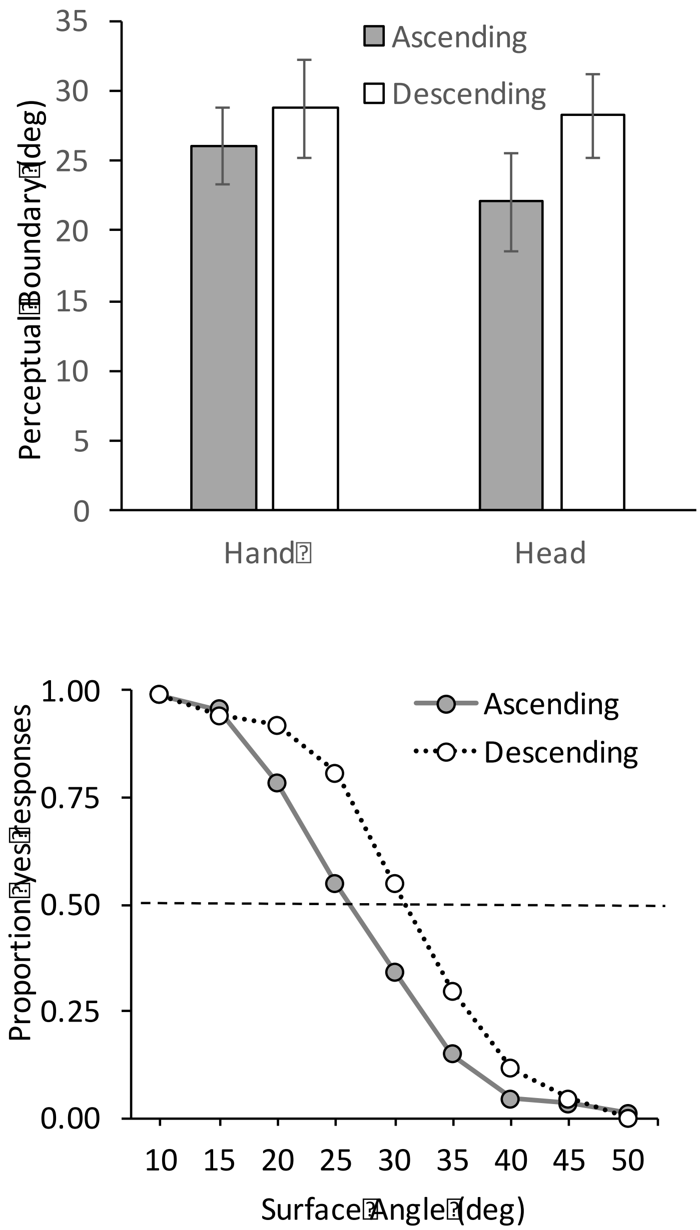

Figure 2. At the level of the individual participants, perceptual boundaries were steeper for Descending than for Ascending sequences, but there was no difference for the Hand and the Head conditions (top). Error bars represent 95% confidence intervals. At the level of the aggregate data, the perceptual boundary (represented by the point at which the dashed line intersects each curve) was also steeper for Descending than for Ascending sequences (bottom).

General Discussion

Previous research has suggested that there is a similitude for perception of a given affordance across disparate anatomical components and across the body and an inert object used as a perceptual tool. The experiment reported here explicitly tested this hypothesis for perception of the maximum surface inclination that could be stood on when that surface was explored with an object wielded by two anatomical components that markedly differ in sensitivity, dexterity, and functionality—the hand and the head. We expected that, despite such differences across anatomical components and despite the novelty of the perceptual task, these two person-plus-object perceptual systems would exhibit the same pattern of nonlinear phase transitions (i.e., negative hysteresis) between inclinations that were perceived to afford standing on those that were not. That is, in both conditions, we expected that the maximum inclination perceived to afford standing on would occur at a steeper angle when inclinations were presented in a descending sequence than when they were presented in an ascending sequence. The results supported this hypothesis both at the level of the individual participants and at the level of the aggregate data (see Figure 2).

The finding that people can perceive a given affordance of a surface by means of two distinct, novel, and temporary person-plus-object perceptual systems even when the anatomical components of such systems exhibit differences in sensitivity, dexterity, and functionality exemplifies the soft assembly of such components in a given perceptual task. Along similar lines, research has shown minimal (if any) differences in perception of affordances of a surface when that surface is explored with an object wielded by different anatomical components including one or the other hand, different configurations of both hands, one or the other foot, or the head (Wagman & Hajnal, 2014, 2016). Although we did not make specific predictions about whether perception would differ across the two anatomical components, the non-significant main effect of Component and the non-significant difference between perceptual and behavioral boundaries in each condition are both consistent with such previous research. Such research has shown that the ability to perceive affordances by means of a wielded object generalizes across anatomical components that differ in physiology, psychophysical achievements, and specialization or expertise in a given task.

The results of the current experiment also suggest that the pattern of nonlinear phase transitions exhibited in this perceptual task also generalizes across anatomical components that differ in physiology, psychophysical achievements, and specialization or expertise in a given task. The finding that perception of this affordance by the two different person-plus-object perceptual systems exhibits the same pattern of nonlinear phase transitions (i.e., negative hysteresis) is consistent with a dynamical systems perspective on perception of affordances. Specifically, such a similitude across anatomical components is consistent with the fundamental tenet of dynamical systems theory that putatively different systems can be constrained in the same way by the same set of lawful principles, regardless of components that comprise those systems (see Chemero, 2009; Kelso, 1995; Kugler & Turvey, 2007; Wagman, 2010)

Limitations and future directions

Previous research has shown that whereas (positive) hysteresis is generally exhibited in behavioral tasks, negative hysteresis is generally exhibited in perceptual tasks. There are a number of possible explanations for this difference, some of which are explicitly grounded in dynamical systems theory (see Frank, Profeta, & Harrison, 2015; Kim & Frank, 2016; Lopresti-Goodman, Turvey, & Frank, 2013; Richardson et al., 2007). Consistent with such research, we found negative hysteresis in perceptual boundaries for standing on an inclined surface across two distinct, novel, and temporary person-plus-object perceptual systems. Unfortunately, however, our experimental design precluded an investigation of the corollary hypothesis that there would be positive hysteresis in the behavioral boundaries for standing on that surface. This could be a topic of future research.

In addition, we found no differences in perception of this affordance across multiple dependent measures when the object used to explore the surface was wielded by the hand or by the head. However, it is possible that some differences across these anatomical components could emerge with more fine grained dependent measures. Previous research has shown, for example, that there are subtle and complex differences in the dynamics of exploratory wielding movements depending on the property of object that the person intends to perceive (Arzamarski Isenhower, Kay, Turvey, & Michaels, 2010; Riley, Wagman, Santana, Carello, & Turvey, 2002). Similarly, there is some evidence that there are also differences in the dynamics of exploratory wielding movements depending on the anatomical components used to wield the object (Stephen & Hajnal, 2011). Whether or not there would be differences in the exploration of a surface with a perceptual tool depending on the anatomical component used to wield that tool is another topic for future research.

Conclusions

Overall, the results of the experiment reported here suggest that there exists a dynamic similitude for perception of a given affordance across two different person-plus-object perceptual systems, each consisting of different anatomical components. Such results are consistent with a dynamical systems perspective on perception of affordances because they support the fundamental tenet of dynamical systems theory that the same principles lawfully constrain behavior of many different systems across many different levels, regardless of the specifics of the components that comprise those systems.

Electronic Supplementary Material

ESM 1. Written copy of participant instructions (instructions_to_participants.doc).

This Word file contains the written instructions that we read to each participant.

ESM 2. Raw data collected. (raw_data.xlsx)

This excel file contains the raw data collected in this experiment.

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