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The Role of Motor Experience in Understanding Action Function: The Case of the Precision Grasp

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Abstract

Recent evidence suggests adults and infants selectively attend to features of action, such as how a hand contacts an object. The current research investigated whether this bias stems from infants' processing of the functional consequences of grasps: understanding that different grasps afford different future actions. A habituation paradigm assessed 10-month-old infants' ($N = 62$) understanding of the functional consequences of precision and whole-hand grasps in others' actions, and infants' own precision grasping abilities were also assessed. The results indicate infants understood the functional consequences of another's grasp only if they could perform precision grasps themselves. These results highlight a previously unknown aspect of early action understanding, and deepen our understanding of the relation between motor experience and cognition.

Processing the actions of others is a central aspect of human social-cognitive functioning. As adults, our analysis of others' behavior is concerned mainly with identifying people's goals and intentions: we process *what* other people are doing mainly so that we may understand *why* they are doing it. But processing what other people are doing is not a trivial task: actions are carried out relatively quickly, often without pauses between actions, and sometimes with actions overlapping one another. The fact that we can do this effortlessly suggests a powerful cognitive system for processing others' actions. Clearly, without such a system, we would be adrift in most social situations. Not surprisingly, then, many view action processing as a crucial accomplishment in infants' social-cognitive development (Baldwin, 2005; Woodward, 2009), and considerable research has been devoted to this topic.

Infants' understanding of action goals— that is, the objects toward which actions are directed — is one aspect of action that has been extensively studied. By 5 to 6 months infants begin to process others' actions as goal directed (Woodward, 1998, 1999). This understanding is initially limited to grasping actions, and extends to other actions in a relatively slow, piecemeal fashion (Woodward, 2003; Woodward & Guajardo, 2002). Developments in action understanding appear to be driven by infants' own motor experience in a causal manner (Sommerville, Hildebrand, & Crane, 2008; Sommerville, Woodward, & Needham, 2005).

A relatively understudied aspect of action perception which has more recently come under investigation is discrimination: distinguishing one action as distinct from another. Recent evidence suggests that action discrimination shares processing similarities with face discrimination (Loucks & Baldwin, 2009). In face discrimination, people make use of distinct sources of featural and configural face information (see Maurer, Le Grand, & Mondloch, 2002, for a review). Loucks and Baldwin discovered that adults also make use of

featural information (local detail regarding fine body motion, such as how a hand contacts an object) and configural information (global spatial-relational properties of action, such as the trajectory of a reach) in action discrimination, and that these two sources of information are processed distinctly, as in face processing. Of particular interest for the current research was the finding that featural action information is selectively attended to over configural action information.

Previous research indicates that young infants are sensitive to featural or hand contact information in the context of construing another's actions as goal-directed. For example, 9-month-old infants view a whole-hand grasp to a toy as goal-directed (Woodward, 1998), but do not view contact made with the back of the hand as goal-directed (Woodward, 1999). More recently, Loucks and Sommerville (under review) found direct evidence that the bias to selectively attend to featural over configural information is present by 10 months of age.

Why do adults and infants pay more attention to relatively small changes in featural information over relatively large changes in configural or temporal information? Although there are potentially a number of reasons, one reason that seems likely is that changes in featural or hand contact information have important implications for what can be done with an object in the future. Adults' grasp selection depends on the goal to be accomplished. For instance, a whole-hand grasp (with the fingers, thumb, and palm encompassing the object) around the handle of the toothbrush is required for brushing one's teeth, while a precision grasp (with fingers and thumb opposed and without contact of the palm) is required for fitting the toothbrush through the narrow opening of a toothbrush holder. Grasp selection is thus prospective in nature (also see Rosenbaum, Vaughan, Barnes, & Jorgensen, 1992, for the related "end-state comfort effect").

In the same vein, the set of possible future actions is constrained by the type of grasp one selects. Imagine, for example, a person reaching for and grasping a cup. If the person used a whole-hand grasp around the side of the cup, you know that the person *could* fill the cup with water. If, however, the person used a precision grasp, with the fingers on the inside of the cup and the opposing thumb on the outside, you know that the person *could not* fill the cup with water, as the hand would obstruct the water flow. In this sense, grasps have functional consequences: using a whole-hand versus precision grip constrains the possible future actions in different ways. Thus, the purpose of the present research was to investigate whether 10-month-old infants are sensitive to the functional consequences of different types of grasps in others' actions, and to investigate the means by which they develop this ability.

Building from previous work, the present research had two goals. The first was to determine whether 10-month-old infants are sensitive to changes in featural information as they relate to changes in the functional consequences of different grasps. If so, the second goal was to assess whether this sensitivity is related to their own motor experience with different grasps. In particular, we were interested in infants' use of the whole-hand versus precision grasp. Research on infants' grasp coordination has found that infants are sensitive to the goal of the action in planning their grasps. Between 5 and 9 months, infants continuously improve their ability to pre-configure their grasp according to object size (von Hofsten & Rönnqvist, 1988). By 9 months, infants are able to pre-configure their grasp in accordance with the orientation of an object (Lockman, Ashmead, & Bushnell, 1984), and also pre-select the optimal grasp depending on the rigidity of an object (Barrett, Traupman, & Needham, 2008). By 10.5 months, infants also modify the speed of their reach in accordance with the future actions to be performed with an object (Claxton, Keen, & McCarty, 2003). While infants can perform whole-hand grasps beginning around 5 months, the precision grasp is not robustly seen until around 9 to 12 months of age (Halverson, 1931). Based on previous findings that infants 9–10 months of age can coordinate their actions in relation to a goal, we

designed a task that would elicit the use of the precision grasp, and discriminate skilled from less skilled precision graspers.

In order to examine these questions, we contrasted the use of the whole-hand grasp with the use of the precision grasp for picking up a bowl in two different orientations. A wide bowl in an upright position can be picked up with a precision grasp (grasping the bowl's rim), while a whole-hand grasp is not functional in this instance (as the rim is too wide to gain adequate purchase). However, if the same bowl is inverted, it can only be picked up with a whole-hand grasp and using a precision grasp would not be functional in this respect (as there is no raised protrusion to grasp). Our hypothesis was that only infants who could perform precision grasps themselves would understand that a precision or whole-hand grasp is only functional for moving a bowl if the bowl's orientation affords such a grasp.

Method

Participants

Participants included sixty-two 10-month-old infants (32 females, 30 males) with an average age of 9 months 24 days (range = 9 months 12 days to 10 months 22 days). Half of the infants were tested in the upright-to-inverted condition, and the other half in the inverted-to-upright condition. All infants were full term (at least 37 weeks gestation), typically developing, and from a large metropolitan area. Participants were recruited from a database maintained by the university at which the research was conducted. Based on parental report of ethnicity, 47 infants were classified as White, 2 as Asian/Pacific Islander, 3 as Hispanic, and 10 as mixed or unlisted ethnicity. An additional 17 infants were tested but excluded from the final sample due to: excessive fussiness ($N = 13$), not engaging in the Action Task ($N = 3$), and experimental error ($N = 1$).

Stimuli

Habituation Task—A green bowl affixed with strips of red, blue, and yellow electrical tape was used in the Habituation Task. The red strip was affixed along the circumference of the inside rim of the bowl, and the blue and yellow strips were affixed along the outside of the bowl, at even intervals. With the tape at these positions, the bowl looked clearly different when inverted.

Action Task—The stimuli for the Action Task were five colorful block objects, identical in shape. On a given trial, the objects were presented inside one of two clear plastic boxes: the wide box ($12.6 \times 10.2 \times 10.2$ cm), or the thin box ($12.6 \times 5.8 \times 5.8$ cm). An object inside the thin box is pictured in Figure 1. With the object inside the thin box, the most efficient grasp to use in order to remove the object is a precision grasp, while a whole-hand grasp is much more difficult.

Procedure

All infants participated in both the Habituation Task and the Action Task. Approximately half of the infants received the Habituation Task first ($N = 30$), and the other half received the Action Task first ($N = 32$). The two tasks took place in separate rooms.

Habituation Task—During the Habituation Task, infants sat in their parent's lap approximately 122 cm in front of a black-curtained stage. The stage ($122 \times 49 \times 62$ cm) supported the bowl, and an actor sat behind the stage. A black screen that could be raised to block the infants' view of the display rested in front of the stage and was raised and lowered between trials.

A schematic of both conditions of the Habituation Task can be found in Figure 2. In all conditions, the task began with a preview trial, in which infants were shown the bowl resting on the right-hand side of the stage, without the actor present. In the upright-to-inverted condition (UI), the bowl was upright, and in the inverted-to-upright condition (IU), the bowl was inverted. The purpose of this trial was to familiarize infants with the display.

Following the preview trial, infants were shown the habituation trials. In the habituation trials of the UI condition, the actor, now seated behind the bowl, said ‘Hi! Look’, then reached towards and grasped the upright bowl with a precision grasp, and moved it across the table to the left-hand side of the display. In the IU condition, the basic elements remained the same, but the actor reached towards and grasped the bowl with a whole-hand grasp. Habituation trials were shown until the infant’s looking on the last three consecutive trials was 50% or less of what it had been on the first three trials, or until 14 trials, whichever came first. Thus, infants viewed a minimum of six and a maximum of 14 habituation trials.

Following habituation, infants were shown a test preview trial, in which the bowl was shown resting on the table inverted (UI condition) or upright (IU condition), without the actor present. The purpose of this trial was to make infants aware of the bowl’s altered orientation. Following the test preview, infants were shown the test trials. Test trials consisted of two different test events, shown in alternating order, two times each (for a total of four test trials). For the UI condition, in the precision event, infants were shown the actor reach towards and grasp the inverted bowl with the old, perceptually similar, but non-functional, precision grasp. In the whole-hand event of the UI condition, infants were shown the actor reach towards and grasp the inverted bowl with the new, perceptually dissimilar, but functional, whole-hand grasp.

In the IU condition, the test events were similar, but the perceptual and functional properties were reversed. In the precision event of the IU condition, infants were shown the actor reach towards and grasp the upright bowl with the new, perceptually dissimilar, but functional, precision grasp. In the whole-hand event of the IU condition, infants were shown the actor reach towards and grasp the upright bowl with the old, perceptually similar, but non-functional, whole-hand grasp.

Importantly, in all test events the actor held her position at the point of grasping, and did not move the bowl across the table. The test event shown first was counterbalanced across infants. If infants are only interested in the featural change in the grasp shape, they should only recover attention to the whole-hand event in the UI condition, and to the precision event in the IU condition. However, if they are more interested in the change in functional consequences, then they should look longer at the precision event in the UI condition, and the whole-hand event in the IU condition.

A trained observer, unaware of the particular events shown on each trial, coded infants’ looking times online. Looking time was calculated from the time that the actor stopped moving until the infants looked away for two seconds, or until the maximum trial length had been reached (60 seconds). A second observer recoded infants’ looking times offline from video. Trials in which both observers identified the same look away as ending the trial were considered agreements. Agreement was high (88%).

Action Task—During the Action Task, infants were seated in their parent’s lap, or on the floor with their parent behind them. On each of five trials, the experimenter presented infants with a block object inside a plastic box. The first two trials were warm-up trials, with the wide box, and the last three trials were test trials, with the thin box. Upon presentation,

the experimenter encouraged infants to remove the object verbally, and if necessary touched the object in order to prompt infants to engage in the task. Parents were told not to encourage or talk to their infant. Infants were given 30 seconds to remove the object, after which if it had not been removed the experimenter removed it for infants. The purpose of this task was to elicit and evaluate infants' precision grasps: Due to the size of the opening of the container, a precision grasp was the most efficient grasp for removing the objects, and while a whole-hand grasp was possible, it was very difficult for infants to accomplish object removal this way.

Action Task Coding—Infants' responses during the Action Task were coded offline by an observer. The grasp ultimately used to successfully remove the object was coded along two dimensions: 1) the type of grasp used, and 2) the planfulness of the grasp. Planfulness has been shown to be an important measure in previous research in this domain, as sometimes infants can display a target behavior simply by virtue of acting randomly (see Sommerville & Woodward, 2005). The type of grasp used was categorized as either a *precision grasp*, with the fingers and thumb in opposition and the palm not in contact with the object, or as an *other grasp*, which was any other kind of grasp (e.g., whole-hand, using the palm). A grasp was considered planful if the infant was looking at the object as they reached for it and if they pre-configured their grasp during their reach (i.e., began to close their grasp before contacting the object). Although infants always preconfigured their initial grasp, relatively often this initial grasp was not successful for removing the object; Grasps were only planful if they were pre-configured and successful. Also coded was the latency to object contact, the latency to the final grasp, and the latency to removal. A second observer coded 25% of participant responses. Agreement was high for both the type of grasp used (100%) and the planfulness (81%). The latency measures were also highly correlated across observers ($r = .99$ for all measures). Cases of disagreement were resolved with discussion.

Results

Action Task

Our goal in administering the Action Task was to identify infants who could efficiently solve the problem and those that could not. Based on infants' performance during the test trials (trials with the thin box), we split infants into two groups of *Precision graspers* and *Non-precision graspers*. Precision graspers were those infants who produced one or more planful precision grasps during the test trials ($n = 15$ in the UI condition, $n = 12$ in the IU condition), and Non-precision graspers were those infants who did not demonstrate any planful precision grasps during the test trials ($n = 16$ in the UI condition, $n = 19$ in the IU condition).

Precision graspers used an average of 1.78 (out of 3) planful precision grasps during the test trials ($SD = 0.80$). In addition, non-precision graspers used significantly more non-planful other grasps ($M = 0.80$, $SD = 0.83$) than precision graspers, ($M = 0.41$, $SD = 0.64$), $t(60) = 2.03$, $p = .047$, $d = 0.54$. Importantly, however, they did not differ on any other dimensions, such as age, or any of the latency measures, $t(60) < 1$.

Habituation Task

In each condition, infants in the two groups did not significantly differ on the number of habituation trials needed to reach criterion, or in their mean looking times to the first three or last three habituation trials, $t(60) < 1$. Thus, both groups of infants were equally attentive to the events depicted in habituation. This indicates that precision grasp infants did not have a general preference for viewing precision grasp events over non-precision graspers.

Infants in the two groups did differ on their looking behavior at test, however. Figure 3 depicts mean recovery scores from habituation across test events for both groups and both conditions (mean looking on the test trials subtracted from mean looking on the last two habituation trials). A 2 (test event) x 2 (grasp ability) x 2 (condition) mixed ANOVA revealed a significant main effect of condition, $F(1,58) = 9.17, p = .004, \eta_p^2 = .14$, and a significant three-way interaction between test event, grasp ability, and condition, $F(1,58) = 4.62, p = .036, \eta_p^2 = .07$. The main effect of condition indicated that infants in the IU condition ($M = 2.35, SD = 4.32$) recovered significantly more to the test events than infants in the UI condition ($M = 1.95, SD = 3.43$). No other main effects or interactions were significant.

The significant three-way interaction indicates that precision and non-precision graspers viewed the events differently depending on the functional consequences of the grasp, as well as the orientation of the bowl at test, in line with our hypothesis. In the UI condition, non-precision graspers recovered significantly from habituation to the whole-hand event, $t(15) = 2.39, p = .03, d = 0.60$, but did not recover to the precision event, $t(15) < 1$. In addition, they looked significantly longer to the whole-hand event than to the precision event, $t(15) = 2.24, p = .04, d = 0.56$. Precision graspers in the UI condition, on the other hand, recovered significantly from habituation to both the precision event, $t(14) = 4.16, p = .001, d = 1.07$, and marginally to the whole-hand event, $t(14) = 2.11, p = .05, d = 0.54$. Although precision graspers tended to look longer at the precision event over the whole-hand event, this difference was not significant, $t(14) = 1.13, p = .28$.

The results of the IU condition were nearly the opposite of the results in the UI condition. In the IU condition, non-precision graspers recovered significantly to the precision event, $t(18) = 3.45, p = .003, d = 0.79$, and did not recover to the whole-hand event $t(18) < 1$. They also looked significantly longer to the precision event than to the whole-hand event, $t(18) = 2.80, p = .01, d = 0.64$. Precision graspers in the IU condition, however, recovered significantly from habituation to both the precision event, $t(11) = 4.30, p = .001, d = 1.24$, and the whole-hand event, $t(11) = 3.57, p = .004, d = 1.03$. Precision graspers also tended to look longer at the whole-hand event over the precision event, but this difference was not significant, $t(11) < 1$.

Another way to characterize the difference between the groups is to compare the mean looking to the non-functional grasps in each condition: that is, the precision event in the UI condition and the whole-hand event in the IU condition. In this case, precision graspers in the UI condition looked significantly longer at the precision event compared to non-precision graspers, $t(29) = 2.74, p = .01, d = 1.02$, and precision graspers in the IU condition looked significantly longer at the whole-hand event compared to non-precision graspers, $t(29) = 3.22, p = .003, d = 1.12$.

While the categorical analyses above suggested differences in perception based on motor performance, we also explored this relation in a continuous manner. For the UI condition, we correlated the number of planful precision grasps with the mean difference in looking times between the two test events: looking to the precision event minus the whole-hand event. This correlation was significant and positive, $r(29) = .395, p = .03$. For the IU condition, we correlated the number of planful precision grasps with the *opposite* mean difference in looking times: the whole-hand event minus the precision event. This correlation was also positive, and approached significance, $r(29) = .345, p = .057$. Thus, even within the group of precision graspers, those infants who were able to produce more planful precision grasps tended to look longer at the non-functional test event relative to the functional test event.

Discussion

Processing of others' behavior is selectively focused on analyzing the features of action, such as how a hand contacts an object, in adulthood (Loucks & Baldwin, 2009) and infancy (Loucks & Sommerville, under review). These results indicate that one possible reason why infants are biased to selectively attend to featural information is that they are beginning to process action with respect to its functional consequences. Moreover, this burgeoning understanding is tied to their own developing motor repertoire. The planfulness of the action is key in this respect: only infants who were able to execute a motor plan for a precision grasp were able to functionally comprehend the use of precision and whole-hand grasps in another individual. Thus, the relation between motor production and action perception we have identified is not about particular motor capabilities, but more specifically about particular motor representations that are *prospective* in nature (Sommerville, Blumenthal, Venema, & Sage, in press; Sommerville et al., 2008). Finally, the results from the continuous analysis reveal that advancing motor sophistication provides additional insight into others' behavior: the more consistently infants were able to execute precision grasps, the stronger their understanding of the functional consequences of another's grasp.

Broadly, these results support the long-held view that infants' self-produced action promotes understanding (Piaget & Inhelder, 1962). More specifically, the current findings extend the relation between motor experience and action processing. While a wealth of research has documented that infants' motor abilities are related to their understanding of actions as goal-directed (Sommerville et al., 2008; Sommerville & Woodward, 2005; Sommerville et al., 2005), only recently has some research suggested that acquiring motor experience with a given action enables infants to predict or anticipate an actor's goal (Sommerville et al., in press). Understanding the functional consequences of a particular grasp requires using current perceptual information about the kind of grasp in order to make a prediction about what future actions *could* occur after the grasp is complete. Importantly, precision graspers only saw static grasps at test, indicating that their recovery to the non-functional event was due to the future action it afforded. Thus, the connections between motor experience and action processing appear to be future-oriented in nature.

Of particular interest is the fact that non-precision graspers were not sensitive to the functional consequences of the whole-hand grasp. Since non-precision graspers can produce whole-hand grasps, we might expect them to understand the functionality of whole-hand grasps. However, in both conditions, non-precision graspers were only sensitive to the perceptual change in featural information – the type of grasp. This indicates that experience with a particular grasp is not sufficient for understanding functional consequences. Rather, it appears that having *contrastive* motor experience with multiple grasp types supports this understanding. This idea is consonant with Baillargeon's (2004) theoretical proposal that infants' learning of events is driven by attention to relevant variability. It seems that the development of the precision grasp gives infants broad insight into how each grasp functions, as they contrast these grasps in their own behavior. Infants without such contrastive experience seem to lack this conceptual insight altogether.

On the other hand, all infants were sensitive to changes in featural information: across both conditions, infants in both groups showed significant recovery to the novel grasp type. The fact that 10-month-olds found these featural changes salient is not unexpected, as it simply matches previous findings with adults (Loucks & Baldwin, 2009) and infants (Loucks and Sommerville, under review). This sensitivity is likely a key step towards gaining a functional understanding of other's action.

Precision graspers, however, were sensitive to more than just featural changes: they were also sensitive to the change in the functionality of the old grasps. Overall, they were not more sensitive to the non-functional grasps over the new, functional grasps. Given the variability in precision grasp performance, it may be that 10-month-olds are at a transitional state in their understanding of functional consequences. Had we sampled older infants – for example, 12-month-olds – who have more experience with precision grasping, we might have observed a stronger preference for the non-functional grasps. The correlational analyses support this possibility: the better infants were at performing planful precision grasps, the stronger their preference for the non-functional grasp. In any case, the current results still clearly indicate that precision graspers evaluate the functional consequences of grasps differently than non-precision graspers.

The concept of functional consequences is similar to the concept of affordances for action (J. J. Gibson, 1979). Infants perceive the environment according to what it affords in terms of possible actions; there is an important link between perception and action. Research has documented such perception-action coupling in infants' gross motor development (Adolph & Berger, 2006; Adolph, Eppler, & E. J. Gibson, 1993), as well as in fine motor development and its relation to tool use (Lockman, 2000; Lockman et al., 1984). However, to date this research has been restricted to infants' perception of the environment for their own action. The current study emphasizes that perception is involved much more broadly in this relation: infants are also sensitive to the affordances of the environment for *another's* action. Understanding the functional consequences of action requires infants to integrate their knowledge of the environment and their own action experience with the ongoing actions of others. Precision graspers were those that evidenced motor planning in their grasp selection, a hallmark of motor development (von Hofsten & Rönnqvist, 1988; Rosenbaum et al., 1992). This achievement appears to have transferred to their perception of other's grasp selection as well.

Such an understanding could act as an important bootstrapping mechanism in the development of tool use, which gradually emerges at the end of the first year (McCarty, Clifton, & Collard, 1999, 2001). Our results suggest 10-month-olds are beginning to understand the spatial relations between others' hands and objects which are critical for this development (Lockman, 2000; McCarty et al., 2001), and could learn from others in this way to enhance tool use representations in a cyclical fashion. We have also examined the degree to which action discrimination undergoes a period of narrowing in infancy, similar to what has been documented in speech perception (Werker & Tees, 1984) and many other domains (Scott, Pascalis, & Nelson, 2007). Younger infants are sensitive to more aspects of action than older infants, who selectively attend to featural information (Loucks & Sommerville, under review). The current findings may be highlighting the end point of this narrowing, and suggest that the driving factor may be infants' increasing motor capabilities.

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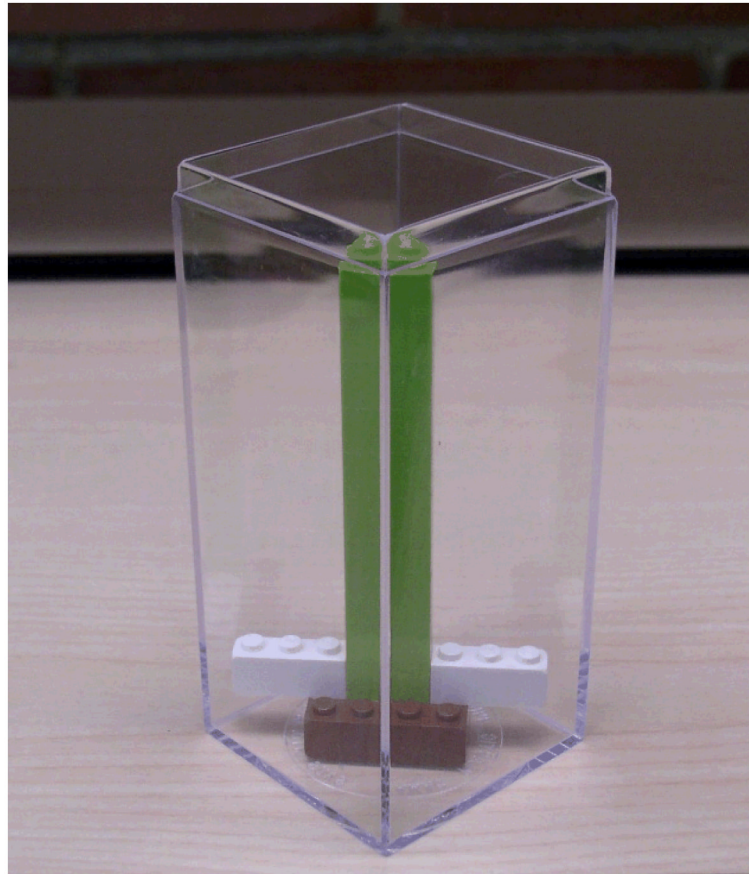


Figure 1. An example block object and the thin box used to assess precision grasping in the Action Task.

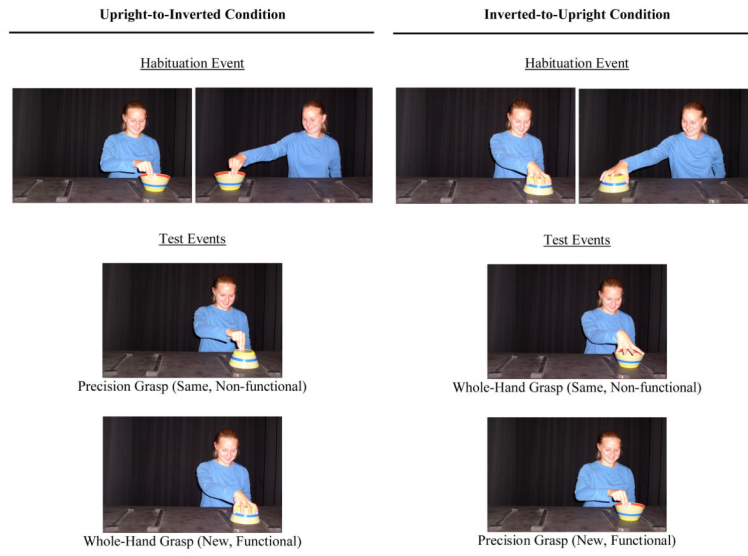
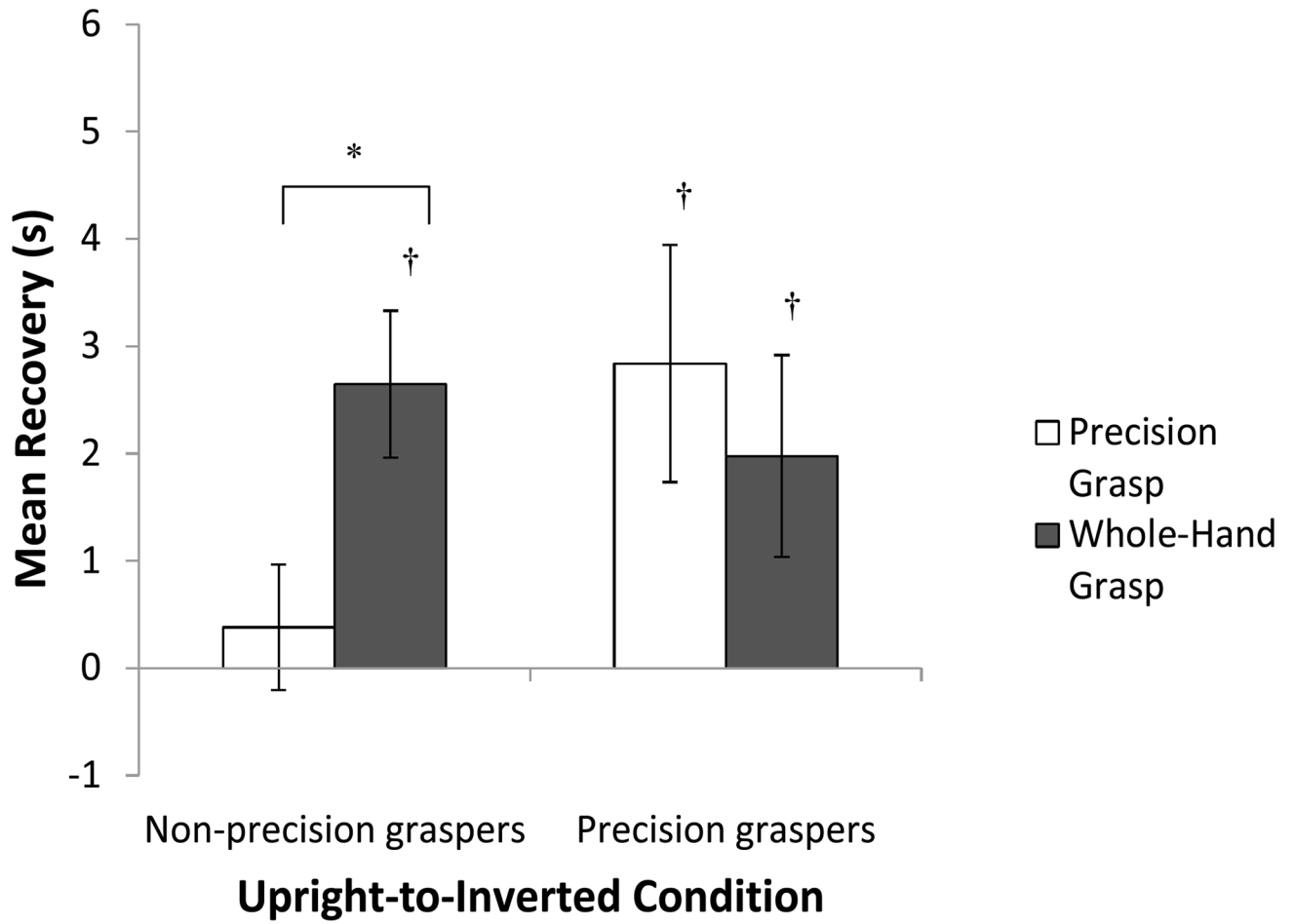


Figure 2.
A schematic of the Habituation Task.



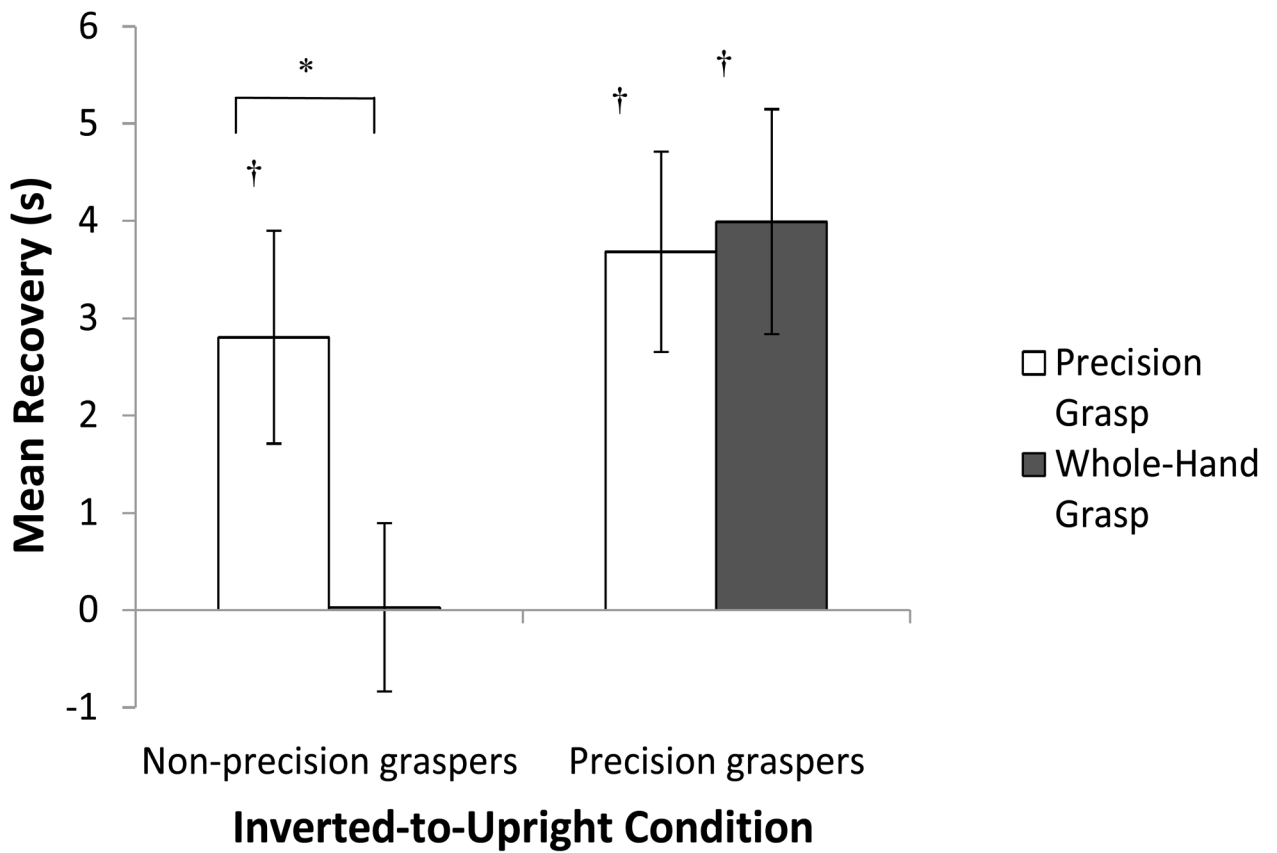


Figure 3. Mean recovery scores relative to the last two trials of habituation for the test events (whole-hand and precision) as a function of action performance (precision versus non-precision graspers) in each condition (upright-to-inverted versus inverted-to-upright habituation). Scores marked with a cross indicate significant recovery from habituation. The bracketed asterisk indicates a significant difference between scores.