Learning About Tools in Infancy

Tracy M. Barrett, Evan F. Davis, and Amy Needham
Duke University

These experiments explored the role of prior experience in 12- to 18-month-old infants' tool-directed actions. In Experiment 1, infants' use of a familiar tool (spoon) to accomplish a novel task (turning on lights inside a box) was examined. Infants tended to grasp the spoon by its handle even when doing so made solving the task impossible (the bowl did not fit through the hole in the box, but the handle did) and even though the experimenter demonstrated a bowl-grasp. In contrast, infants used a novel tool flexibly and grasped both sides equally often. In Experiment 2, infants received training using the novel tool for a particular function; 3 groups of infants were trained to use the tool differently. Later, infants' performance was facilitated on tasks that required infants to grasp the part of the tool they were trained to grasp. The results suggest that (a) infants' prior experiences with tools are important to understanding subsequent tool use, and (b) rather than learning about tool function (e.g., hammering), infants learn about which part of the tool is meant to be held, at least early in their exposure to a novel tool.

Keywords: tool use, infancy, object knowledge, spoons, handles

Using tools is an important skill across many animal species, including humans (Creem & Proffitt, 2001), chimpanzees (McGrew & Collins, 1985), and dolphins (Krutzen et al., 2005). When investigating tool use in human infants, researchers have related tool use to infants' object manipulation skills (Bushnell & Boudreau, 1993, 1998; Lockman, 2000) or their planning skills (Berger & Adolph, 2003; McCarty, Clifton, & Collard, 1999, 2000). By far, the tool most studied in the infant literature has been the spoon (Connolly & Dagleish, 1989; McCarty et al., 1999, 2000).

Tool use is especially well-suited to inform researchers about interactions among perception, cognition, and action (Creem & Proffitt, 2001). These three elements have been studied in concert before in many studies, especially those investigating infants' anticipation of visible object properties in reaching (Lockman, Ashmead, & Bushnell, 1984; von Hofsten & Fazel-Zandy, 1984),

infants' reaching for moving objects (Spelke & von Hofsten, 2001; von Hofsten, 1980), and infants' reaching for objects in the dark (Clifton, Rochat, Litovsky, & Perris, 1991). All of these studies have investigated various aspects of embodied cognition. Because cognitive and perceptual processes are embedded in an ongoing stream of action in people's typical experiences, the best context for studying them is within this embedded context (Gibson, 1988; Neisser, 1976; Oyama, 2002; Thelen & Smith, 1994). The pair of experiments described in this article continues this tradition.

Learning to Use a New Tool

Experience must be a critical component of learning how to use a new tool. Although it is common to think of prior experiences with objects as beneficial for action, in the case of tool use, it may be that prior experience makes action less variable and less flexible (e.g., think of how consistent you are when you grasp and use a spoon). Thus, tool experience may have positive or negative consequences on subsequent tool use, depending on how flexible infants must be in transferring their actions from one context to another.

Flexibility is an important component of infant motor development, because infants must figure out how to move their bodies to accomplish goals in a variety of different conditions (Adolph & Berger, in press). Here, we are interested in how using a tool in one particular way can enhance accuracy but reduce flexibility in infants' subsequent use of the tool.

Using Prior Experiences to Inform Action

In the infant literature, there is evidence that prior experiences can influence infants' plans for action. Infants 9 months of age and older were found to be more likely to imitate actions using appropriately matched objects than they were using less appropriately matched objects (Killen & Uzgiris, 1981; McDonough & Mandler, 1998). For example, when an experimenter modeled a toy dog drinking from a cup and a toy car drinking from a cup, infants were

more likely to reproduce the most commonly matched combination—the toy dog drinking from a cup. Further, psychologists have found that prior experiences guide infants' reaching and grasping (Claxton, Keen, & McCarty, 2003; Clifton et al., 1991; Granrud, Haake, & Yonas, 1985; Needham, 1999). Clifton et al. (1991) conducted an intriguing study of 6.5-month-old infants reaching for objects in different lighting conditions so as to manipulate infants' access to visual information for use in guiding actions. Their results showed that in both the light and dark conditions, infants reached for a large object with two hands extended in tandem and reached for a small object with one hand extended further than the other in anticipation of the size of the object. These and other results have provided convincing evidence that infants incorporate knowledge about specific objects into subsequent sequences of action. Together, these findings indicate that past experiences are important for guiding infants' actions on objects. Here, we are interested in how past experiences, both of a class of tools (spoons) and of one particular novel tool, can bias infants' subsequent actions on and use of those tools.

Within the context of tool use, prior experiences with the tool are likely to be very important for informing subsequent actions with the tool. In this research, we investigated both (a) whether familiarity with a tool (a spoon) leads to decreased flexibility in the use of that tool in a novel way to accomplish a novel goal (Experiment 1) and (b) whether infants' patterns of use of a novel tool can be traced back to different training experiences the infants received with this tool (Experiment 2).

Experiment 1

The goal of Experiment 1 was to determine whether infants would exhibit different patterns for acting on a familiar tool (spoon) versus a novel tool (composed of a thin straight handle at one end and a rounded oval handle at the other). In addition, we investigated the flexibility of these patterns. We hypothesized that having set patterns for acting on a tool, although beneficial for the use of the tool for that particular purpose, can have negative consequences when one is required to use the tool in a novel way.

The novel task in this experiment involved inserting the tool into an opening in the side of a box to turn on a set of lights inside the box that were visible through a window in the front of the box. On some trials, the opening was large enough to permit insertion of either end of the tool. On other trials, the opening was only large enough to permit insertion of the thin handle of the spoon or the novel tool. The experimenter demonstrated a grasp of the round end of the tool and inserted the straight end into the opening. The infants' subsequent behaviors with the tools were observed to assess any differences in their reproduction of the action as a function of the tool they were using. We expected that infants would be less likely to imitate the experimenter and, consequently, less likely to solve the task with the spoon than with the novel tool. The rationale was that prior experiences with spoons would contribute to the activation of a plan of action that involved holding the spoon by its handle. Comparison of infants' actions with the spoon and the novel tool (which should have had no specific associations) could bring to light these influences of prior experience on subsequent tool use actions.

Method

Participants

Twenty-eight 12- to 18-month-old infants participated in the study (16 male, 12 female). The mean age for participants was 15 months, 3 days (SD = 1 month, 14 days; age = 12 months, 9 days to 18 months, 3 days). The demographics of the sample were as follows: 26 Caucasian infants, 1 African American/Caucasian infant, and 1 Asian/Caucasian infant. The highest obtained education levels of the infants' mothers were as follows: 2 had completed some college education, 15 had obtained a degree from a 4-year college, and 10 had completed some postgraduate education. The highest obtained education levels of the infants' fathers were as follows: 2 had obtained a high school degree, 7 had completed some college education, 13 had obtained a degree from a 4-year college, and 5 had completed some postgraduate education. One infant's demographic information was incomplete. Data from 12 additional infants were collected and excluded, 7 because of fussiness (would not complete a majority of the test trials), 4 because of experimental error, and 1 because of parental interference.

Apparatus and Stimuli

Infants were tested individually sitting on a caregiver's lap at a wooden table 74 cm in height. The tabletop was 81 cm from left side to right side and 64 cm from the infant to the experimenter, who sat facing the infant across the table. A half circle (23 cm in radius) was cut out of the infant's side of the table so that the table surrounded the front of the infant. The tabletop was covered with white contact paper and a colored grid formed by tape. Two video cameras filmed the procedure from two perspectives: An overhead video camera positioned approximately 182 cm above the tabletop captured action that occurred on the tabletop, and a side camera positioned 122 cm behind the experimenter, approximately 45° to the right of the infant, captured a view of the caregiver, infant, and experimenter.

The object used for assessing hand preference was a 6-cm orange cube. The spoon used in this experiment was a standard adult-sized teaspoon measuring 16 cm in total length, with a bowl that was 5.5 cm in length and 3.2 cm at its greatest width. The width of the spoon's handle at its widest was 0.8 cm. The novel tool was fashioned out of wood and measured 14 cm in total length, with the round handle measuring 6.5 cm in length and 7.5 cm at its greatest width. The thickness of the novel tool's straight handle was 1 cm, and its round handle was 0.3 cm thick. The entirety of the tool was painted silver to approximate the spoon's coloring.

The test task used a *light box* that measured 14.0 cm in length, 10.0 cm in height, and 12.5 cm in width and was painted green (see Figure 1). The front of the box had a Plexiglas window through which one could see an LED display of colored lights that would turn on when an object passed through an opening in the right side of the box (breaking a beam of infrared light). The internal circuitry and batteries that enabled the lights to illuminate were hidden inside the box behind a wooden wall. The entire light box was affixed to a white wooden base (41 cm in length, 2 cm in height, and 14 cm in width), which enabled the experimenter to secure it to the table.
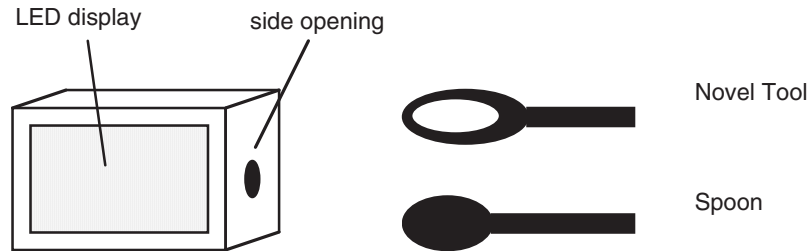
Figure 1. Stimuli for Experiment 1: The light box action consists of grasping the round end of either the novel tool or the spoon and inserting the straight handle into the side opening, which activates the LED display.

The experimenter altered the size of the opening by replacing an interchangeable frame, which allowed for there to be hard and easy trials. The *easy trials* (4-cm circular opening that allowed for a grasp of either end to result in a successful outcome) served as a check on whether the infants were physically capable of completing the task. If more than half of the infants failed on the easy trials, it would indicate that the task was too difficult. The *hard trials* (2-cm opening that required a grasp of the tool's round end and insertion of the tool's thinner straight end for a successful outcome) tested the infants' willingness to grasp the round end of the novel tool or the spoon to complete the task.

Procedure

This experiment used two tools as stimuli (spoon and a novel tool). Each infant received a series of baseline and test trials during their laboratory visit. There were one baseline and four test trials for each of the tools, completed in one block. The order of the tools was randomized such that 13 infants received their baseline and test trials with the spoon first before continuing with the trials for the novel tool, and 15 infants received the opposite sequence. Within the test trials, each infant received either two hard trials first followed by two easy trials, or vice versa. Within the hard and easy trials, each infant received two chances at producing the action. The tool's position when presented in front of the infant alternated (once with the straight handle on the infant's right and once with the handle on the infant's left).

Before the experiment began, the infant's reaching preference was assessed. A small block was placed in front of the infant on three sequential trials. The hand that was used in the majority of the three reaches for the block was considered to be the infant's dominant reaching hand.

Next, the infants participated in a baseline trial for the first tool, which was used to assess spontaneous production of the target action. The experimenter placed the light box and the first tool in front of the infant but did not demonstrate how to use the objects. The tool was positioned vertically in front of the box such that its round end was closest to the infant. The trial lasted for 30 s, after which the objects were retrieved.

Following the baseline trials, the infants participated in two test trials. Out of the infant's sight, the experimenter affixed either the 2-cm or the 4-cm opening to the light box. After placing the light box on the table and the tool to the right side of the box, the experimenter grasped the tool's round end and inserted its straight end into the side opening of the box. The tool was then placed back in its original position, and the demonstration was repeated once

more for the infant. Then the experimenter grasped the ends of the tool with both hands and placed the tool horizontally in front of the infant, saying "Now it's your turn." The light box was pushed toward the infant, and after 30 s elapsed, the tool and light box were retrieved and the trial ended. If the infant was off task during the trial, the experiment pointed to the opening of the light box and said, "Can you put it in here?" This entire procedure was repeated once more, but the position of the tool was counterbalanced over the two trials. After those two trials were completed, the experimenter altered the light box out of the infant's sight to have a different size opening than in previous trials. The same procedure was repeated for the next two trials. After the infant completed the baseline and test trials using the first tool, the experimenter repeated the entire procedure with the other tool.

Measures

The videotaped sessions were digitized for use in computer coding. Six measures (success, latency to initial contact, grasp placement at initial contact, latency to initial attempt, grasp placement at initial attempt, and perseveration) were obtained to examine infants' actions on the spoon and the novel tool.

A success was defined as a trial on which the infant activated the light box (inserted the tool into the opening and turned on the light) and was scored as either *yes* or *no*. If the infant had trouble inserting the handle into the opening but was holding the tool in the correct manner, he or she was given credit for succeeding. Infants should have succeeded in a majority of the easy trials regardless of the tool used, thus signifying that they were capable of completing the task. However, we hypothesized that infants would show differential performance on the hard trials depending on the tool that was used. On these trials, infants had to grasp the tool's round end and insert its straight end into the opening. Therefore, if infants had a plan for acting on spoons based on prior experiences in standard settings, they might exhibit a tendency to grasp the spoon's straight end and be less likely to reproduce the correct action. Alternatively, infants might be more likely to succeed with the novel tool because they should have no bias for grasping either end.

Latency to initial contact was defined as the amount of time from the tool presentation (the point when the experimenter's hands left the tool) until the infant first contacted the tool with his or her hand(s). In other research, longer latencies have been used as indicators of planning in infants (McCarty et al., 1999). If infants show longer latencies to contact the spoon rather than the novel tool, it could be evidence that they drew on cognitive

resources to plan their grasps of spoons rather than simply acting on readily available visual information. *Grasp placement at initial contact* of the tool by the infant's hand(s) was coded at the same point in time as the latency measure. An experienced coder determined this placement to be either a grasp along the tool's round end or some other position along the tool (including the straight end, middle of the straight and round end, or contacting the tool using two hands). If infants were reluctant to grasp the spoon's round end at the initial contact but were more willing to grasp the novel tool's round end, it would provide evidence that their prior experiences can influence their actions with the spoon.

Latency to initial attempt was defined as the amount of time from the infant's initial contact of the tool to his or her initial attempt to replicate the target action. An attempt was considered to occur when the infant used the tool to contact the box on the side of the opening. *Grasp placement at initial attempt* was defined as the placement of the infant's hand along the tool at the point of the initial attempt to replicate the target action. This point was the moment of contact of the tool to the side of the opening. An experienced coder determined this placement to be either a grasp along the round end of the tool (as the experimenter had demonstrated) or some other position along the tool (including the straight end or the middle of the straight and round ends). If infants were reluctant to grasp the round end of the spoon for their first attempt to reproduce the action but were more willing to grasp the round end of the novel tool, it would provide evidence that they had biases about the spoon that influenced their actions.

For the hard trials, coders tabulated the amount of *perseveration* of incorrect attempts (trying to insert the large end of the tool into the small opening). Repeated attempts in rapid succession to insert the large end of the tool into the small opening were considered to be only one attempt. A separate attempt was considered to occur when the tool was withdrawn from the box at least the distance of half the tool. It was hypothesized that infants would perseverate in the incorrect strategy more with the spoon and be more likely to consider alternate strategies when applying the novel tool.

To assess reliability of the coding of these measures, a subset of all participants ($n = 6$) were recoded by a trained observer who was unaware of the goals or hypotheses of this experiment. Reliability for quantitative data was calculated by means of Pearson's product–moment correlation. The range of agreement for these variables was .84–1.0 ($M = .92$). Reliability for qualitative data was calculated by means of Cohen's Kappa formula. The range of agreement for these variables was .86–1.0 ($M = .94$).

Results

Preliminary analyses. We analyzed the baseline trials to assess the number of infants who spontaneously reproduced the target action. Infants were unlikely to reproduce the action using either tool without seeing a demonstration (3 times out of 13 trials using the spoon, 2 times out of 15 trials using the novel tool).

A preliminary analysis revealed no main effect of the order in which infants received the easy and hard trials ($p = .56$). Success rates for the easy trials were calculated for each tool. Infants were highly successful in producing the target action with both the novel tool (92%) and the spoon (78%). Because a large percentage of the infants succeeded in completing the task for both tools, it can be assumed that this task is developmentally appropriate for infants

between the ages of 12 and 18 months. Further analyses were only conducted on data from the hard trials, because these were the trials of interest.

Generalized estimating equations (GEE) analyses were used to predict for five dependent variables (success, grasp placement at initial contact, grasp placement at initial attempt, latency to initial contact, and latency to initial attempt) from the between-subjects variables (gender, age, tool order, and tool type) and the within-subject variable (trial). This type of analysis is a regression method introduced by Liang and Zeger (1986), used to examine data that consist of repeated measures of an individual taken over time. This method in particular is useful for examining correlated categorical data. The GENMOD procedure in the SAS (Version 9.1) programming language estimated the parameters of the model numerically through an iterative fitting process (maximum likelihood). The parameters were then interpreted as odds ratios (e.g., infants are 6.80 times more likely to succeed with the novel tool than with the spoon). Chi-square tests of independence were conducted as a follow-up for the significant categorical variables of the GEE analyses.

Because SAS programming code for GEE analyses at the moment does not exist for research designs that have more than one within-subject variable, tool type was considered a between-subjects variable for the analyses in Experiment 1, despite the same infants having participated in trials using both the spoon and novel tool. We feel confident that this is an acceptable way of handling the analyses for a couple of reasons. Our analyses revealed no effect of tool order, suggesting that completing the trials with one tool has no impact on performance with the other tool. Furthermore, considering the tool type variable to be between-subjects as opposed to within-subject actually increases the error term in the analyses, thus making it more difficult to find significant results.

Main analyses: Success. A GEE analysis found three predictors of infants' success in reproducing the correct action: tool type, gender, and age (see Table 1). The odds ratio for the variable tool type estimated that the likelihood that infants succeeded was 5.99 times greater when they used the novel tool as compared with the spoon ($p < .01$). In addition, the odds ratio for the variable gender estimated that the likelihood that male infants succeeded was 4.95 times that of the female infants ($p < .01$). Lastly, the odds ratio for the variable age estimated that the likelihood for success increased by a factor of 1.02 for each one-unit (day) increase in the infant's age and increased by a factor of 1.82 for every month (or 30-day) increase in the infant's age ($p < .05$).

A 2×2 chi-square test of independence had tool type (spoon, novel tool) and success (yes, no) as between-subjects factors. This analysis, $\chi^2(1, N = 102) = 13.33$, $p < .01$, indicated that infants succeeded more in the novel tool trials (56.86%) than in the spoon trials (21.57%; see Figure 2).

Another chi-square test had gender (male, female) and success (yes, no) as between-subjects factors. This analysis, $\chi^2(1, N = 102) = 5.32$, $p < .05$, indicated significantly more success on the part of the male infants (49.12%) as compared with the female infants (26.67%). To assess whether infants of different genders performed differently depending on the tool used, we conducted another chi-square test of independence holding tool type constant. The analysis of gender and success for the spoon trials, $\chi^2(1, N = 51) = 4.10$, $p < .05$, indicated that female infants succeeded less

Table 1
Summary of GEE Analysis for Variables Predicting Infants' Success in Reproducing the Action and Producing the Correct Grasp Placement at Initial Contact and Initial Attempt to Reproduce the Action in Experiment 1 (N = 28)

Variable	Success				Grasp placement at initial contact				Grasp placement at initial grasp			
	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	e^b	CI (odds)
Tool type	1.79**	0.61	5.99	1.82–19.65	1.61**	0.49	5.01	1.93–13.00	1.61**	0.61	5.03	1.52–16.59
Age	0.02**	0.01	1.02	1.01–1.03	0.01*	0.01	1.01	1.00–1.02	0.01	0.01	1.01	1.00–1.03
Gender	−1.60*	0.65	0.20	0.06–0.73	−1.50**	0.52	0.22	0.08–0.62	−1.68**	0.65	0.19	0.05–0.67
Trial	−0.17	0.27	0.84	0.49–1.44	−0.24	0.48	0.79	0.31–2.03	0.13	0.36	1.13	0.55–2.31
Tool order	−0.10	0.59	0.90	0.29–2.85	0.40	0.47	1.50	0.59–3.79	0.46	0.59	1.58	0.50–4.99
Constant	−9.27	3.39			−6.53	2.61			−7.50	3.30		

Note. GEE = generalized estimating equations; CI = confidence interval.
* $p < .05$. ** $p < .01$.

than male infants. Alternately, the analysis of gender and success for the novel tool trials yielded a nonsignificant result, $\chi^2(1, N = 51) = 2.05$, $p > .05$, indicating no differences between the male and female infants. Taken together, these analyses show that the female infants succeeded less than the male infants; however, this was not because of a general deficit in the female infants' tool use. The analyses revealed that female infants appeared to fare as well as male infants on the novel tool trials (45.45% and 65.52%, respectively) but showed significantly worse performance than male infants on the spoon trials (8.70% and 32.14%, respectively).

Main analyses: Grasp placements. A GEE analysis found three predictors of infants' grasp of the round end of the tool at initial contact: tool type, gender, and age (see Table 1). The odds ratio for the variable tool type estimated that the likelihood that infants initially grasped the round end of the tool was 5.01 times greater for the novel tool trials as compared with the spoon trials ($p < .01$). In addition, the odds ratio for the variable gender

estimated that the likelihood that male infants initially grasped the round end of the tool was 4.48 times that for female infants ($p < .01$). Also, the odds ratio for the variable age estimated that the likelihood that infants initially contacted the round end of the tool increased by a factor of 1.01 for each one-unit (day) increase in their age and increased by a factor of 1.35 for each month (30-day) increase in their age ($p < .05$).

A 2 × 2 chi-square test of independence had tool type (spoon, novel tool) and grasp placement at initial contact (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(1, N = 101) = 10.88$, $p < .01$, indicated that when initially contacting the tool, infants were more likely to grasp the round end if they were using the novel tool (49.02%) as opposed to the spoon (18.00%).

Another chi-square test had gender (male, female) and grasp placement at initial contact (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(1, N = 101) = 6.79$,
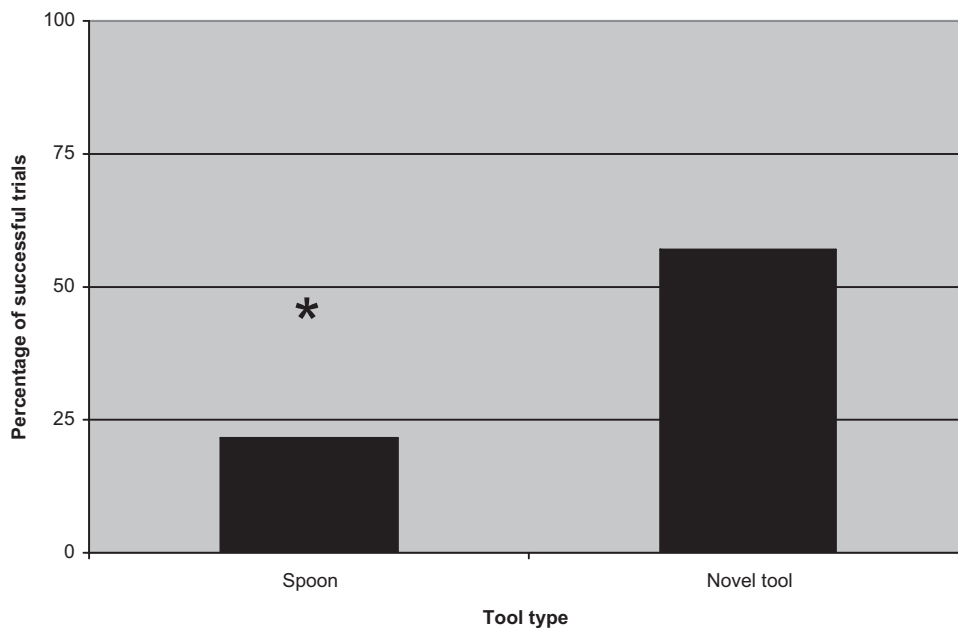

Figure 2. Results for Experiment 1: The percentage of successful trials (i.e., infants completing the target action) for each tool. * $p < .05$.

$p < .01$, indicated that when initially contacting the tool, male infants were more likely to grasp the round end (44.64%) than were female infants (20.00%). To assess whether infants of different genders initially grasped the tool differently depending on which tool was used, we conducted another chi-square test of independence holding tool type constant. The analysis of gender and grasp placement at initial contact for the spoon trials yielded a nonsignificant result, $\chi^2(1, N = 50) = 2.50, p > .05$, indicating no differences between the genders. Alternately, the analysis of gender and grasp placement at initial contact for the novel tool trials yielded a significant result, $\chi^2(1, N = 51) = 4.58, p < .05$, indicating that male infants were more likely to initially grasp the novel tool by the round handle (62.07%) than were female infants (31.82%).

A GEE analysis found two predictors of infants' grasp of the round end for their first attempt to reproduce the action: tool type and gender (see Table 1). The odds ratio for the variable tool type estimated that the likelihood that infants grasped the round end of the tool was 5.03 times greater for the novel tool trials as compared with the spoon trials ($p < .01$). In addition, the odds ratio for the variable gender estimated that the likelihood that male infants grasped the round end of the tool for their first attempt was 5.37 times that for female infants ($p < .01$).

A 2×2 chi-square test of independence had tool type (spoon, novel tool) and grasp placement at the initial attempt (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(1, N = 93) = 8.63, p < .01$, indicated that for the initial attempt, infants were more likely to grasp the round end of the tool in the novel tool trials (46.94%) than in the spoon trials (18.18%).

Another chi-square test had gender (male, female) and grasp placement at the initial attempt (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(1, N = 93) = 7.81, p < .01$, indicated that for the initial attempt, male infants were more likely to grasp the round end of the tool (46.00%) than were female infants (18.60%). To assess whether infants of different genders grasped the tool for the initial attempt differently depending on the tool that was used, we conducted another chi-square test of independence holding tool type constant. The analysis of gender and grasp placement for the initial attempt for the spoon trials yielded a nonsignificant result, $\chi^2(1, N = 44) = 2.02, p > .05$, indicating no differences in grasp placements between the genders. Alternately, the analysis of gender and grasp placement for the initial attempt for the novel tool trials yielded a significant result, $\chi^2(1, N = 49) = 6.20, p < .05$, indicating that male infants were more likely to grasp the novel tool by the round end (62.96%) than were female infants (27.27%).

Main analyses: Latencies. A GEE analysis did not find any of the independent variables to be predictors of the latencies for infants to initially contact the tool. However, on average, infants were found to be fairly quick to initially contact the tool ($M = 1.12$ s, $SD = 2.33$). In addition, none of the independent variables were found to be predictors of the infants' latencies to make their initial attempt. However, it may be inferred that infants were motivated to reproduce the action, because on average, their latencies were short ($M = 3.75$ s, $SD = 5.35$).

Main analyses: Perseveration. To assess the flexibility of infants' strategies used to reproduce the target action, we tabulated the number of times that infants perseverated in the incorrect strategy (grasped straight end, inserted round end). The number of

perseverative errors ranged from one to five incorrect attempts within one trial. The analyses revealed that infants perseverated in the incorrect strategy more in the spoon trials ($M = 0.72, SD = 1.19$) than in the novel tool trials ($M = 0.41, SD = 0.85$), $t(2) = 2.13, p < .05$.

Discussion

Infants showed differential performance in the light box task as a function of the tool that was used. They were significantly more likely to succeed in grasping the tool's round end to insert the straight end into the box and turn on the lights when using the novel tool than when using the spoon. Infants' failures with the spoon could not be attributed to task complexity, because infants were highly successful using either tool when the opening was large enough to accommodate either end. Moreover, there was no evidence that infants generalized the solution between the spoon and novel tool trials. The data revealed two additional factors that predict the infants' tool-directed actions.

Tool Effect

During the test trials, infants were unlikely to grasp the round end of the spoon at initial contact. Also, the analyses revealed that the infants frequently chose to grasp the spoon's straight end for their first attempt at activating the light box. In contrast, infants appeared to be much more flexible when grasping the novel tool for use, showing no biases for grasping a particular end.

Infants' inflexibility regarding the spoon can also be seen in the actions that were taken after their initial attempt to solve the task. Infants demonstrated more perseverative errors (repeatedly grasping straight end and applying the round end to the opening) throughout the spoon trials compared with the novel tool trials.

The infants' biases in handling the spoon suggest that prior experience with the spoon influenced their tool-directed actions. These biases are most likely a result of the large amount of experience that infants (in a Western culture) receive with this tool throughout the 1st year of life. From very early on, infants must observe others around them using spoons frequently for eating, scooping, stirring, and other actions. Infants are also usually being spoon-fed by their caregivers by 6 or so months of age. Finally, infants begin to spoon-feed themselves, usually after the first year of life, which furnishes them with practice in the motor skills necessary for spoon use. These experiences provide infants with a wealth of information about the functional properties of spoons and the mechanics of spoon use.

Gender Effect

The analyses of infants' responses on the test trials revealed an unexpected gender effect (see Table 2 for a summary). Female infants were less likely than the male infants to grasp the round end of the novel tool both at initial contact and at their initial attempt to solve the task but showed no appreciable differences in their grasps of the spoon. However, female infants were less likely than male infants to succeed in reproducing the target action with the spoon but showed no appreciable differences with the novel tool. This suggests that, initially, the female infants showed a straight handle preference with both the novel tool and the spoon for their

Table 2
Frequency Counts and Percentages of Female and Male Infants' Hand Placement on the Round End of Each Tool at Initial Contact, Initial Attempt, and Subsequent Success in Experiment 1

Behavior or outcome	Female infants		Male infants	
	Spoon	Novel tool	Spoon	Novel tool
Initial contact	2 of 23 (8.70%)	7 of 22 (31.82%)	7 of 27 (29.93%)	18 of 29 (62.07%)
Initial attempt	2 of 21 (9.52%)	6 of 22 (27.27%)	6 of 23 (26.09%)	17 of 27 (62.96%)
Success	2 of 23 (8.70%)	10 of 22 (45.45%)	9 of 28 (32.14%)	19 of 29 (65.52%)

first grasp of and their first action with the tool. However, at some point during the trial, the female infants demonstrated more flexibility in manipulating the novel tool, causing them to have the same success rates on the novel tool as the male infants. Their actions with the spoon did not show the same pattern. Instead, the male infants became more likely to grasp the round end of the spoon after their first attempt, which resulted in more successes using the spoon than there were for the female infants.

The question remains as to why female infants were relatively inflexible when using the spoon as compared with the male infants. Because female infants' success rate with the novel tool was not different from the male infants', it seems likely that the female infants' relatively poor performance was linked to an inflexibility in using the spoon in a novel way and not a general deficit in motor skills. One possibility is that infants of different genders receive different experiences with spoons. One study discovered that during the 1st year of life, male infants spent more time self-feeding (defined as bottle and finger foods) than female infants (Feng, Harwood, Leyendecker, & Miller, 2001). This finding could mean that female infants are spoon-fed by their caregivers for longer periods of time than are male infants. This might give female infants more opportunities to observe another's actions using spoons than male infants have. These extra opportunities may in turn strengthen the female infants' biases for grasping the straight end of the spoon and may also contribute to their straight-end bias when initially grasping the novel tool. Whatever is producing this difference between the genders seems to be tied to the infants' particular experiences with the tool, and this difference would be unlikely if the infants received similar experiences with the tool.

Age Effect

Lastly, the analyses revealed that age was a predictive factor in the infants' actions with the tools. Older infants were more likely to grasp the round end of the tools than younger infants for use in their first attempt to reproduce the action and, thus, were more likely to succeed in reproducing the action. This is not an unexpected result, because infants' motor and cognitive abilities are refined over time. This effect is not likely to be attributable to motor development, because infants throughout the age range were very skilled at completing the easy trials. Given the overall pattern of results, we think it is likely that these results reflect refinement in the infants' cognitive abilities, in particular an increase in flexibility. That is, infants may be more likely to understand that there are multiple ways to approach a problem, or they may be better able to incorporate multiple kinds of information into a motor plan. It is interesting to note that the older infants were not

significantly more likely to grasp the round end of the tool at their initial contact, but they were more likely to have their hands on the round end of the tool for their first attempt. This suggests that the younger infants were more likely to use the tool in the way that they first picked it up, but the older infants were flexible enough to adjust their grips before their first attempts to complete the action (for a similar finding, see McCarty et al., 1999). Thus, failure to activate the light box could be produced by a lack of inhibition of a trained (and reinforced) action of grasping the spoon's handle combined with a difficulty in altering this initial response when it proved unsuccessful.

Conclusions

Experiment 1 provided evidence that infants' prior experience with a tool influences their subsequent actions on the tool. Moreover, these actions with a familiar tool appear relatively inflexible when compared with actions using a novel tool. The critical experiences with the spoon could have been observations of others' spoon use, self-produced exploration of the spoon, or both. However, it could be claimed that something other than prior experience drove the differences in the way the infants manipulated the tools. For example, the spoon and the novel tool are not shaped exactly the same. There may be something inherently easier about grasping the handle rather than the bowl of the spoon, whereas the novel tool may be equally graspable at either end. This may have resulted in the infants demonstrating a bias for grasping the spoon handle while demonstrating no bias when grasping the novel tool. Although it seems unlikely that this could be the sole explanation behind the infants' behavior in this experiment, it would be beneficial to further investigate the role of experience in influencing infants' subsequent actions on tools.

Experiment 2

There are at least two kinds of learning that people can engage in when they are learning how to use a new tool. First, they may engage in grasp-specific learning. For example, after observing a spoon used in context or using it oneself, one can extract information about where and how to grasp the spoon to achieve the goal of eating (e.g., grasp with radial grip on the handle). Second, people may engage in functional learning. For example, when observing a spoon in use or using it oneself, one may learn about its functional possibilities (e.g., scooping, stirring) and not anything specific about how it is to be grasped.

Evidence from the adult literatures on functional brain organization and brain disorders supports this distinction, Brain-imaging

studies have revealed that observing tools strongly activates the left dorsal premotor cortex, and naming of tools activates the left ventral premotor cortex and left posterior parietal cortex, which are the brain regions responsible for aspects of visual–motor processing and, therefore, likely to be related to motor actions (Chao & Martin, 2000; Grafton, Fadiga, Arbib, & Rizzolatti, 1997; Kellenbach, Brett, & Patterson, 2003; Martin, Haxby, Lalonde, Wiggs, & Ungerleider, 1995). Also, it appears that the brain is wired to automatically retrieve information about how to grasp a tool, which has been shown to increase the efficiency of action by shortening response times (Tucker & Ellis, 1998, 2001).

Apraxia research provides support for the distinction between tool grasp and tool function (as well as the distinction between retrieving instructions for use from semantic memory and determining function directly from structure; see Goldenberg & Hagmann, 1998). Within the spectrum of apraxic disorders, there exists a division based on patients' behavioral deficits. Ideomotor apraxia encompasses disabilities in learned, skilled movement that cannot be explained by motor deficits, poor coordination, or the inability to retain semantic or motor representations. Patients enact maladaptive motor actions by selecting the inappropriate hand position or posture to use when manipulating or using familiar tools (Buxbaum, Sirigu, Schwartz, & Klatzky, 2003; Sirigu, Cohen, Duhamel, & Pillon, 1995). Patients with conceptual or ideational apraxia produce skillful actions with objects but actions that are functionally out of context (e.g., using a toothbrush like a spoon). That complementary deficits can be seen in ideomotor and conceptual apraxia suggests that grasp information and function information are dissociable in the brain (Johnson-Frey, 2004).

We designed Experiment 2 to give infants training with the novel tool from Experiment 1 in an effort to produce the kinds of grasping biases observed with the spoon in Experiment 1.[1] If we can successfully produce this bias experimentally, we can better understand the bias and compare it with other experimentally induced biases. To accomplish this goal, we had all of the infants in Experiment 2 receive experience using the novel tool for the same function—inserting it into a tube to dislodge some pom-poms. However, the infants experienced one of three different grasping conditions. One group was trained to use the round end as the handle, a second group was trained to use the straight end as the handle, and a third group received training with each of the handles on alternate days. After this experience, infants' use of each end of the novel tool was assessed in a transfer task. Because we wanted to determine what the infants learned about the tool (that it was to be used for inserting or that it was to be grasped on one end or the other), we structured the transfer tests to allow for the teasing apart of these factors. Specifically, we would be able to observe whether infants' performance was facilitated (relative to inexperienced controls) on a new insertion task or on a new task that required them to grasp the tool using the handle they had practiced grasping.

Method

Participants

Forty-eight 13- to 18-month-old infants participated in this experiment (12 per condition). The average ages and genders of the infants in each condition were as follows: round handle train-ing ($M = 16$ months, 0 days, $SD = 46$ days; 7 male, 5 female), straight handle training ($M = 15$ months, 20 days, $SD = 43$ days; 7 male, 5 female), dual handle training ($M = 15$ months, 18 days, $SD = 44$ days; 6 male, 6 female), and control ($M = 14$ months, 24 days, $SD = 43$ days; 6 male, 6 female). The ages were calculated using the date of each infant's test visit (second visit for training participants, first and only for control participants).

The demographics of the sample were as follows: 38 Caucasian infants, 2 African American infants, 4 African American/Caucasian infants, and 3 Asian/Caucasian infants. The highest obtained education levels of the infants' mothers are as follows: 1 had obtained a high school degree, 6 had completed some college education, 19 had obtained a degree from a 4-year college, and 21 had completed some postgraduate education. The highest obtained education levels of the infants' fathers were as follows: 1 had obtained a high school degree, 7 had completed some college education, 18 had obtained a degree from a 4-year college, and 21 had completed some postgraduate education. One infants' demographic information was incomplete. Two additional infants participated in this experiment but did not come into the laboratory for their follow-up visit and, therefore, were not included in these analyses.

Apparatus and Stimuli

There were several components to the at-home training set that the families received. The novel tool was the same one described in Experiment 1. One plastic tube measured 9.0 cm in length and had an opening that measured 2.5 cm in diameter. The other plastic tube measured 11.5 cm in length and had an opening that measures 4.5 cm in diameter.[2] The ends of the tube were covered with colored tape (green, red, yellow, or blue) to provide a smooth, safe edge. The pom-pom balls were standard craft grade, measuring 3 cm and 5 cm in diameter, and were in random colors. The task in the at-home training set was to use the novel tool to push the pom-pom balls out of the plastic tube.

During the laboratory visit, the caregiver, infant, and experimenter sat at the same table described in Experiment 1. For the buffer task, the infants were presented with four balls: a pink rubber ball (diameter = 6.5 cm); a clear, red plastic ball with a spinning picture inside (diameter = 6.5 cm); a blue, squishy plastic ball (diameter = 9.0 cm); and a purple and green, porcupine-like Koosh ball (diameter = 9.0 cm).

There were two test tasks in this experiment (see Figure 3). The same light box described in Experiment 1 was used for one task. The goal of this task was for the infant to grasp the round end of

---

[1] One cannot consider the experiences that infants get with the novel tool to be analogous to experiences that infants get with spoons. For instance, in most circumstances, infants' experiences with spoons take place every day over an extended period of time—spoons can be seen in varied contexts (e.g., feeding, stirring, scooping) and being used by a variety of people (e.g., older siblings, parents, strangers). The training experience with the novel tool will be relatively short, the tool will be used only in one context, and in most circumstances the tool will be seen being used by only one (or two) caregivers and the experimenter.

[2] The wider tube used larger pom-poms, so the tube had to be made slightly longer so as to dissuade the infants from using their hands to reach in and pull out the pom-poms.
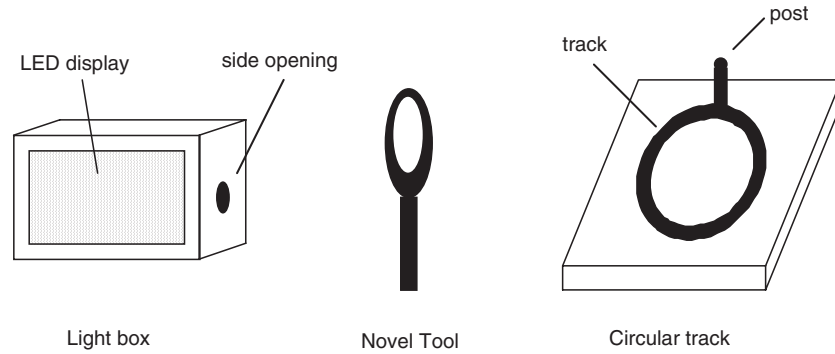
Figure 3. Stimuli for Experiment 2: The light box action consists of grasping the round handle of the novel tool and inserting the straight handle into the side opening, which activates the LED display. Conversely, the circular track action consists of grasping the straight handle of the novel tool and lassoing the round handle over the post, which can be pulled around the track.

the tool and insert the straight end into the side opening, which would cause an LED display to light up. The round end of the tool would not fit into the side opening. The other test task used a circular track that was constructed from a yellow wooden box (all sides 31 cm in length and 2.5 cm in height). There was a 1.5-cm-wide ring cut out of the top of the box 8 cm from the center of the box, and a red post 5 cm in height and 1 cm in diameter ran along the circular ring track. The goal of this task was to grasp the straight handle of the novel tool and lasso the round end over the red post and pull the post around the track, which caused a fun noise.

Procedure

Participating families came in for two laboratory visits. On the first visit, we assessed the infants' initial actions with the training objects to verify whether there existed any biases in use of the novel tool or if the infants spontaneously produced the training action. After this initial assessment, the experimenter demonstrated how to carry out the training by completing an infant's first session in the laboratory with the caregiver(s) present.

Families received one novel tool, one or two plastic tubes, and various pom-pom balls and were asked to play for approximately 5 min a day with the objects ($M = 34.72$ total min for the week, $SD = 9.15$) for a total of 7 days ($M = 6.33$ days, $SD = .93$).[3] They were instructed to supervise the events closely and to never leave the infant alone with the training objects. The training consisted of encouraging the infant to grasp the tool and insert it into the tube to push out pom-pom balls placed inside. Either the parents or the infant replaced the pom-pom balls inside the tube and the parents retrieved the tool and placed it down for the infant to repeat the action. Parents were asked to keep a daily log marking the duration of each training session as well as noting how many action sequences (picking up the tool and inserting it into the tube) the infant produced ($M = 42.53$ total actions for the week, $SD = 18.06$).[4]

The infants were randomly assigned to one of four conditions. In one condition, the tube was only large enough to fit the straight end of the tool inside; thus, parents trained the infants to grasp the round end of the tool and insert the straight end in the tube to perform the action. In another condition, the tube was large enough to fit both ends of the tool inside, and parents trained the infants to grasp the straight end of the tool and insert the round end of the tool in the tube to perform the action. In another condition, the families received both tubes and alternated using them and the different handles for the action on different days. After the at-home training sessions, participants came in for a laboratory visit to assess whether the training had an effect on how the infants used the tool. Lastly, there was also a control group that did not receive the at-home training experience and only participated in the second of the two laboratory visits.

The families returned for a second laboratory visit approximately 1 week later ($M = 7.25$ days, $SD = 0.77$). First, we conducted a trial on which the parents enacted a typical training session so that we could evaluate whether the at-home training had been performed correctly. To establish some distance between the actions that the infant produced with the novel tool on this trial and future trials, the experimenter gave the infant a buffer task that did not include the use of the novel tool. The experimenter presented four balls sequentially to the infant for grasping and exploration. The balls were retrieved before continuing with future trials.

Next, the experimenter presented the tool and test apparatus to the infant for 30 s (baseline trial). This served the purpose of determining whether the infant spontaneously performed the target action. The tool was presented vertically in front of the infant, with the test apparatus just behind the tool. The handle that should be grasped to complete the action was presented closest to the infant; thus, for the baseline light box trials the round handle was closest to the infant, and for the baseline circular track trials the straight handle was closest to the infant.

---

[3] The by-condition breakdown was as follows: round handle: $M = 40.25$ min ($SD = 13.20$, range = 26–70); straight handle: $M = 31.33$ min ($SD = 4.68$, range = 23–40); and dual handle: $M = 32.58$ min ($SD = 4.40$, range = 26–39).

[4] The by-condition breakdown was as follows: round handle: $M = 32.25$ actions ($SD = 9.29$, range = 23–45); straight handle: $M = 54.86$ actions ($SD = 23.08$, range = 11–80); and dual handle: $M = 36.88$ actions ($SD = 9.80$, range 22–53).

The order of the two test tasks was counterbalanced. All of the infants received both test tasks within one laboratory session. For each test trial, the infants saw two demonstrations of the action and then received 30 s to replicate the demonstration, after which the objects were retrieved and the trial ended. One task was activating the light box from Experiment 1, and the procedure was almost exactly the same, with the exception that only the small opening was used, requiring the straight end of the tool to be inserted. After the experimenter gave the infant 30 s to replicate the demonstration, the tool and light box were retrieved and the trial ended. If the infant was off task during the trial, the experimenter pointed to the opening and said, "Can you do it too?" The second task involved grasping the straight end of the tool and lassoing the round end of the tool over a post and pulling it along a circular track, which produced an interesting noise. After the experimenter gave the infant 30 s to replicate the demonstration, the tool and circular track were retrieved and the trial ended. If the infant was off task during the trial, the experimenter pointed to the post and said, "Can you do it too?" Each infant received two trials for each test task. The tool's position when presented in front of the infant alternated for the two trials (once with the straight end on the infant's right, once with the straight end on the infant's left).

Measures

The measures were the same as in Experiment 1. Data from a subset of all participants ($n = 8$; 2 infants randomly selected from each training condition) were recoded by a trained observer, who was unaware of the goals or hypotheses of this experiment. Reliability for quantitative data was calculated by means of Pearson's product–moment correlation. The range of agreement for these variables was .83–.94 ($M = .89$). Reliability for qualitative data was calculated by means of Cohen's Kappa. The range of agreement for these variables was .92–1.0 ($M = .96$).

Results

Preliminary analyses. Analyses of the baseline trials revealed that infants were unlikely to spontaneously reproduce the target action for either task (4 times out of 44 trials for the light box trials, 6 times out of 42 trials for the circular track trials) without a demonstration. The limited number of successes were distributed nearly equally over the four training conditions.

The light box and circular track trials were analyzed separately using the same GEE analysis procedure and chi-square test of independence as in Experiment 1.[5] The independent variables of interest were as follows: gender, age, task order, and training condition (between-subjects) and trial (within-subject).

Light Box Trials

Main analyses: Success. A GEE analysis found two predictors of infants' success in reproducing the target action: round handle training and dual handle training (see Table 3). The odds ratio estimated that the likelihood that infants succeeded in reproducing the action was 70.81 times greater when the infants were trained in the round handle grasp than if they had no previous training with the tool ($p < .001$). In addition, the likelihood that infants succeeded in reproducing the action was 5.62 times greater when the

infants were trained in the dual handle condition than if they had no previous training with the tool ($p < .05$). This analysis did not find training in the straight handle condition to predict for differences in success at reproducing the action compared with the control condition.

As a follow-up, the data were analyzed by means of 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and success (yes, no) as between-subjects factors. This analysis, $\chi^2(3, N = 96) = 32.25$, $p < .001$, indicated significantly different patterns of success depending on the training the infants received (see Figure 4). A 2×2 chi-square test of independence on training condition (round handle, straight handle) and success (yes, no), $\chi^2(1, N = 48) = 20.49$, $p < .01$, indicated that infants who received the round handle training performed significantly better (95.83%) than the infants who received the straight handle training (33.33%).

Main analyses: Grasp placements. A GEE analysis found two predictors of infants' grasp of the round end at initial contact with the tool: round handle training and dual handle training (see Table 3). The odds ratio estimated that the likelihood that infants initially grasped the round handle was 3.79 times greater when the infants were trained in the round handle grasp than if they had no previous training with the tool ($p < .05$). In addition, the likelihood that infants grasped the round handle was 3.56 times greater when the infants were trained in the dual handle condition than if they had no previous training with the tool ($p < .05$). This analysis did not find the odds of infants initially grasping the round handle of the tool to be different for the straight handle training and control conditions.

As a follow-up, the data were analyzed by means of 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and grasp placement (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(3, N = 96) = 9.80$, $p < .05$, indicated significantly different initial grasp patterns depending on the training the infants received. A 2×2 chi-square test of independence on training condition (round handle, straight handle) and grasp placement (grasps round end, grasps other), $\chi^2(1, N = 48) = 5.49$, $p < .05$, indicated that infants who received the round handle training were more likely to grasp the round end of the tool at initial contact (58.33%) than were the infants who received the straight handle training (25.00%).

A GEE analysis found two predictors of infants' grasp of the round end for their initial attempt: round handle training condition and gender (see Table 3). The odds ratio estimated that the likelihood that infants grasped the round handle for the initial attempt was 5.82 times greater when the infants trained in the round handle grasp than if they had no previous training with the tool ($p < .05$).

As a follow-up, the data were analyzed by means of 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and grasp placement at initial attempt (grasps round end, grasps other) as between-

---

[5] Note that it was necessary to dummy-code the variable training condition for the GEE analyses. The control group was used as the baseline comparison; thus, these analyses predicted for differences in the three other conditions (round handle, straight handle, and dual handle) as compared with the control group.

Table 3

Summary of GEE Analysis for Variables Predicting Infants' Success in Reproducing the Action and Producing the Correct Grasp Placement at Initial Contact and Initial Attempt to Reproduce the Action for the Light Box Trials in Experiment 2 (N = 48)

Variable	Success				Grasp placement at initial contact				Grasp placement at initial grasp			
	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	e^b	CI (odds)
Training												
Round handle	4.26**	1.23	70.81	6.24–803.52	1.33*	0.66	3.79	51.04–13.83	1.76*	0.79	5.82	1.24–27.25
Straight handle	0.44	0.76	1.55	0.35–6.84	−0.05	0.69	0.95	0.24–3.68	0.02	0.84	1.55	0.20–5.24
Dual handle	1.73*	0.75	5.62	1.30–24.32	1.27*	0.64	3.56	1.02–12.45	1.20	0.76	3.31	0.74–14.71
Trial	−0.66	0.46	0.52	0.21–1.28	−0.30	0.46	0.74	0.30–1.84	−0.85	0.49	0.43	0.17–1.11
Gender	−0.64	0.63	0.53	0.15–1.81	−0.36	0.50	0.69	0.26–1.85	−1.36*	0.67	0.26	0.07–0.94
Order	−0.46	0.63	0.63	0.18–2.18	−0.71	0.50	0.49	0.18–1.31	−0.77	0.65	0.47	0.13–1.66
Age	0.01	0.01	1.01	0.99–1.02	0.01	0.01	1.01	1.00–1.02	0.01	0.01	1.01	1.00–1.02
Constant	−3.54	2.98			−3.52	2.30			−3.24	2.81		

Note. The variable training condition was dummy-coded using the control group as the baseline comparison. GEE = generalized estimating equations; CI = confidence interval.
* $p < .05$.   ** $p < .01$.

subjects factors. This analysis, $\chi^2(3, N = 81) = 10.35$, $p < .05$, indicated significantly different initial grasp patterns depending on the training the infants received. A 2 × 2 chi-square test of independence on training condition (round handle, straight handle) and grasp placement (grasps round end, grasps other), $\chi^2(1, N = 40) = 6.08$, $p < .05$, indicating that infants who received the round handle training were more likely to grasp the round end of the tool for their initial attempt (70.83%) than were infants who received the straight handle training (31.25%).

Gender was also found to be a predictor of grasp placements for the infants' initial attempt at reproducing the light box action. The odds ratio estimated that the likelihood that male infants grasped the round handle for their initial attempt was 3.90 times that for

female infants ($p < .05$). This analysis did not find infants with training in the straight handle grasp or dual handle to initially grasp the round end of the tool more or less than did infants in the control condition.

As a follow-up, the data were analyzed by means of 2 × 2 chi-squared test of independence with gender (male, female) and grasp placement at initial attempt (grasps round end, grasps other) as between-subjects factors. This analysis, $\chi^2(1, N = 81) = 2.22$, $p > .05$, indicated that there were no significant differences in grasp placements at the initial attempt to reproduce the light box action for male or female infants.

Main analyses: Latencies. A GEE analysis did not find any of the independent variables to be predictors of the infants' latencies
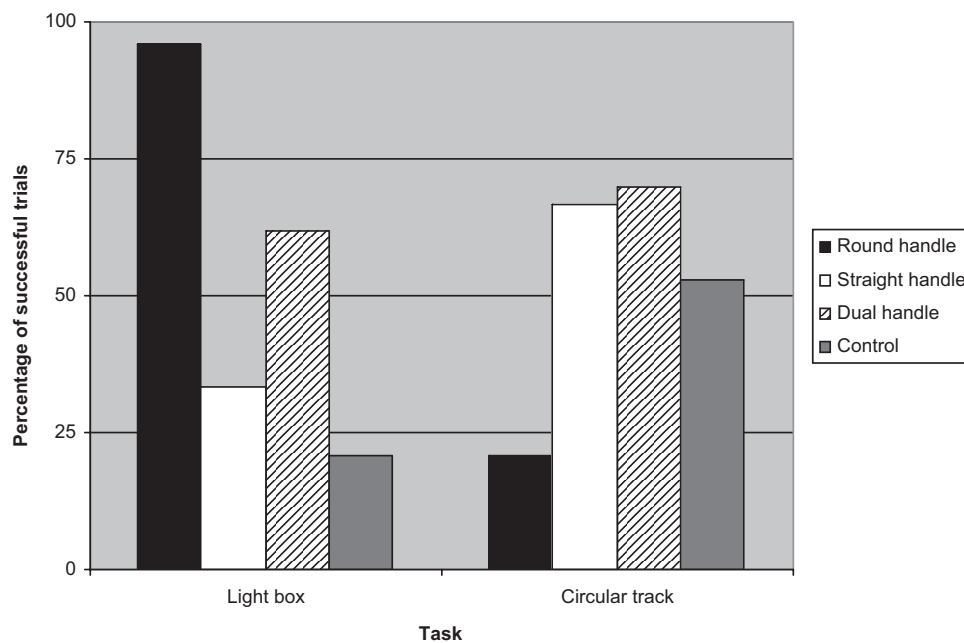

Figure 4. Results for Experiment 2: The percentage of successful trials (i.e., infants completing the target action) for each of the two tasks by training condition.

to initially contact the tool. However, overall, infants had short latencies to initially contact the tool ($M = 1.01$ s, $SD = 1.57$). In addition, a GEE analysis did not find any of the independent variables to be predictors of the latencies for infants' to make their initial attempt. Overall, the infants had short latencies to make their first attempt at the action, suggesting that they were engaged in the task ($M = 3.96$ s, $SD = 2.97$).

Main analyses: Perseveration. To assess the flexibility of infants' strategies to reproduce the target action, we tabulated the number of time infants perseverated in the incorrect strategy (grasped straight end, inserted round end) and compared across training conditions, $F(3, 92) = 4.88$, $p < .005$. The number of perseverative errors ranged from one to five incorrect attempts within one trial. Infants who received the round handle training perseverated in the incorrect strategy the least ($M = 0.33$, $SD = 0.92$) compared with the infants in the straight handle training ($M = 0.83$, $SD = 1.27$), dual handle training ($M = 0.75$, $SD = 1.54$), and control groups ($M = 2.00$, $SD = 2.28$), $t(1) = 2.21$, $p < .05$.

Circular Track Trials

Main analyses: Success. A GEE analysis found one predictor of infants' success: round handle training (see Table 4). The odds ratio estimated that the likelihood that infants who were trained in the round handle grasp succeeded was 0.20 that for the infants who had no previous training with the tool ($p < .05$). This analysis did not find training in the straight handle or dual handle conditions to predict the infants' performance as compared with the control condition.

As a follow-up, the data were analyzed by means of 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and success (yes, no) as between-subjects factors. This analysis, $\chi^2(3, N = 96) = 14.85$, $p < .01$, indicated significantly different patterns of success depending on the training the infants received (see Figure 4). A 2×2 chi-square test of independence on training condition (round handle, straight handle) and success (yes, no), $\chi^2(1, N = 48) =$

10.24, $p < .01$, indicated that infants who received the straight handle training were more likely to succeed (66.67%) than were infants who received the round handle training (20.83%).

Main analyses: Grasp placements. A GEE analysis found no predictors of infants' initial grasp of the straight end at initial contact. However, we conducted a 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and grasp placement at initial contact (grasps straight end, grasps other) as between-subjects factors to assess a differential pattern across all four groups. This was warranted because the initial GEE analysis only compared each training group against the control group and not against each other. This analysis, $\chi^2(3, N = 94) = 6.22$, $p = .09$, indicated a trend for differential initial grasp patterns depending on the training the infants received. A 2×2 chi-square test of independence on training condition (round handle, straight handle) and grasp placement (grasps straight end, grasps other), $\chi^2(1, N = 48) = 5.49$, $p < .05$, indicating that infants who received the straight handle training were more likely to grasp the straight end of the tool at initial contact (75.00%) than were infants who received the round handle training (41.67%).

Next, a GEE analysis found one predictor of infants' grasp of the straight end of the tool for their initial attempt: round handle training (see Table 4). The odds ratio estimated that the likelihood that infants who received the round handle training grasped the straight handle for their initial attempt was 0.05 that for the infants who had no previous training with the tool ($p < .05$).

As a follow-up, the data were analyzed by means of 4×2 chi-square test of independence with training condition (round handle, straight handle, dual handle, control) and grasp placement at initial attempt (grasps straight end, grasps other) as between-subjects factors. This analysis, $\chi^2(3, N = 77) = 17.18$, $p < .01$, indicated significantly different initial grasp patterns depending on the training the infants received. A 2×2 chi-square test of independence on training condition (round handle, straight handle) and grasp placement (grasps straight end, grasps other), $\chi^2(1, N = 42) = 7.83$, $p < .05$, indicated that infants who received the

Table 4
Summary of GEE Analysis for Variables Predicting Infants' Success in Reproducing the Action and Producing the Correct Grasp Placement at Initial Attempt to Reproduce the Action and Latency to Produce Initial Attempt to Reproduce the Action for the Circular Track Trials in Experiment 2 (N = 48)

Variable	Success				Grasp placement at initial attempt				Latency to produce initial attempt			
	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	e^b	CI (odds)	B	$SE\ B$	Z	p
Training												
Round handle	-1.60^*	0.92	0.20	0.03–1.23	-3.07^*	1.25	0.05	0.00–0.53	-0.49	1.87	-0.26	.79
Straight handle	0.37	0.85	1.45	0.27–7.73	-1.24	1.28	0.29	0.02–3.53	0.91	1.90	0.48	.63
Dual handle	0.34	0.84	1.41	0.27–7.32	-1.48	1.27	0.23	0.02–2.74	-3.85^*	1.91	-2.01	.04
Trial	0.20	0.13	1.22	0.95–1.57	-0.22	0.50	0.80	0.30–2.12	1.37	0.99	1.38	.17
Gender	-0.02	0.63	0.98	0.29–3.35	0.38	0.69	1.47	0.38–5.70	1.90	1.31	1.45	.15
Order	-0.08	0.09	0.93	0.78–1.10	0.11	0.31	1.12	0.60–2.07	0.00	0.12	0.00	1.00
Age	0.01	0.01	1.00	0.99–1.01	0.00	0.01	1.00	0.98–1.01	-0.02	0.02	-1.55	.12
Constant	0.39	3.23			3.02	3.69			15.16	7.03		

Note. The variable training condition was dummy-coded using the control group as the baseline comparison. GEE = generalized estimating equations; CI = confidence interval.
$^* p < .05$.

straight handle training were more likely to grasp the straight end of the tool for their initial attempt (76.19%) than were infants who received the round handle training (31.82%).

Main analyses: Latencies.   A GEE analysis did not find any of the independent variables to be predictors of the latencies for infants' to initially contact the tool. Overall, infants were relatively quick to contact the tool ($M = 1.26$ s, $SD = 3.64$). However, a GEE analysis found one significant predictor of infants' latencies to initially attempt the action: dual handle training (see Table 4). Infants who trained in the dual handle condition had shorter latencies to make their initial attempt ($M = 2.59$ s, $SD = 1.73$) than infants who did not have any prior experiences with the tool ($M = 6.00$ s, $SD = 5.77$). Infants who trained in the round handle grasp ($M = 4.97$ s, $SD = 5.61$) and the straight handle grasp ($M = 6.44$ s, $SD = 5.65$) had latencies to initially attempt the action similar to those of the control group.

Main analyses: Perseveration.   To assess the flexibility of infants' strategies to reproduce the target action, we tabulated the number of time infants perseverated in the incorrect strategy (grasped round end, used straight end) and compared by training condition, $F(3, 92) = 18.01$, $p < .0001$. The number of perseverative errors ranged from one to three incorrect attempts within one trial. Infants who received the round handle training perseverated in the incorrect strategy the most ($M = 1.29$, $SD = 1.08$) compared with the infants in the straight handle training ($M = 0.21$, $SD = 0.51$), dual handle training ($M = 0.08$, $SD = 0.28$), and control groups ($M = 0.17$, $SD = 0.48$), $t(1) = 4.24$, $p < .0001$.

Discussion

The results of this experiment are consistent with the perspective that grasping information takes precedence in infants' action on tools: Infants' actions in test were strongly influenced by the handle that they grasped in training. The analyses revealed that infants who received the round handle training were more likely than infants in the control group to succeed in the light box task (which required a round handle grasp for success) but less likely than infants in the control group to succeed in the circular track task (which required a straight handle grasp for success). This differential pattern of success can be attributed to the infants' likeliness to grasp the round handle both at initial contact with the tool and for their initial attempt to perform the action.

Infants who received the straight handle training did not perform differently than infants in the control group. This can be attributed to the control group's tendency to grasp the straight handle of the tool and their relatively high success rate on the circular track task and low success rate on the light box task. This tendency was not a result of having the circular track trials first, which could have provided experience grasping the straight handle. When the control group's successful actions on the light box were examined, they were about equally distributed between infants who received the circular track first ($n = 2$) and the light box first ($n = 3$). Although the control group's success and grasping patterns were unexpected because of the results from the control condition in Experiment 1, the effect of training remains apparent—infants who received the straight handle training did have notably different patterns for both tasks than did infants who trained in the round handle grasp. Whether infants have a baseline tendency to grasp the straight

handle of the novel tool is not clear from the results of these two experiments and is discussed further in the General Discussion.

The behavior patterns exhibited by the infants who trained with both handles of the tool provided additional support for the perspective that grasping information takes precedence over function in guiding infants' tool-directed actions. Experience using both handles resulted in more successful performances (i.e., more successes than in the control group) on both test tasks. In addition, for the light box trials, these infants' performance did not surpass that of the infants who trained in the round handle grasp. However, the infants' performance did slightly surpass that of those infants who trained in the straight handle grasp for the circular track task. As mentioned above, the caregivers noted that the infants often preferred to grasp the straight handle for their at-home training, especially in the dual handle condition. One might conclude from this that the infants excelled in the task that required the straight handle grasp because of increased motivation or attention during the training when grasping the tool in the preferred manner.

Examination of the infants' perseverative errors provided additional evidence that infants integrated grasping information into their tool use in the test trials. Infants who received the round handle training demonstrated more perseverative errors on tasks that required a different grasp placement on the tool than the one required in training. That is, they showed the highest levels of perseverative errors in the circular track task and the lowest levels of perseverative errors in the light box task. These infants did not often change their strategies, despite producing unsuccessful attempts with the tool.

Lastly, the analyses revealed that infants who received the dual handle training were significantly faster to make an initial attempt at reproducing the action, but only for the circular track task. This effect could signify that the dual handle training provided some unforeseen benefit to the infants. Perhaps infants who received the dual handle training learned that the tool could be used for multiple purposes, and therefore, they may have been more ready to replicate any action with the tool, even if it was not one of the actions from the training session. Alternately, the infants' slight straight handle bias may have resulted in more efficient use of the tool when grasped by the straight handle.

Two conclusions can be drawn from the patterns of behavior that the infants exhibited in this experiment. First, the infants' differential patterns of successes and failures reproducing the correct action for the two transfer tasks suggest that grasping experience takes precedence over functional experience in early tool use. Second, the experiences that infants received in the at-home training sessions were effective in establishing biases in grasping and using the tool in the laboratory. From this, one may infer that infants store information based on prior experiences with a tool and that this information influences their future actions with the tool.

General Discussion

The present experiments examined infants' actions with tools to investigate set tendencies for tool use and to probe the flexibility versus rigidity of these action patterns. We addressed these issues in Experiment 1 by examining how infants used a familiar tool for a novel task compared with their use of a novel tool for this same task. In a follow-up experiment, infants were given specific train-

ing with the novel tool, and the their performance was assessed on two transfer tasks that required different manipulations of the tool. Several conclusions can be drawn from the results of these experiments.

First, infants do have biases that affect their initial actions on a tool. The results of Experiment 1 indicated that infants have biases for grasping a spoon at its handle rather than at its bowl. In contrast, the infants did not show a bias for grasping one particular end of a tool that they had not seen or used before. Thus, the infants were shown to be flexible when using the novel tool for the target action, often grasping the round end. This resulted in more successful reproductions of the target action when using the novel tool than when using the spoon. Evidence for the influence of learning can also be seen in Experiment 2. Those infants who trained to grasp a specific handle were more likely to use that handle when grasping the tool in the laboratory test session, even if it was inappropriate for the goal. Infants in both experiments who demonstrated a grasping bias were also likely to perseverate in incorrect tool-use strategies (sometimes up to five times during a 30-s trial!). This provides convincing evidence that infants do use prior experiences to inform their actions and that what they have learned is applied rigidly.

The analyses from Experiment 1 revealed that age and gender were significant predictor variables of success in reproducing the task and the location of the infants' grasp placements; however, the analyses of Experiment 2 did not show the same pattern of results. What we conclude from this set of findings is that when infants receive similar experiences with a tool, as they did in Experiment 2 (i.e., approximately the same duration and number of self-produced actions on the tools), behavioral differences due to gender and age are not observed. This suggests that the different patterns in behavior by male and female infants and younger and older infants from Experiment 1 might have been tied to the quality and/or quantity of experiences they received with spoons outside the laboratory.

The other main focus of these experiments was what infants learn about tool use. These experiments suggest that grasping experience (as opposed to functional information) takes precedence in infants' learning about and actions on tools. Experiment 2 showed that training in a specific grasp placement facilitated infants' performance in tasks on which the correct tool use matched the grasp placement in training, and it resulted in poorer performance in tasks on which successful tool use required a novel grasp placement. In addition, the infants who received the dual handle training performed well in both tasks. Conversely, the hypothesis for the primary role of functional information was not supported: Infants' performance was not uniformly enhanced in the task that required the tool to be used for the same function as it was in training.

Handle Biases

Why did the infants in Experiment 1 imitate the experimenter's actions on the novel tool but not on the spoon? There are many possible answers to this intriguing question. Certainly the most obvious answer is *because infants know that you grasp a spoon by its handle*. But what does this answer mean? One possibility is that infants acquire knowledge about tools and draw on this knowledge to plan their actions on new tools. This knowledge base might

include grasping information (e.g., where a tool is grasped) and function information (e.g., under what circumstances you reach for that tool vs. a different one), but it would also potentially include information about how heavy a tool is likely to be (e.g., a hammer vs. a flyswatter) or how dirty it is likely to be (e.g., a flyswatter vs. a spatula; for more ideas along these lines, see Creem & Proffitt, 2001; Goldenberg & Hagmann, 1998).

Another possibility is less conceptual—that infants have more of an automatic response that produces a handle grasp in the context of a familiar handled tool and that this response is difficult to inhibit. This idea is akin to the priming of grasping instructions when simply viewing a tool that has been shown in adults (we discuss this further in the next section). However, because infants have limited cognitive resources, they may be less able to override the primed grasping information or, alternately, less able to attend to the relevant grasping information in the demonstration because it conflicts with their previous experiences.

It is also possible that graspability played a role in the behavior we observed. That is, perhaps the spoon's perceived graspability was greatest at its handle, but the novel tool seemed about equally graspable at both ends. One problem with this argument is that the infants in Experiment 2 apparently did not regard both ends of the novel tool as equally graspable, and it does not seem as though perceived graspability of the same tool should vary much from infant to infant. So, the extent to which graspability was driving the infants' behavior with these objects remains unclear.

Another question related to graspability is whether infants this age tend to identify a particular part (e.g., a straight, thin part) of an object as its handle. Despite our best intentions to construct a tool with two equally graspable handles, and despite the fact that infants in Experiment 1 showed no biases in grasping the tool, the infants in Experiment 2 demonstrated a tendency to grasp the straight handle of the tool. This resulted in infants in certain training conditions showing behavior patterns that were not significantly different from those of infants in the control group, as was originally predicted. Grasping biases could be attributable to a number of factors, including the similarity of the tool's structure to that of a spoon, the variety of handled objects that infants had encountered in the past, or the ease with which infants can manipulate a straight handle versus a round handle. These results do look like mixed evidence for a straight handle–grasping preference. It may be that the 12–18-month age range is when infants have enough experience grasping handled objects to begin to expect that the straight thin part of a novel object is its handle. This set of experiments do not allow us to decide among all the possibilities of why the infants were inflexible in using familiar tools in novel ways; however, we believe this question warrants further exploration.

The results of these experiments have implications for the conceptualization of early tool use. Experience with multiple ways of grasping a tool results in increased levels of flexibility with the tool. However, this flexibility comes at the expense of attaining high levels of success on one particular use of the tool. Consequently, training in one specific manipulation creates a highly skilled infant in similar contexts, but it does so at the expense of flexibility in grasping and using the tool in different ways. It is obvious that infants do not have the cognitive capacity and flexibility that adults do, but it is interesting to note that even adults show similar inflexibility in Duncker's (1945) classic *candle-*

mounting task, which elicits functional fixedness. Whether our infants had a version of functional fixedness is as yet unclear. Some evidence suggests that functional fixedness is acquired over the preschool period (German & Defeyter, 2000), but one possibility is that the extent to which tool use is rigid or flexible has more to do with the user's experience with and/or knowledge about the tool than it does with their age. Thus, we ought to be able to find other situations in which less experience or knowledge actually support more flexible actions with tools at various points in development. In light of the present results, it seems counterproductive to assign a specific age to the development of functional fixedness.

Biological Bases of Tool Use

How do people go from seeing a tool to enacting the actions that allow them to use the tool appropriately? Visual information from the tool is processed, along with information about the goal for using the tool, to guide their actions. Neuropsychologists have determined that the human visual system is composed of two neural pathways of visual processing: the ventral pathway, which is active during the visual identification or recognition of objects, and the dorsal pathway, which is active during the processing of visual information that is relevant for acting on an object (Milner & Goodale, 1995; Ungerleider & Haxby, 1994). Although studies have shown a double dissociation between the activity of these pathways, indicating some degree of independence between them, there are many situations in which the processing done by one pathway must depend on that done by the other (Creem & Proffitt, 2001; Johnson-Frey, 2004). One can reach for a novel object without relying on stored information, but in the case of using a familiar tool in an appropriate way, one typically needs to access information about the identity of the object to know how best to grasp it for effective use.

Creem and Proffitt (2001) provided evidence for the interdependence of these two forms of processing in tool-use tasks by using a dual-task paradigm. Faced with a distractor task that taxed processing along the ventral pathway, adults reaching for a handled tool were less likely to grasp the tool in a functional way than were participants in a control group. Thus, grasping a tool must involve ventral stream processing. In addition, brain insults along the dorsal and ventral pathways have been shown to disrupt aspects of visual processing, which can subsequently hinder the production of functional behavior on objects. For instance, apraxia is a disorder of purposeful movement that cannot be explained by muscular or intellectual disabilities. During tool use, individuals with apraxia often make manual errors such as poorly placing or orienting their hand or arms or enacting only partially correct behaviors (Buxbaum, Schwartz, & Carew, 1997; Carey, Harvey, & Milner, 1996; Goldenberg & Hagmann, 1998; Sirigu et al., 1995).

The results of the present experiments raise the question of why infants learn about how a tool should be grasped prior to learning the tasks for which it might be useful. As suggested in neuropsychological literature, motor areas of the brain are automatically activated during the perception of tools. This priming of grasping information facilitates faster responses. Research on stimulus–response compatibility is a good example of how manual behaviors can be facilitated by such priming (Tucker & Ellis, 1998, 2001). From an evolutionary perspective, this could be the edge

that was necessary for survival, perhaps in circumstances in which swift action with tools was needed (e.g., fighting, hunting).

Moreover, for the most part, the way one grasps a tool will be consistent across different uses. For example, a spoon is held by the handle for multiple actions, like stirring, scooping, and eating. The same grasping information would be strengthened across different functional uses. However, the specific function a tool is used to accomplish may vary from task to task. As in the example above, the way the spoon is applied to objects in the various tasks will be different. Thus, those associations would not be strengthened as much.

Amount of Exposure

What does it mean that grasping information is learned and applied rigorously after only about 35 min of exposure time? We believe this suggests that the acquisition of grasping information is of primary importance in early infancy. Evidence from other areas of development also highlights the early emergence of abilities related to motion and action. At a very early age, infants attend to and use information regarding object motion. For instance, infants demonstrate the ability to obtain a moving target when they first begin to obtain stationary objects (von Hofsten & Lindhagen, 1979). Also, it has been suggested that self-produced actions constrain aspects of perceptual development (Bushnell & Boudreau, 1993; Held & Hein, 1963). There is little doubt that the ability to perceive and use aspects of motion and action is fundamental to the development of the human infant.

Even if grasping information is acquired rapidly and shown to impact infants' behaviors, this does not imply that these biases are particularly strong or long lasting. Infants at this age may have difficulty overriding even weak biases that are automatically retrieved during the perception of tools. Future research could investigate the persistence of grasping biases over time or investigate the number of trials it would take for infants to reverse any biases that were established.

In addition, it would be revealing to investigate the role that self-produced actions with tools have in establishing grasping biases and to contrast this with observing other-produced actions with tools. That is, how crucial is it to have actually manipulated the tool to establish these biases? Will infants who have only observed tool use be more flexible in their manipulations with the tool than infants who have established some motor memory for the action from having produced the actions themselves? It may be that observing actions highlights functional information, because the infants will not have experienced the grasping relationship directly. Currently, our laboratory is following up with several of these research questions.

These findings are similar to several recent sets of results in the infant cognition literature that show effects of experiences prior to testing on infants' responses to the test events (e.g., Needham, Dueker, & Lockhead, 2005; Sommerville, Woodward, & Needham, 2005; Wang & Baillargeon, 2005; Wilcox & Chapa, 2004). These findings, along with the present findings, show the important role that learning plays in infants' early representations of objects and events. Whether the procedure is called *priming* (and is relatively brief) or *training–learning* (and is more protracted), these results reveal a remarkable capacity for flexibility in infants' knowledge. Infants' accumulated knowledge is not static and brit-

tle but, rather, fluid and flexible, easily modified by new and relevant encounters.

Final Comments

The experiments reported in this article set out to explore the effects of knowledge on tool-directed actions in infancy. At an early age, humans use their experiences to act on tools. In most circumstances, these experiences help to make their actions more flexible and adaptive, but in other circumstances, these experiences saddle individuals with a degree of "tunnel vision" and render strategies inflexible and ineffective. Learning more about this fascinating process may reveal important interactions among perception, action, and cognition in infancy and may bring to light previously unsuspected continuities in these processes among infants, adults, and other animals.

References

Adolph, K. E., & Berger, S. E. (in press). Motor development. In W. Damon & R. Lerner (Series Eds.) & D. Kuhn & R. S. Siegler (Vol. Eds.), *Handbook of child psychology, Vol. 2: Cognition, perception, and language* (6th ed.). New York: Wiley.

Berger, S. E., & Adolph, K. E. (2003). Infants' use of handrails as tools in a locomotor task. *Developmental Psychology, 39,* 594–605.

Bushnell, E., & Boudreau, J. P. (1993). Motor development and the mind: The potential role of motor abilities as a determinant of aspects of perceptual development. *Child Development, 64,* 1005–1021.

Bushnell, E. W., & Boudreau, J. P. (1998). Exploring and exploiting objects with the hands during infancy. In K. J. Connolly (Ed.), *The psychobiology of the hand* (pp. 144–161). London: Mac Keith Press.

Buxbaum, L. J., Schwartz, M. F., & Carew, T. G. (1997). The role of semantic memory in object use. *Cognitive Neuropsychology, 14,* 219–254.

Buxbaum, L. J., Sirigu, A., Schwartz, M. F., & Klatzky, R. (2003). Cognitive representations of hand posture in ideomotor apraxia. *Neuropsychologia, 41,* 1091–1113.

Carey, D. P., Harvey, M., & Milner, A. D. (1996). Visuomotor sensitivity for shape and orientation in a patient with visual form agnosia. *Neuropsychologia, 34,* 329–337.

Chao, L. L., & Martin, A. (2000). Representation of manipulable man-made objects in the dorsal stream. *NeuroImage, 12,* 478–484.

Claxton, L. J., Keen, R., & McCarty, M. E. (2003). Evidence of motor planning in infant reaching behavior. *Psychological Science, 14,* 354–356.

Clifton, R. K., Rochat, P., Litovsky, R. Y., & Perris, E. E. (1991). Object representation guides infants' reaching in the dark. *Journal of Experimental Psychology: Human Perception and Performance, 17,* 323–329.

Connolly, K., & Dagleish, M. (1989). The emergence of a tool-use skill in infancy. *Developmental Psychology, 25,* 894–912.

Creem, S. H., & Proffitt, D. R. (2001). Grasping objects by their handles: A necessary interaction between cognition and action. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 218–228.

Duncker, K. (1945). On problem-solving. *Psychological Monographs, 58*(5, Whole No. 270).

Feng, X., Harwood, R. L., Leyendecker, B., & Miller, A. M. (2001). Changes across the first year of life in infants' daily activities and social contacts among middle-class Anglo and Puerto Rican families. *Infant Behavior and Development, 24,* 317–339.

German, T. P., & Defeyter, M. A. (2000). Immunity to functional fixedness in young children. *Psychonomic Bulletin & Review, 7,* 707–712.

Gibson, E. J. (1988). Exploratory behavior in the development of perceiving, acting, and the acquiring of knowledge. *Annual Review of Psychology, 39,* 1–41.

Goldenberg, G., & Hagmann, S. (1998). Tool use and mechanical problem solving in apraxia. *Neuropsychologia, 36,* 581–589.

Grafton, S. T., Fadiga, L., Arbib, M. A., & Rizzolatti, G. (1997). Premotor cortex activation during observation and naming of familiar tools. *NeuroImage, 6,* 231–236.

Granrud, C. E., Haake, R. J., & Yonas, A. (1985). Infant's sensitivity to familiar size: The effect of memory on spatial perception. *Perception & Psychophysics, 37,* 459–466.

Held, R., & Hein, A. (1963). Movement-produced stimulation in the development of visually-guided behavior. *Journal of Comparative and Physiological Psychology, 56,* 872–876.

Johnson-Frey, S. H. (2004). The neural bases of complex tool use in humans. *Trends in Cognitive Science, 8,* 71–78.

Kellenbach, M. L., Brett, M., & Patterson, K. (2003). Actions speak louder than functions: The importance of manipulability and action in tool representation. *Journal of Cognitive Neuroscience, 15,* 30–45.

Killen, M., & Uzgiris, I. C. (1981). Imitation of actions with objects: The role of social meaning. *Journal of Genetic Psychology, 138,* 219–229.

Krutzen, M., Mann, J., Heithaus, M. R., Connor, R. C., Bejder, L., & Sherwin, W. B. (2005). Cultural transmission of tool use in bottlenose dolphins. *Proceedings of the National Academy of Sciences, USA, 102,* 8939–8943.

Liang, K. Y., & Zeger, S. L. (1986). Longitudinal data analysis using general linear models. *Biometrika, 73,* 13–22.

Lockman, J. J. (2000). A perception–action perspective on tool use development. *Child Development, 71,* 137–144.

Lockman, J. J., Ashmead, D. H., & Bushnell, E. W. (1984). The development of anticipatory hand orientation during infancy. *Journal of Experimental Child Psychology, 37,* 176–186.

Martin, A., Haxby, J. V., Lalonde, F. M., Wiggs, C. L., & Ungerleider, L. G. (1995, October 6). Discrete cortical regions associated with knowledge of color and knowledge of action. *Science, 270,* 102–105.

McCarty, M. E., Clifton, R. K., & Collard, R. R. (1999). Problem solving in infancy: The emergence of an action plan. *Developmental Psychology, 35,* 1091–1101.

McCarty, M. E., Clifton, R. K., & Collard, R. R. (2000). The beginnings of tool use by infants and toddlers. *Infancy, 2,* 233–256.

McDonough, L., & Mandler, J. M. (1998). Inductive generalization in 9- and 11-month-olds. *Developmental Science, 1,* 227–232.

McGrew, W. C., & Collins, D. A. (1985). Tool use by wild chimpanzees (*Pan troglodytes*) to obtain termites (*Macrotermes herus*) in the Mahale Mountains, Tanzania. *American Journal of Primatology, 9,* 47–62.

Milner, A. D., & Goodale, M. A. (1995). *The visual brain in action.* Oxford, England: Oxford University Press.

Needham, A. (1999). How infants grasp two adjacent objects: Effects of perceived display composition on infants' actions. *Developmental Science, 2,* 219–233.

Needham, A., Dueker, G. L., & Lockhead, G. (2005). Infants' formation and use of categories to segregate objects. *Cognition, 94,* 215–240.

Neisser, U. (1976). *Cognition and reality: Principles and implications of cognitive psychology.* New York: W. H. Freeman.

Oyama, S. (2002). The problem of change. In M. H. Johnson, Y. Munakata, & R. O. Gilmore (Eds.), *Brain development and cognition: A reader* (2nd ed., pp. 18–28). Malden, MA: Blackwell.

Sirigu, A., Cohen, L., Duhamel, J., & Pillon, B. (1995). A selective impairment of hand posture for object utilization in apraxia. *Cortex, 31,* 41–55.

Sommerville, J. A., Woodward, A. L., & Needham, A. (2005). Action experience alters 3-month-old infants' perception of others' actions. *Cognition, 96,* B1–B11.

Spelke, E. S., & von Hofsten, C. (2001). Predictive reaching for occluded

objects by 6-month-old infants. *Journal of Cognition and Development, 2,* 261–281.

Thelen, E., & Smith, L. B. (1994). *A dynamic systems approach to the development of cognition and action.* Cambridge, MA: MIT Press.

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. *Journal of Experimental Psychology: Human Perception and Performance, 24,* 830–846.

Tucker, M., & Ellis, R. (2001). The potentiation of grasp types during visual object categorization. *Visual Cognition, 8,* 769–800.

Ungerleider, L. G., & Haxby, J. V. (1994). "What" and "where" in the human brain. *Current Opinion in Neurobiology, 4,* 157–165.

von Hofsten, C. (1980). Predictive reaching for moving objects by human infants. *Journal of Experimental Child Psychology, 30,* 369–382.

von Hofsten, C., & Fazel-Zandy, S. (1984). Development of visually guided hand orientation in reaching. *Journal of Experimental Child Psychology, 38,* 208–219.

von Hofsten, C., & Lindhagen, K. (1979). Observations on the development of reaching for moving objects. *Journal of Experimental Child Psychology, 28,* 158–173.

Wang, S., & Baillargeon, R. (2005). Inducing infants to detect a physical violation in a single trial. *Psychological Science, 16,* 542–549.

Wilcox, T., & Chapa, C. (2004). Priming infants to attend to color and pattern information in an object individuation task. *Cognition, 90,* 265–302.

Members of Underrepresented Groups: Reviewers for Journal Manuscripts Wanted

If you are interested in reviewing manuscripts for APA journals, the APA Publications and Communications Board would like to invite your participation. Manuscript reviewers are vital to the publications process. As a reviewer, you would gain valuable experience in publishing. The P&C Board is particularly interested in encouraging members of underrepresented groups to participate more in this process.

If you are interested in reviewing manuscripts, please write to the address below. Please note the following important points:

• To be selected as a reviewer, you must have published articles in peer-reviewed journals. The experience of publishing provides a reviewer with the basis for preparing a thorough, objective review.

• To be selected, it is critical to be a regular reader of the five to six empirical journals that are most central to the area or journal for which you would like to review. Current knowledge of recently published research provides a reviewer with the knowledge base to evaluate a new submission within the context of existing research.

• To select the appropriate reviewers for each manuscript, the editor needs detailed information. Please include with your letter your vita. In the letter, please identify which APA journal(s) you are interested in, and describe your area of expertise. Be as specific as possible. For example, "social psychology" is not sufficient—you would need to specify "social cognition" or "attitude change" as well.

• Reviewing a manuscript takes time (1–4 hours per manuscript reviewed). If you are selected to review a manuscript, be prepared to invest the necessary time to evaluate the manuscript thoroughly.

Write to Journals Office, American Psychological Association, 750 First Street, NE, Washington, DC 20002-4242.