

Task Constraints on Affordance Boundaries

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RUNNING HEAD: Task Constraints on Affordance Boundaries

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Abstract

The actualization of a simple affordance task—grasping and moving wooden planks of different sizes using either one or two hands—was assessed in the context of task-relevant (plank sequence, plank presentation speed) and task-irrelevant (cognitive load) manipulations. In Experiment 1, fast (3 sec/plank) and self-paced ( $\approx 5$  sec/plank) presentation speeds revealed hysteresis: The transition point for ascending series was greater than the transition point for descending series. Hysteresis was eliminated in the slowest presentation speed (10 sec/plank). In Experiment 2, hysteresis was exaggerated by a cognitive load (counting backward by seven) for both fast and slow presentation speeds. These results suggest that behavioral responses to the attractor dynamics of perceived affordances are processes that require minimal cognitive resources.

## Task Constraints on Affordance Boundaries

One requirement for the successful completion of a task or action is that organisms prospectively perceive that the particular task or action is possible (Gibson, 1979; Kim & Turvey, 1998; Turvey, 1992; Warren 1984). As an example, consider my wanting to move planks that are sitting on a sawhorse. In addition to perceiving that a given plank is in fact movable, I must also perceive whether I can reach it from my current posture (as opposed to leaning over), and whether I should grasp it with one hand or two. It is common to construe the perception and actualization of such action possibilities as a symbolic computational process, whereby the individual uses mental representations (e.g., a body schema) to mediate contact with environmental objects, surfaces and events (Craig, 1943; von Eckardt, 1993). This common characterization, however, fails to exploit the mutually defining roles that an actor's body and the environment play in the perception and actualization of actions (Gibson, 1966; 1979; Turvey & Shaw, 1979). Indeed, everyday actions occur quite rapidly without **explicit** decision-making or planning, and are dynamically and adaptively constrained online by an actor's body and his or her environment. To extend our example, if a neighbor stops by to chat while I am moving the aforementioned planks, my attention will be diverted from the grasping and moving task. If it starts to rain, I may work quickly to get the planks under shelter before they get wet. Changing constraints on attention or speed may influence how I accomplish an ongoing task. Treating such cases of prospective control as matters of perception rather than computation reflects an ecological-dynamical systems approach entailed by the concept of *affordances*. The overall aim of the current paper is to investigate how changes in situation or task constraints—namely, having to grasp and move

objects at different speeds or while completing a concurrent cognitive task—influence the perception and actualization of that affordance.

As a psychological term, the word affordance was first introduced by J. J. Gibson (1979) to capture the reciprocity of an animal and its environment. More specifically, affordances refer to opportunities for action that are scaled relative to the organism in question (Michaels & Carello, 1981; Sanders, 1997; Stoffregen, 2003; Turvey, Shaw, Reed, & Mace, 1981), and embody the assertion that individuals directly perceive the *meaning* of environmental surfaces and objects in relation to their own bodily dimensions and capabilities (Gibson, 1979). The phrase “directly perceive” means that organisms perceive these possibilities for action without inference or comparison between a stored representation of their body and a representation of the object in the world to be acted upon. For instance, the perception of stair climbability is not determined by the absolute height of the risers. Instead, individuals perceive the climbability of stairs by detecting information that specifies the relationship between the stairs and their leg length.

The stair-climbing example is taken from an early investigation of affordances that demonstrated how this ratio of riser-height to leg-length not only predicts whether an individual will perceive a stair riser as climbable, but also captures the affordance of stair-climbability across different individuals (Warren, 1984). Specifically, riser-height/leg-length = 0.88 was shown to demarcate the boundary between step-on-able and not step-on-able regardless of anthropometric differences across individuals. This intrinsically-scaled dimensionless ratio is referred to as an action-scaled ratio or pi-number and captures the invariant relationship between an organism and an environmental object in defining some action possibility. With the use of a more general formalism  $E/A$  (where  $E$  is the measured

environmental property and  $A$  is the measured action-relevant property of an intentional agent) these ratios have been used to characterize the perceived sit-on-ability of chairs (Mark, 1987; Mark & Vogele, 1987), the pass-through-ability of apertures (Warren & Whang, 1987), the reach-ability of objects at different distances (Carello, Groszofsky, Reichel, & Solomon, 1989; Mark, Nemeth, Gardner, Dainoff, Paasche, Duffy & Grandt, 1997), and the grasp-ability of objects of differing lengths (Cesari & Newell, 1999; Richardson, Marsh & Baron, 2007).

The significance of affordance research is that it not only demonstrates how action-scaled perception is invariant across differences in the absolute metrics of environmental properties or the properties of an individual's action system (van der Kamp, Savelsbergh, & Davis, 1998; Mark & Vogele, 1987; Warren, 1984), but that the perception of an affordance boundary dynamically constrains the mode of activity an individual engages in (Gardner, Mark, Ward, & Edkins, 2001; Mishima, 1994; Warren & Whang 1987). For instance, research on reaching behavior has demonstrated that individuals not only perceive what is reachable by a scaling of the distance and height of the object to be reached, but whether an object can be reached by extending the arm, or by bending at the hip and extending the arm (Carello et al., 1989; Mark et al., 1997).

Typically, research investigating affordances has involved manipulating the physical properties of environmental objects or surfaces (e.g., Warren & Whang, 1987) or an actor's action capabilities (e.g., Mark, 1987; Mark, Balliet, Craver & Douglas, 1990) in order to reveal how the action-scaled perception of an affordance or affordance boundary constrains the mode of action an individual engages in. However, many everyday actions occur in the context of other activities—including those that are relevant to accomplishing the task and

those that are irrelevant to the task—that constrain the perception or actualization of affordances. For example, these other activities might demand attention and cognitive resources, or place time pressures on the ability to perform a given action. To return to the plank-grasping example mentioned above, an individual's perception of whether a plank can be grasped and moved from one location to another—or how to go about moving it—might be affected by whether that individual is conversing with someone else or is simply in a hurry. Thus far, little attention has been paid to how other activities influence the perception and actualization of affordances. Consequently, one aim of the current study was to investigate how the boundary between graspable with one-hand or graspable with two is affected by task constraints such as working at different speeds or while completing a concurrent cognitive task. A second aim is to consider the difference between the two types of constraints, those relevant to the task and those that are not. For example, speed is relevant to the execution of the task—the speed of object presentation dictates the pace of grasping and moving—performing mental activity is not relevant to the execution of the task—mental activity does not alter what the limbs can do in grasping and moving.

The grasping paradigm was employed for two reasons. First, a number of previous investigations have shown that the perception of whether an object should be grasped with one- or two-hands is clearly action-scaled, with the pi-number capturing the boundary between grasping modes invariantly across different individuals (e.g., Cesari & Newell, 1999, 2000b; Newell, Scully, Tenenbaum & Hardiman 1989a). There are even commonalities across age. Experiments with 3- to 5-year-old children show that the transition from one- to two-hand grasping occurs at a pi-number around .60 (Newell et al., 1989a). Experiments with adults reveal similar pi-numbers ranging from  $.58 \pm .16$  (Cesari &

Newell, 2000b) to  $.70 \pm .12$  (Richardson et al., 2007) depending on the task and objects used.

A second rationale for using the grasping paradigm is of special relevance. A number of these experiments have shown that the shift from one mode of grasping to another exhibits the typical features of a self-organized dynamic system. In a dynamic system, stable macroscopic patterns of behavior emerge from the lawful interaction between an animal and its environment (Kelso, 1995; van der Kamp et al., 1998). Thus, the pi-number indexing the boundary between graspable with one-hand and graspable with two-hands is understood to be a control parameter (Newell et al., 1989a; Richardson et al., 2007; Warren, 1984), a variable that, at some critical value, induces a spontaneous transition from one mode of behavior to another (cf. Strogatz, 1994), a one- or two-hand grasp. These abrupt shifts lead to a reconfiguration of the organization of the system and satisfy the criteria of a non-linear phase transition (Kelso, 1995; Turvey, 1990). It is important to note, however, that there is an asymmetry in the scaling of many control parameters. In grasping experiments, for example, when the control parameter is scaled in an ascending order from smaller to larger pi-numbers, at a critical point the transition from one- to two-hand grasping must occur because it is no longer physically possible to continue grasping the objects with one-hand. When scaled in a descending order, larger to smaller pi-numbers, the transition is not certain to occur because two-hand grasping is physically possible for each object. Thus, a scaling of the control parameter in different directions can cause behavioral shifts to occur at different points.

When a transition from one stable state to another occurs at later points in the sequencing as a function of the direction of parameter scaling (e.g., larger pi-numbers in the

ascending sequences and smaller pi-numbers in the descending sequences), *hysteresis* is said to have occurred. This demonstrates how the history of the system's past behavior affects the system's present behavior, the point of transition. When a transition occurs from one state to another at earlier points as a function of the direction of parameter scaling (e.g., smaller pi-numbers in the ascending sequences and larger pi-numbers for the descending sequences), *enhanced contrast* is said to have occurred; future states of the system influence its present behavior. Finally, if the transitions occur at a single parameter value regardless of the direction of scaling, a *critical point transition* is said to have occurred. Previous research on the affordance of graspability has tended to show hysteresis: The transition from one- to two-hand grasping typically occurs at a later point than the switch between two- to one-hand grasping (Richardson et al., 2007; van der Kamp et al., 1998). Interestingly, however, when the perception of graspability is not grounded in ongoing action, the "future-looking" phenomenon of enhanced contrast is more common (Richardson et al., 2007; for other examples of enhanced contrast in affordance perception, see Fitzpatrick, Carello, Schmidt, & Corey, 1994; Hirose & Nishio, 2001; see also Tuller, Case, Ding & Kelso, 1994, for rationalizations of the different types of phase transitions in speech perception).

From a dynamical systems perspective, different constraints, either relevant or irrelevant to the focal task, may affect the system at a local level without changes in the behavior at a more global level being observed. A commonplace example is standing while talking with friends. Individuals can do both things (standing and talking) at the same time successfully without any outwardly apparent global changes in behavior. However, at a more local level, say at the level of postural sway, differences may be seen. Postural sway for pairs of individuals who converse with each other will become entrained, while the sway

for pairs of individuals who converse with someone outside of the dyad will not become entrained (Shockley, Santana, & Fowler, 2003). This is just one example of how the addition of constraints on the overall animal-environment system need not prohibit the task from being accomplished but simply influence the global organization or dynamics of the system in subtle ways.

With respect to object grasping, manipulating the speed of object presentation is comparable to manipulating the speed of scaling the control parameter or pi-number. It is a manipulation that is immediately relevant to the focal task. In contrast, the addition of a concurrent cognitive task (e.g., counting backwards by sevens) is a situational constraint that is not immediately relevant to the focal task. Nevertheless, both types of constraints should lead to a re-parameterization of the grasping system resulting in a qualitative change in behavior. Namely, individuals should make the transition from one- to two-hand grasping at different pi-numbers. But how should the transition point be affected? It has been argued that the opportunity to be analytic may undermine the normal online perception and actualization of affordances (cf. Heft, 1993). To the extent that slow presentations provide just such an opportunity to be analytic, hysteresis should be reduced. To the extent that a cognitive load precludes the opportunity to be analytic, hysteresis should be enhanced. The opportunity to be analytic is more likely with slow presentations and without cognitive distractions. Consequently, we expect hysteresis to be reduced under such circumstances. The influence of presentation speed on the transition between one and two-hand grasping is assessed in a context without a cognitive load (Experiment 1) and in a context in which a task-irrelevant cognitive load was imposed on the individual participants (Experiment 2).

### Experiment 1

Experiment 1 examined the effect of a task-relevant manipulation, the speed of object presentation, on the point of transition between one- and two-hand grasping.

### Method

*Participants.* Twenty-four participants from the University of Connecticut participated as partial fulfillment of a course requirement. **One participant failed to grasp the objects properly; for this reason his data were excluded from the analysis.** The remaining twenty-three participants (8 Males, 15 Females) had an average hand span of  $21.07 \pm 1.78$  cm.

*Materials.* Two sets of narrow wooden planks, 2 cm high and 6.5 cm wide, ranging in length from 3 to 30 cm, in 1 cm increments and in weight from 18 g to 160 g, were used as the objects. These objects were painted black with their ends red and were kept behind a black curtain occluded from the participant's view until they were continuously presented on an 85 cm high shelf via a conveyer belt. A box with a 34 x 10 cm hole cut out of the lid sat on a table that was positioned 2.5 m away and served as a receptacle to receive the objects from the participants. An auditory metronome that was only heard by the experimenter was used to pace the presentation of the planks for both the slow- and fast-paced presentation sequences. A digital video camera that sat adjacent to the presentation ramp was used to record the session for each participant so that it could be later coded for analysis.

*Procedure.* Individual participants were required to lift each object **and** move it from the presentation ramp to the receptacle. Participants were told that they could do this with either one or two hands, and that they shouldn't think about it too much, but just do what "felt right." Although each object could be grasped with one hand by lifting the object across the 6.5 cm width, the participants were instructed that they could only grasp the

objects by the red ends alone. To ensure that participants understood how they could be grasped, the experimenter demonstrated grasping the smallest object in the set (3 cm) with one hand, and grasping the largest object in the set (30 cm) with two hands.

Each participant completed two trials in which the sequence of planks was presented one by one in an ascending and in a descending order. A filler trial was used in the middle of the experiment, in which the objects were presented to the participants in a random order. This served as a means of resetting the system between the ascending and descending trials. The presentation sequence (ascending or descending first) was counterbalanced across participants.

Each participant was randomly assigned to receive the planks of wood at a slow-, self- or fast-pace. In the slow-paced presentation condition, the wood was presented continuously via the conveyer belt in 10 s intervals. For the self-paced condition, the frequency of object presentation was scaled to each participant's preferred duration of action. This was accomplished by the experimenter placing the wood on the conveyer belt after the participant deposited the prior object in the receptacle, which on average was in 4 to 5 s intervals. For the fast-paced condition, the wood was presented in 3 s intervals. When all trials were completed, hand-span, measured as the length between the dominant hands' outstretched thumb and pinky finger, as well as the size of the maximum object that could be grasped was collected for each participant.

*Design and Analysis.* The experiment was a 2 (sequence: ascending, and descending)  $\times$  3 (speed: slow-, self-, or fast-paced)  $\times$  2 (order: ascending 1<sup>st</sup> or descending 1<sup>st</sup>) mixed design with the last two factors manipulated between subjects. The transition from one mode of grasping to another within each sequence for each participant was calculated as the plank

length at which a participant transitioned from one- to two-hand grasping (or vice versa) divided by the participant's hand-span. For example, the transition from one- to two-hand grasping in the ascending trials was calculated by taking the length of the largest plank of wood grasped with one-hand, before which all planks of wood were grasped with one-hand, and adding that number to the length of the smallest plank of wood grasped with two-hands, beyond which all planks were grasped with two-hands, and dividing by two. This mean plank length of transition in cm was then divided by the participant's hand-span in cm resulting in a dimensionless pi-number (van der Kamp et al., 1998; Richardson et al., 2007). This process was the same for the descending trials.

### Results and Discussion

Inspection of Figure 1a reveals that transitions from one mode of behavior to another did occur for both the ascending and descending sequences for all participants. That is, all participants switched from one- to two-hand grasping in the ascending sequences and from two- to one-hand grasping for the descending sequences, and did so without abandoning the selected mode. A 2 (sequence)  $\times$  3 (speed)  $\times$  2 (order) mixed design analysis of variance (ANOVA) was conducted on the average transition points for each participant. A main effect of sequence,  $F(1, 17) = 10.80, p < .01, \eta^2 = .39$ , revealed that the transition between grasping modes occurred at a significantly larger pi-number for the ascending trials ( $M = .75 \pm .11$ ; largest plank grasped with one-hand was 19 cm) than the transition between grasping modes in the descending trials ( $M = .69 \pm .13$ ; the smallest plank grasped with two-hands was 9 cm). These differences indicate that the point of transition depended on the direction of scaling the control parameter (pi-number). As previously seen in the investigation of grasping behaviors, on average most participants tended to remain in an assembled mode of

behavior (either one- or two-hand grasping) because they were influenced by what they previously did; that is hysteresis occurred.

Although there was no main effect of speed,  $F < 1.00$ , there was a significant interaction between speed and sequence,  $F(2, 17) = 3.93, p < .05, \eta^2 = .32$ , indicating that the manipulation differentially influenced the point of transition in the ascending and descending sequences (Figure 1b). Both at an individual level (Table 1) and as indicated by the overall means, participants in the self- and fast-paced conditions remained in the one-hand grasping mode for an extended period of time, switching later in the ascending sequences ( $M_{\text{self}} = .77 \pm .09$  and  $M_{\text{fast}} = .75 \pm .10$ ), than the descending sequences ( $M_{\text{self}} = .71 \pm .10$  and  $M_{\text{fast}} = .61 \pm .15$ ). For these conditions, hysteresis occurred. Although individual participants in the slow-paced condition displayed a variety of behaviors (Table 1), the overall means did not show the pattern of hysteresis typically seen in experiments investigating the actualization of affordances (Richardson et al., 2007). Rather, using linear methods (e.g. means) to analyze non-linear behaviors (e.g. phase transitions) seemed to cancel out the differing dynamical patterns of individuals (Carello & Moreno, 2005), such that at the group level the transition from one mode of grasping occurred at a critical value of the control parameter regardless of the direction of scaling ( $M_{\text{ascending}} = .72 \pm .13$  and  $M_{\text{descending}} = .72 \pm .15$ ).

Since participants tend to switch modes at a smaller pi-number in the descending sequences than in the ascending sequences, it is possible that participants who experience the descending sequence first may continue to use two-hands for a longer period of time than participants who experience the ascending sequence first. The analysis revealed that this was not the case as there was no main effect of order,  $F < 1.00$ , nor an interaction

between sequence and order,  $F(1, 17) = 4.14, p > .05, \eta^2 = .20$ . There was also no interaction between speed and order,  $F(2, 17) = 1.78, p > 0.5, \eta^2 = .17$ , nor was there an interaction between sequence, speed, and order,  $F < 1$ . Thus, the manipulation of speed did not differentially influence the point of transition for those participants who experienced the descending sequence first as opposed to the ascending sequence.

It can be concluded that the manipulation of some task-relevant factors, such as the sequence and speed of object presentation, influence the point of transition from one mode of behavior to another. More specifically, it appeared that the unusually slow condition caused individual participants to switch from the normal mode of action which is typically engaged in (hysteresis) to a variety of behaviors. It may have been that participants in this condition were not as responsive to the flow of the attractor dynamics (did not shift to the stronger attractor at a critical point) as were participants in the self- and fast-paced presentation conditions, therefore the direction of scaling the control parameter did not matter for the overall group level dynamics.

As noted in the Introduction, Heft (1993) has proposed that some affordance paradigms seem to invite more reflective analytic judgments, in contrast to online processes involved in actualization during more naturalistic contexts. In an investigation of perceiving what is reachable, it was found that overt judgment tasks yielded overestimates of reaching ability (Carello et al, 1989). When those judgments were nested within a larger task, necessarily focusing participants' attention away from reaching, overestimation was eliminated (Heft, 1993). Heft suggested that improved accuracy was a consequence of perception and action operating independently of intellectual reasoning. This seems relevant to why a critical point transition was seen in the unusually slow-paced presentation

condition of the current experiment. In these situations, participants had ample time to visually inspect each object that was presented to them and decide whether they should grasp it with one hand or two. During the self- and fast-paced presentation conditions, participants' attention may have been focused on maintaining the pace of object presentation thereby perceiving what needed to be grasped with one- or two-hands in a more online fashion. It is important to note that the frequency of object presentation was manipulated; no prescriptions as to how fast or slow the participants had to move the planks from one platform to the other were imposed. Hence, it was possible for some participants to move the planks more quickly during the slow paced presentation conditions, forcing them to wait for the next plank of wood for a longer period of time than other participants who moved the objects more slowly throughout the trials. Therefore, the slow paced presentation task may have provided more opportunities for analytic reflection for some participants than for others.

To determine whether we could undercut analytic modes of perceiving and acting, we also examined the impact of a cognitive load, a manipulation that is not immediately relevant to the grasping task. An ecological dynamical systems perspective would anticipate that cognitive load should reengage more responsive online action patterns, that is, hysteresis. Thus in Experiment 2, we manipulated cognitive load, in addition to sequence and speed of stimuli, to undercut participants' abilities to engage in thought-intensive judgment processes (Heft, 1993). We expected hysteresis to occur under cognitive load and fast presentation speed situations.

## Experiment 2

Experiment 2 was aimed at extending the findings of Experiment 1 and investigating how the addition of a task-irrelevant manipulation—a cognitive load requiring participants to count backwards by sevens starting from a random three-digit number—in combination with a speed of object presentation manipulation, might affect the point of transition between one- and two-hand grasping. From a dynamical systems perspective, we would expect the behavioral consequences of the task-irrelevant manipulation to eliminate any tendencies to engage in an analytic mode of action. Therefore no critical point transitions are expected to occur in the overall means, whereas hysteresis is.

In addition, we increased measurement sensitivity by using smaller increments in plank size, and we increased experimental power by including a larger sample size.

### Method

*Participants.* Forty-eight participants (20 Males and 28 Females) from the University of Connecticut participated as partial fulfillment of a course requirement. The participants had an average hand span of  $20.74 \pm 1.80$  cm. All procedures were approved by the university's Institutional Review Board.

*Materials.* In order to obtain a more continuous measure of the transition point from one- to two-hand grasping, the objects used in the current experiment differed somewhat from those used in Experiment 1. The two sets of narrow wooden planks, 2 cm high and 6.5 cm wide, ranged in length from 4.5 to 24.5 cm, in 0.5 cm increments, and in weight from 22 g to 135 g. These objects were painted black with their ends red and were kept behind a black curtain occluded from the participants view until they were continuously presented on an 85 cm high shelf after traveling on a conveyer belt. The box used in Experiment 1 was replaced with a second shelf that sat 85 cm high and 2.5 m away from the presentation shelf

and was used to collect the objects. An auditory metronome that was only heard by the experimenter was used to pace the presentation of the objects. A digital video camera that sat adjacent to the presentation ramp was used to record the session for each participant to allow later coding of grasping.

*Procedure.* The procedure was similar to that used in Experiment 1 with each participant receiving the objects in two critical trials: ascending and descending sequences, the order of which was counterbalanced across participants, with a random sequence used to reset the system in between. The self-paced presentation sequence was eliminated, hence, only the slow- and fast-paced presentation conditions were used. In addition, participants were randomly assigned to either a cognitive load condition (counting backwards by sevens aloud starting from a random three digit number while grasping the planks), or not.

*Design and Analysis.* The experiment was a 2 (sequence: ascending, and descending)  $\times$  2 (speed: slow-, or fast-paced)  $\times$  2 (cognitive load: counting backwards by 7s or not)  $\times$  2 (order: ascending 1<sup>st</sup> or descending 1<sup>st</sup>) mixed design. The transition from one mode of grasping to another within each sequence for each participant was calculated as done in Experiment 1.

## Results and Discussion

Experiment 2 was aimed at extending the findings of Experiment 1 by investigating how the addition of a task-irrelevant cognitive load, counting backwards by sevens, might affect the point of transition between one- and two-hand grasping modes. Our hypothesis was that the addition of the non-task relevant cognitive load would eliminate any analytic mode of responding in the slow-paced presentation sequence and result in the more typical action pattern of hysteresis.

As demonstrated in Experiment 1, Figure 2a reveals that transitions from one mode of behavior to another did occur for both the ascending and descending sequences. A 2 (sequence)  $\times$  2 (speed)  $\times$  2 (cognitive load)  $\times$  2 (order) mixed design ANOVA verified that the points of transition between the ascending ( $M = .73 \pm .09$ ; largest plank grasped with one-hand was 20 cm) and descending ( $M = .59 \pm .15$ ; smallest plank grasped with two-hands was 5.5 cm) sequences differed significantly,  $F(1, 40) = 44.94, p < .01, \eta^2 = .53$ ; on average, all participants exhibited hysteresis (see Table 2 for individual-level responses and Figure 2a for group-level behaviors). Similar to our findings from Experiment 1, presentation sequence interacted with speed,  $F(1, 40) = 6.29, p < .05, \eta^2 = .10$ , with the overall means in the fast-paced condition ( $M_{\text{ascending}} = .74 \pm .09$  and  $M_{\text{descending}} = .55 \pm .16$ ) indicating stronger hysteresis relative to that in the slow-paced condition ( $M_{\text{ascending}} = .71 \pm .10$  and  $M_{\text{descending}} = .63 \pm .14$ ) (Figure 2b). **The finding of hysteresis in the slow-paced condition in this experiment is in contrast to the findings of Experiment 1 where participants in the slow-paced condition exhibited a critical point transition.** Again, there was no main effect of speed,  $F < 1.00$ .

The greater power of this experiment for a two-cell main effect comparison may account for us being able to detect a main effect of order,  $F(1, 40) = 6.56, p < .05, \eta^2 = .14$ , which also interacted with sequence,  $F(1, 40) = 7.44, p < .01, \eta^2 = .16$  (Figure 2c). Participants in the descending first condition switched modes at lower pi numbers overall, with hysteresis being stronger.

As hypothesized, a significant interaction between sequence and cognitive load revealed that the introduction of cognitive activity also significantly influenced the point of transition between the ascending and descending sequences,  $F(1, 40) = 4.53, p < .05, \eta^2 =$

.10 (Figure 2d). Similar to those participants who experienced the fast presentation speed, participants who counted backwards by sevens while lifting and moving the objects made the transition on average at a later point in the descending conditions ( $M_{\text{ascending}} = .73 \pm .09$  and  $M_{\text{descending}} = .59 \pm .15$ ) than those in the no cognitive load condition ( $M_{\text{ascending}} = .73 \pm .10$  and  $M_{\text{descending}} = .63 \pm .16$ ); that is, hysteresis was exaggerated. With the differences in the transition points for the ascending and descending sequences averaging out, the main effect of cognitive load was not significant,  $F(1, 40) = 3.01, p > .05, \eta^2 = .07$ . No other interactions were significant.

### Conclusions

The current paper investigated the dynamic nature of actualized affordances by means of a plank-grasping paradigm. It was hypothesized that the addition of task-relevant and task-irrelevant manipulations might lead to differences in the dynamics underlying the actualization of affordances, a difference that would be manifest in differing points of transitions between one- and two-hand grasping.

For the task-relevant manipulation of speed, individual participants in the slow-paced object presentation conditions in Experiments 1 and 2 exhibited a variety of behavioral transitions as opposed to the typical pattern of hysteresis observed in affordance actualization. For Experiment 1, the overall means indicated that a critical point transition occurred with no differences found between the pi-numbers for the ascending and descending sequences. It is possible that reducing the speed of object presentation led to atypical shifts in the point of transition, resulting in a decrease in the number of individuals who exhibited hysteresis overall. More specifically, it is possible that this condition encouraged more analytic judgments about how to grasp each object, in contrast to the more

naturalistic and rapid online detection and actualization of affordance possibilities seen in the other speed conditions. Contrary to the critical point transition seen in the overall means for Experiment 1, the overall means for the slow-paced condition of Experiment 2 suggested that hysteresis occurred. Inspection of Table 2 indicates that the majority of participants exhibiting hysteresis in this condition (11 out of 17) were in the cognitive load condition. Those participants in the slow paced no load condition exhibited a similar pattern to that seen for Experiment 1, with a variety of behaviors being exhibited. For the self- and fast-paced presentations of both Experiments, more participants exhibited the typical action patterns for affordance experiments, hysteresis, where the point of transition from one mode of grasping to another depended on the direction of approach. It can be concluded that the frequency of object presentation acts as an additional control parameter in the investigation of affordances.

For Experiment 2, the non-task relevant manipulation of adding a cognitive load led to an intensification of the normal hysteresis pattern. Participants remained in the assembled mode of two-hand grasping for longer periods of time in the descending sequences. In the trials where there was no addition of a cognitive load, the overall means suggest more moderate hysteresis was exhibited.

Traditionally, experiments with an additional cognitive task are interpreted in terms of competition for limited resources which place a higher demand on attentional resources (Kahneman, 1973; Posner, 1978). According to an ecological theory of perception, the detection and actualization of affordances is a direct self-organizing dynamical process, and thereby does not require the organism to recruit additional cognitive resources. Behavior emerges from the changing interplay between various components of the organism and the

environment which leads to the spontaneous self-organization of action (Adolph & Berger, 2006; Smotherman & Robinson, 1996). While we believe this to be true, the results of the current experiment appear to suggest that under some conditions, such as in the slow-paced presentation condition of Experiment 1, affordances might engage a more analytic mode of actualization (Heft, 1993), rather than the on-line embodiment of them. It is important to note that by “analytic”, we simply mean that the individual’s behavior was less influenced by the immediate history or ongoing dynamics of their action as a result of having more opportunity to reflect upon, attend to, and detect the information that specifies the point at which comfortable one-hand grasping is possible or not. Indeed, although the experimental instructions did not explicitly require participants to transition at the same “critical” point for the ascending and descending trials (which may have corresponded to the point of optimal energy efficiency) in affordance experiments such as the ones presented here, participants might take this to be implied. Consequently when given the opportunity, such as during the slow-paced presentation conditions, participants may tend to act in accordance with what they see as the goal of the experiment.

It is also plausible that differences in the constraints on the perceiving-acting system are what contributed to the discrepancies in action-scaled ratios between the slow- and fast-paced conditions, as well as between the no cognitive load and cognitive load present trials. It appears that these two types of manipulations, task-relevant and non-task relevant are in fact complementary. As expected, they result in differences in the underlying dynamics of the system. With increasing constraints on the perceiving-acting system, the less likely it is for an individual to engage in analytic processes and the more likely it is for an individual’s behavior to be constrained by the direct detection of affordances.

Although the results of the current study do not allow for any firm conclusions to be made about whether the actualization of affordances is in fact a direct process as opposed to an analytic one, the experiments presented here do demonstrate how the prospective perception of body-scaled action possibilities, and the invariance of action-scaled ratios, are always relative to (or under) a very specific set of constraints and transformations (Turvey, 1992). In other words, the current experiments not only highlight the intrinsic role that task-relevant properties of both the physical body and the environment play in constraining the everyday perceiving and acting of individuals, but indicate that the non-physical properties of an individual's environmental context, as well as the task-irrelevant factors of an individual's other activities, play an equally defining role.

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Table 1.

*Distribution of Behavior Modes for Individuals in Experiment 1*

Behavior	Speed		
	Self	Slow	Fast
Hysteresis	4	3	6
Enhanced Contrast	2	3	-
Critical Point	2	2	1

Table 2.

*Distribution of Behavior Modes for Individual Participants in Experiment 2*

Behavior	Speed	
	Slow	Fast
	Cognitive load	
Hysteresis	11	11
Enhanced Contrast	-	1
Critical Point	1	-
	No cognitive load	
Hysteresis	6	10
Enhanced Contrast	4	2
Critical Point	2	-

Figure Captions

*Figure 1.* a) The percentage of participants using the two-hand grasping mode at each pi-number (binned in .05 intervals) for both the ascending and descending presentation sequences in Experiment 1. The data have been averaged across all speed conditions.

*b)* The sequence by speed interaction in Experiment 1. The bars (with standard errors) represent the average point of transition, as a pi-number, from one mode of grasping to another for each speed condition.

*Figure 2.* a) The percentage of participants using the two-hand grasping mode at each pi-number (binned in .05 intervals) for both the ascending and descending presentation sequences in Experiment 2. The data have been averaged across all speed conditions.

*b).* The sequence by speed interaction in Experiment 2. The bars (with standard errors) represent the average point of transition, as a pi-number, from one mode of grasping to another for each speed condition. *c).* The sequence by order interaction in Experiment 2. The bars (with standard errors) represent the average point of transition, as a pi-number, from one mode of grasping to another for each presentation sequence. *d).* The sequence by cognitive task interaction in Experiment 2. The bars (with standard errors) represent the average point of transition, as a pi-number, from one mode of grasping to another for each cognitive load condition.

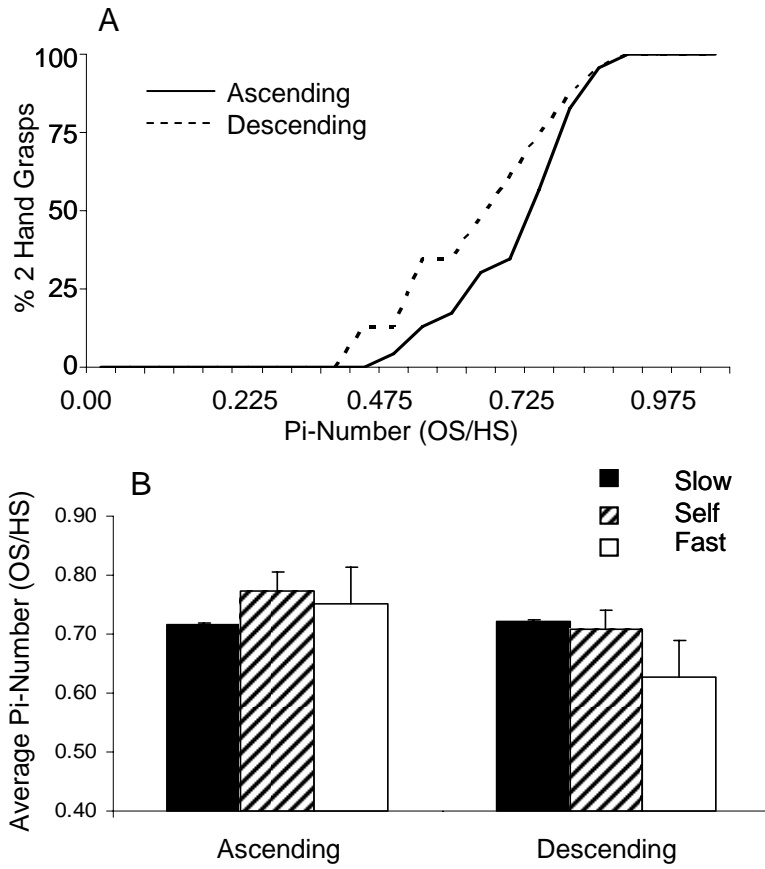


Figure 1.

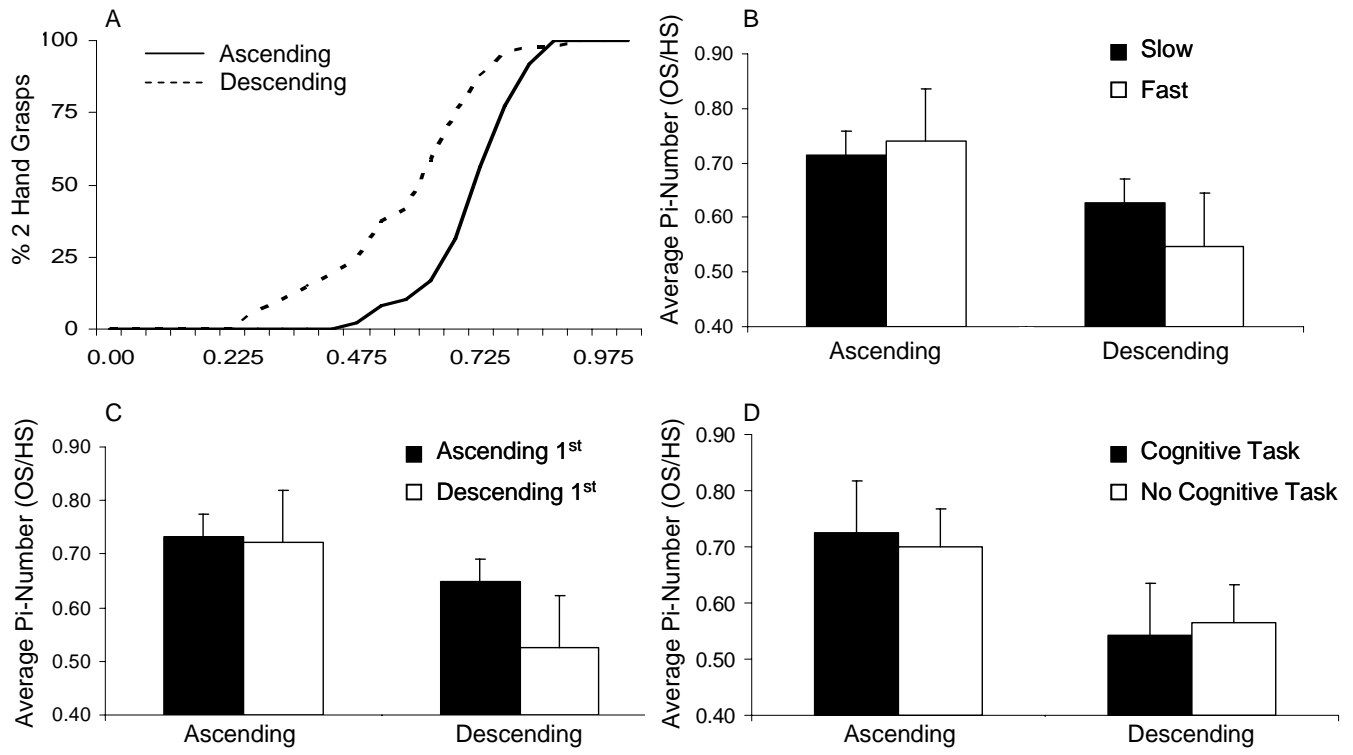


Figure 2.