Infants' Anticipations and Grasps of Familiar and Unfamiliar Tools

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Abstract

Infants must learn how to use many tools in order to engage in a variety of daily tasks. An unpublished pilot study in our lab suggests that 6.5 to 8.5-month-old infants fixated more on the handle of a familiar tool than 3- to 5-month-olds (Hirtle, Strouse, Borten, & Needham, 2007). The current study aimed to extend this prior research by also obtaining measures of infants' grasping behaviors on tools. Infants were more likely to make anticipations of the hand reaching for the handle of the peeler than the handle of the spoon, and were also more likely to make anticipations of the hand reaching for the usable portion of the spoon than the handle portion of the spoon. The only reliable predictor of infants' first grasp location on the tools was age, with 12.5-month-olds more reliably grasping the handle of an adult spoon. Results are discussed in terms of the experiences they have had with these tools and how they interpret those experiences.

Introduction

In the span of one day, most people will use many different types of tools in many different ways. A pencil or pen used to write a note or a fork to eat a meal are both perfect examples of tools that someone might use everyday. Although most people do not think much about the tools they use, the ability to correctly use tools is essential to the efficiency of daily tasks in life. People learn to use these tools beginning in infancy as they learn how to engage in a variety of daily tasks such as eating and playing. Studying how infants' tool use abilities develop is interesting because there are many different aspects of tool use to consider such as cognitive skills, motor skills, and previous experience with the tools involved in the task. Tool use is generally thought of as an ability that begins developing early in infancy due to observing others. It is also thought of as an early form of problem solving because infants must recognize what a certain tool is used for to then use it for its intended purpose, or even for a different purpose (McCarty, Clifton, & Collard, 2001).

Infants' exploration of and experiences with objects help infants learn about the world around them. Infants use tools to expand their active attempts of exploring and gaining information about the world. Infants' trial and error attempts that come before successful tool use could be considered an exploration or opportunity for perceptual learning rather than cognitive gaps (Lockman, 2000). Although infants have much less experience and knowledge about tools than adults, they are nevertheless continually learning about how to use them and working toward the mastery level of adults. More mature and developed tool use is usually marked by fluency and flexibility, which means that the child can use the tool in a consistent manner and they can also adapt their knowledge of the tool for other uses (Adolph, 2005).

Expanding upon an unpublished pilot study in our lab, our first research question was whether infants would anticipate that a hand would grasp the handle of a familiar tool (a spoon) versus an unfamiliar, yet similarly shaped tool (a vegetable peeler). The unpublished pilot study provides strong evidence that suggests infants gain knowledge about tool use and form preferences for the graspable parts of tools, i.e. the handle (Hirtle, et al., 2007). There is also evidence that infants will look predictively toward (i.e. anticipate) the goal object or destination of a reach, and we expected that infants would be much more familiar with the use of a spoon than the use of a vegetable peeler because of both their visual experience and hands-on experience (Cannon & Woodward, 2012). To determine whether infants anticipate where a hand will grasp these tools, the infants in this study saw videos of a hand hovering over the midline of the tools as well as videos of a hand grasping each tool's handle. We assessed infants' looking at these videos using an eye-tracker.

The second research question in this study was whether infants would use their knowledge of handles in their grasping behaviors. This question arose from previous research indicating more refined planning for tools that are to be used in self-directed actions such as spoons (Claxton, McCarty, & Keen, 2009) than for tools that are to be used in other-directed actions. To find information on infants' grasping behaviors, the infants were given both of the familiar and unfamiliar tools for a period of time in different orientations before and after viewing the eye-tracking video. The infants examined in this study were 9.5-months-old and 12.5-months-old to examine early tool use and because previous research has shown that most 12-month-old infants can feed themselves with a spoon, but 9-month-old infants are not yet skilled in self-feeding with a spoon (McCarty, et al., 2001).

Previous research on infant reaching and grasping behaviors indicates that infants are beginning to plan their motor actions before reaching for an object. In a study by Claxton, Keen, and McCarty (2003), 10-month-old infants were given a ball to either fit into a tube or throw into a bucket. The experimenter first demonstrated the task without showing their reach for the ball to the infant. The researchers found significant differences in the kinematics of reaches for the tube task versus the bucket task, such that the adjustments infants made when reaching were different for each task. The authors suggested that the difference in the kinematics of the reaches can be interpreted as reflecting infants' anticipations of what they would do with the ball after grasping it (i.e. throw or fit it into a tube). Through this, infants exhibited future-oriented behavior that indicates that they had some sort of representation of the future state of events that was not available from their perception of the ball alone (Claxton, et al., 2003).

Other research has suggested that infants use perceptual information about an object to plan their reaching behavior (Barrett, Davis, & Needham, 2007). In one study, the researchers examined 11 and 13-month infants' planning and execution of each grasp using one symmetrically shaped object and one asymmetrically shaped object. Barrett, et al. (2007) found several developmental differences in the infants' actions in relation to the symmetry of the object. Thirteen-month-old infants were better equipped to obtain and use information about the object as well as better able to plan actions that accommodated the object's shape than the 11-month-old infants. Further, a follow up study examined the differences in reaching for two different types of balls and found that across age groups (5-, 9-, 12-, and 15-months-old) infants displayed appropriate handshapes for the type of ball they were reaching for. However, developmental differences arose in an analysis of the infants executions of clean grasps with the older infants showing more clean grasps and shorter latencies to grasping. These two studies indicate that infants are able to select the actions necessary to grasp objects (i.e. plan), but cannot actually perform the actions until somewhat later in development (Barrett, Traupman, & Needham, 2008).

Additionally, infants have been found to differentiate between actions with an ambiguous goal and actions with a clear goal such as a grasp, in situations where actions were either completed or not (Hamlin, Hallinan, & Woodward, 2008). Infants watched an experimenter either reach for a toy and grasp it or place the back of her hand on the toy, and then were provided with the opportunity to reach for either of the two toys. The researchers found that infants as young as 7-months reproduced the goal-directed actions in which the experimenter reached with an open hand towards the toy, indicative of a future grasp, regardless of the completion of the action. The infants were not able to reproduce the goal-ambiguous actions such as pointing to the toy or placing of the back of the hand on the toy. These studies provide evidence that infants as young as 7-months of age selectively differentiate actions based on their goal directedness, and their sensitivity to goal directedness can be expressed not only in their responses to visual habituation procedures but also in their overt actions (Hamlin, et al., 2008).

Although the finding that infants differentiate their actions based on goal directedness is important, there is also evidence that some goal-directed actions are easier for infants to engage in than others. In a study by McCarty, et al. (2001) infants were found to use more appropriate grips for goal-directed actions that were self-directed. Infants of 9, 14, 19, and 24 months of age were encouraged to use a hairbrush, spoon, magnet, and toy hammer to achieve a demonstrated goal. It was concluded that, "Older children were more likely than younger ones to grasp and use the tool with a radial grip...children grasped and used the tools more efficiently in the self-directed condition than in the other- and object-directed conditions" (p. 245). Infants were also found to grasp the self-directed tools more slowly than the externally directed tools, which supports earlier research suggesting that infants reaching is more carefully planned for depending on the object (McCarty et al., 2001; Barrett, et al., 2007).

To further understand infants' knowledge of reaching and grasping tools at an even younger age well before their physical grasping actions become refined, researchers also study what infants anticipate while they watch other people's actions. Most of this research is done by showing infants photographs or videos on an eye-tracking device that records infants' fixations on the screen both temporally and spatially. A fixation is maintaining a point of gaze at a single location for a specified duration, typically somewhere between 100 and 200 milliseconds. An anticipation (or prediction) of a hand's actions is often considered as a fixation on the hand that then reliably and systematically reaches an area of interest (AOI) before something interesting happens within the AOI to attract infants' attention (Gredebäck, Johnson, & von Hofsten, 2010). Prior research suggests that an understanding of goal directed actions is apparent early in development (Cannon & Woodward, 2012; Woodward, 1998).

One particular study that provides evidence for infant anticipations of actions is by Cannon and Woodward (2012). This study aimed to test whether infants can generate predictions based on previously established goals even when the context (i.e. location) of the goal has changed. Infants watched either a hand or claw repeatedly reaching to grasp one of two objects. To distinguish goal predictions from simple movement anticipations, the researchers familiarized infants with repeated reaching for two stimuli. Next, in the test phase, the objects were the same as before but their locations were switched. The infants who watched a hand reaching reliably predicted that the hand would reach to grasp the same object in the new location, but infants who watched a claw reaching reliably predicted that the claw would reach to grasp at the same location for a different object. The conclusion drawn from this result was that by 11 months of age, infants will analyze the goal of an *agent* (i.e. hand) to develop predictions about its next actions, but do not show the same analysis for an inanimate object (i.e. claw) (Cannon & Woodward, 2012).

Not only can young infants anticipate the goal-directed actions of a hand, studies have also demonstrated that infants are able to anticipate the outcomes of feeding actions with hand-held spoons. Six-month-olds predict that when an adult is feeding him/herself with a spoon, the food will be brought to the mouth and not other parts of the body like the ear (Kochukhova & Gredebäck, 2010). The study suggested that goal anticipation during feeding actions develops by 6 months of age. Additionally, this study demonstrates that infants discriminate between familiar and unfamiliar tool use actions in their visual anticipation behaviors. This finding was discussed as a possible result of infant experience with feeding and spoons.

Infants also make significantly more visual anticipations to a target or goal when observing a functional action than for a nonfunctional action (Hunnius & Bekkering, 2010). When infants were either presented with three action sequences in which objects were used in a way that it is meant to be used or three action sequences in which objects were used in a way that they are not meant to be used. For example, in one sequence infants were presented with either the experimenter bringing a cup to his/her mouth (functional) or bringing the cup to his/her ear (nonfunctional). The results show that infants as young as 6-months-old exhibit knowledge about which actions are associated with certain objects. This research suggests that early in development infants begin to learn about objects and develop expectations for other people's actions (Hunnius & Bekkering, 2010).

Clearly there is an abundance of research supporting infants' early knowledge of reaching and grasping for objects, their planning of behaviors, and their anticipations of goals. However, very little is known about how infants integrate this information about the handle portions of tools into their visual and manual behaviors. Previous unpublished research in our lab found that in general infants of both age groups (3- to 5-month-olds and 6.5-month-old to 8.5-month-olds) looked more at the usable, bowl portion of spoons (a familiar tool) than the handles. However, the older infants fixated more on the handle of the spoon and less to the usable portion than did the younger infants. The current study was proposed as an extension of the pilot study. The current study's design differed from the pilot in several integral ways. The eye-tracking stimuli were videos rather than pictures, and examined the infants' anticipations rather than fixations. Anticipations are assumed to exemplify infants looking at a location in anticipation of future events, indicating knowledge of what will happen (Gredebäck, et al., 2010). Additionally, the type of unfamiliar tool was changed so that the unfamiliar tool was shaped more similarly to a spoon (i.e. the hammer was changed to a vegetable peeler). Last, grasping measures were also obtained in order to compare infants' visual and manual behaviors towards the handles of tools.

The first hypothesis was that the older infants would outperform the younger infants in making anticipations towards the handle of a familiar tool. The second hypothesis was that that the older infants would more reliably grasp the handle portion of the familiar tool than would the younger infants. A third hypothesis was that familiarity with a tool would result in increased behaviors, both visual anticipations and manual grasping, towards the handle portion of the tool. An additional question that was explored was whether infants' behaviors towards the handle portions of both tool would increase following the experiences in the experiment.

Methods

Participants

Participants in this study were full-term infants and their caregivers. Participants were excluded from data analysis if they were too fussy or irritable to participate in both measures (n=2), if they did not make any anticipations (n=1), if eye-tracking measures could not be collected due to equipment failure (n=1), or if the average looking time was <5% (n=2). Twenty-five 9.5–month-old infants participated in the study (M=9 months and 23 days, SD=9 days) and eighteen 12.5-month-old infants participated in the study (M=12 months and 23 days, SD=11 days). Table 1 provides further information about the races and birth weights of the infants.

Apparatus

Infants were seated in a high chair or in the parent's lap if the infant was not comfortable in the high chair. Tools were presented to the infant approximately 5 inches away on either the attached high chair table or a similar hard, flat surface if the infant was in a caregiver's lap. When the infant was in the high chair during grasping measures, the caregiver was seated beside the infant (see Figure 1). The four tools that the infant was presented with in the grasping measures were of roughly the same sizes and shapes with varying colors; a turquoise peeler was 7 inches, a red peeler was 7.5 inches, a purple spoon was 5.5 inches, and a silver spoon was 6.5 inches (see Figure 2). The six tools that the infant was presented with in the eye-tracking measures were also of approximately the same size and shape and of varying colors, as is demonstrated in the illustration of the areas of interest (AOIs) which are described in a later section (see Figure 4). Different vegetable peelers and spoons were used in the two different measures (grasping and eye-tracking) so that infants' brief experiences with the tools in the grasping measures would be less likely to influence their behaviors in the eye-tracking measures.

The experimenter sat roughly 2 feet away. During the eye-tracking portion, a 17 inch Tobii T120 infrared remote eye-tracker was used. Infants were situated approximately 2.5 feet in front of the eye-tracker (see Figure 3). Caregivers were situated behind the infant for the eye-tracking portion so that the system would not confuse the corneal reflections of the infant and caregiver. For both grasping and eye-tracking measures, caregivers were instructed not to direct their child's attention to the screen nor the tools presented to the infant.

Procedures

After the caregiver or caregivers completed media and tool experience questionnaires along with the proper consent forms, both caregiver and infant were directed into a room in which the study took place. Once the infant was situated the measures were obtained.

Grasping measures. Participants were first presented with a total of four tools to explore for approximately 30 seconds each: two vegetable peelers and two spoons (see Figure 2). The peeler portion of the vegetable peeler was safely covered by protectors and an additional layer of tape. Each presentation of the tool was made using the experimenter's fingertips on each end of the tool rather than a grasp so that no grasp was shown to the participant (see Figure 1). This was important because no grasp was demonstrated for the infant during the time of the study, and so presumably the grasps that the infant made were of his or her own volition.

The order of the tool presentation and the tool's orientations were both counterbalanced. It was important to counterbalance the orientation of the tool to help eliminate any bias in grasping that may have been due to the child's natural hand preferences. For instance if the infant had a right hand preference, he or she may be more likely to grasp all tools with the right hand and to grasp the portion of the tool that was closest to that hand. It was important to counterbalance the presentation order of the tools to avoid any bias toward one particular tool.

Following these grasping measures, the eye-tracking measures were taken once and the same procedure for grasping measures was repeated.

Eye-tracking measures. Images and videos of 3 spoons and 3 vegetable peelers were shown on the Tobii eye-tracker (see Figure 4). Different spoons and vegetable peelers were used in the grasping and eye-tracking measures so as not to bias the infants towards a particular tool. Before watching the experimental stimuli for the study, a calibration video was played in order to calibrate the eye-tracker to the participants' corneal reflections. A 9-point calibration sequence was used in order for the eye-tracker to score the infants' visual behaviors. An image appeared at 9 different points on the screen while a tune sounded through the speakers behind the screen. If infants became inattentive, the experimenter pressed a key to recapture the infant's attention with a new noise and a different toys appearance in the center of the screen. Calibration was repeated for any of the 9 points that were not found or inaccurate in the first calibration. Once the infant was calibrated to all points, the experimenter continued to the experimental phase.

There were four total orientations each tool could be in the experimental phase. The four orientations result from the tool presented with the handle vertically pointed up or down and a hand reaching for such tool either from the left or the right of the frame. There were only two presentation orders of the tools, either all spoons first or all peelers first, which was counterbalanced. Just as in the grasping measures, the counterbalances of orientations and orders were important to avoid bias towards a particular tool.

The stimuli that the participants watched always consisted of the same four phases for each tool in the following order: baseline, first hover, grasp, and second hover. In the baseline phase, infants saw simply a picture of each tool with the hand directed towards the tool. In both the first hover and second phases, infants watched a video of a hand moving towards the tool, hovering over the tool's middle, and then retreating to the original position. In the grasp phase, infants watched a video of a hand moving towards the tool, grasping the tool, setting it down, and then retreating to the original position. The purpose of the two hover phases was to compare the infants' anticipations before and directly after watching a hand grasp the handle of a tool. Each infant would watch all six tools (3 spoons and 3 vegetable peelers) go through each of these four phases to total 24 separate eye-tracking measures. The average length of the movie the infant would watch was two minutes and seven seconds. Although the movie was relatively short, it was still difficult to direct the infant's attention to the screen. If needed, the experimenter would express interest in the video verbally to try and recapture the attention of the infant. As mentioned, the same grasping measure was repeated. This was done to compare the infants' grasping behaviors before and after watching the video in which infants saw a hand grasp the handle of the tools. The conditions from grasping measures and eye-tracking measures were paired up, and participants were randomly assigned to one of the resulting eight conditions that counterbalanced tool orientation and presentation order in both the grasping measures and eye-tracking measures.

Measures

The independent variable of this study, or the main focus of the study, is the frequency of infant behaviors (both visual and manual) towards tool handles. Because there are two separate measures of infants' behaviors towards handles, the independent variable can be analyzed as a measure of anticipation behaviors or grasping behaviors. The dependent variables of the study are the between-subjects variable of age (9.5- or 12.5-months-old) and the two within-subjects variable of tool type (spoon or peeler) and phase (first or second hover for eye-tracking measures and pre or post video watching for grasping measures).

Coding Scheme

Grasping coding scheme. The coding for the grasping measures was accomplished through the Datavyu program (datavyu.org). Each instance of a grasp was stamped in time by a research assistant so that the exported data would include both frequency and length of time. A grasp was defined as the infant using at least two fingers to lift the tool off of a surface. To define a grasp it also helped to establish what was not a grasp: having the tool only in the mouth without assistance of the hands or lifting the vegetable peeler by placing a finger in the hole on the end of the peeler. Each grasp was coded as a handle, middle, or usable end grasp. A middle grasp was included because this type of grasp was quite frequent, and it could indicate that the child does not know where to grasp or the infant may be grasping there because it seemingly balances the weight of the object. If the coder was unsure about which section of the tool the infant was grasping, both were coded. In further data analysis, if both a middle grasp and handle grasp were coded then a handle grasp was represented in the data, and if both a middle grasp and usable end grasp were coded then a usable end grasp was represented in the data. Due to the limited time frame and scope of the study, analysis was only performed on the infants' first grasp of each tool. Additionally, the first grasp generally provides more information about the infants' planning behaviors. Two trained research assistants independently coded 21% of the data (9 participants). Cohen's κ was calculated as a measure of reliability between the two coders. There was excellent agreement between coders, $\kappa = .924$, 95% CI [.853, .994], $p < .001$.

Eye-tracking coding scheme. The coding of the eye-tracking data was done through Tobii software. First, the videos were cut down into scenes for every tool in each phase, totaling 24 scenes per condition. The videos were cut into separate scenes so that each phase could be coded separately, and so that eventually the analysis could determine whether infants' looking behaviors increased or decreased between phases. The baseline phase was not included in analysis because there was no movement and therefore infants could not make anticipations. After cutting the videos into scenes, AOIs were created to encompass the areas on the video that corresponded to the hand, handle, and usable portions of tools (see Figures 5 and 6). These AOIs allowed the Tobii software on the eye-tracker to compute the amount and duration of fixations. An AOI for the middle portion of the hand was not created because the portion was extremely small and did not represent a significant enough portion of the screen.

After the AOIs were created, Tobii Studio software (version 2.1.14) was used to sum the total amount of time infants fixated inside of each AOI and the other parts of the screen. A fixation was defined as looking for a minimum duration of 100 ms within a radius of 50 pixels. Anticipations were defined as first fixating on the hand, followed by fixating on either the usable or handle portions of the tools. Anticipations had several criteria. First, the infant had to fixate on any portion of the screen before fixating on the handle or usable AOI. If the infant did not fixate on anything before these AOIs, they could not have fixated on the hand and could not have anticipated where the hand would grasp. The next criteria for anticipations were that the infant had to fixate at the hand followed by a fixation on the handle or usable portion of the tool. If the infant fixated on the hand followed by a fixation on a portion of the tool before the hand reached the tool, this was considered anticipation. One participant was excluded in anticipation analysis because he/she did not fixate on anything before the handle AOI, and therefore did not meet the first criteria for anticipation.

Results

Grasping results

Because infants' first grasps before watching the video were unlikely to be independent from their grasps after watching the video, and the outcomes of the dependent variables were categorical, we analyzed our data using a generalized estimating equation (GEE). First used by Liang and Zeger (1986), GEE is a regression method used to analyze data from studies using repeated measures design. We have used GEE to successfully analyze similar data in prior work in our lab (e.g. Barrett, et al., 2007). A GEE analysis was used to predict one dependent variable (first grasp location) based on one within-subjects variable of interest (before and after video experience) and one between-subjects variables of interest (age group). A GEE analysis was run for each individual tool (i.e. adult spoon, infant spoon, peeler 1, and peeler 2), both peelers together, both spoons together, and all of the tools together. We chose this analysis because these portions were our main areas of interest, and this allowed the grasping analysis to parallel the eye-tracking analysis. Each individual analysis notes how many participants were excluded. Although this exclusion criterion ultimately led to a much smaller sample size in several of the analyses, especially if the analyses included fewer tools, it was necessary. Further research should explore other analysis options that do not limit the existing sample size.

Adult spoon. The GEE analysis found age to be the only reliable predictor of infants' first grasp location on the silver, adult spoon: infants were more likely to first grasp the handle of the adult spoon if they were older (β= 1.01, $\chi^2(1)$= 4.88, p= .027, 95% CI [.11, 1.91]). Figure 7 also depicts these results. The GEE analysis did not find phase (before or after the video portion of the study) to be a reliable predictor of the first grasp location of the adult spoon (β= .13, $\chi^2(1)$= .10, p= .75, 95% CI [-.65, .90]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of the adult spoon (β= -.34, $\chi^2(1)$= .28, *p*= .60, 95% CI [-1.59, .91]). Seven infants were excluded in this analysis because they did not first grasp the tool on the handle or usable portion in either grasping phase (N=36).

Infant spoon. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of the infant spoon (β= -.05, $\chi^2(1)$= .01, *p*= .91, 95% CI [-.93,.83]). The analysis did not find phase to be a reliable predictor of the infants' first grasp location of the infant spoon (β= -.14, $\chi^2(1)$= .12, *p*= .73, 95% CI [-.97, .68]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of the infant spoon (β= .55, $\chi^2(1)$= .72, *p*= .40, 95% CI [-.72, 1.83]). Nine infants were excluded in this analysis because they did not first grasp the tool on the handle or usable portion in either grasping phase (N=34).

Peeler 1. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of Peeler 1 (β= -.67, $\chi^2(1)$= 2.22, *p*= .14, 95% CI [-1.56, .21]). The analysis did not find phase to be a reliable predictor of the infants' first grasp location of Peeler 1 (β< .000, $\chi^2(1)$< .000, *p*= 1.00, 95% CI [-.87, .87]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of Peeler 1 (β= .93, $\chi^2(1)$= 1.95, *p*= .16, 95% CI [-.37, 2.22]). Nine infants were excluded in this analysis because they did not first grasp the tool on the handle or usable portion in either grasping phase (N=34).

Peeler 2. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of Peeler 2 (β= -.16, $\chi^2(1)$= .25, *p*=. 61, 95% CI [-.76,.45]). The analysis also did not find phase to be a reliable predictor of the infants' first grasp location of Peeler 2 (β= .22, $\chi^2(1)$= .52, *p*= .47, 95% CI [-.37, .80]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of Peeler 2 (β= .32, $\chi^2(1)$= .52, *p*=

.47, 95% CI [-.56, 1.20]). 10 infants were excluded in this analysis because they did not first grasp the tool on the handle or usable portion in either grasping phase (N=33).

Both peelers. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of both peelers (β= -.16, $\chi^2(1)$= .25, *p*= .62, 95% CI [-.76, .45]). The analysis also did not find phase to be a reliable predictor of the infants' first grasp location of both peelers (β= .21, $\chi^2(1)$= .53, *p*= .47, 95% CI [-.37, .80]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of both peelers (β= .32, $\chi^2(1)$= .52, p= .47, 95% CI [-.56, 1.20]). Three infants were excluded in this analysis because they did not first grasp the tool on the handle or usable portion in either grasping phase (N=40).

Both spoons. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of both spoons (β= .49, $\chi^2(1)$= 2.39, *p*= .12, 95% CI [-.13, 1.11]). The analysis also did not find phase to be a reliable predictor of the infants' first grasp location of both spoons (β< .000, $\chi^2(1)$< .000, *p*= 1.00, 95% CI [-.56, .56]). The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of both spoons (β= 1.03, $\chi^2(1)$= .05, *p*= .82, 95% CI [-.78, .99]). One infant was excluded in this analysis because he/she did not first grasp the tool on the handle or usable portion in either grasping phase (N=42).

All tools. The GEE analysis did not find age to be a reliable predictor of the infants' first grasp location of all of the tools (β= .16, $\chi^2(1)$=. .52, *p*= .47, 95% CI [-.27, .59]). The analysis also did not find phase to be a reliable predictor of the infants' first grasp location of all of the tools (β= .10, $\chi^2(1)$= .25, *p*= .62, 95% CI [-.30, .51]. The analysis also did not find the interaction between age and phase to be a reliable predictor of the first grasp location of all of the tools (β= .23, $\chi^2(1)$= .52, *p*= .47, 95% CI [-.39, .85]). One infant was excluded in this analysis because he/she did not first grasp the tool on the handle or usable portion in either grasping phase (N=42).

Eye-tracking results

To answer the question "Is there a difference in anticipations for the handles of both tools between age groups?" a 2-way mixed ANOVA was used. Age group, 9.5-months and 12.5-months, was entered as a between participant factor. Anticipations toward the spoon handle versus the peeler handle was entered as a within participant variable. Partial eta squared was calculated as a measure of effect size. A significant main effect of the type of tool was found, $F(1, 40)=16.39$, $p<.001$, $\eta_p^2=.291$ ($M_{spoon}=.44$, $SD_{spoon}=.77$, $M_{peeler}=1.56$, $SD_{peeler}=1.37$). Follow up analyses with a paired samples t-test indicate that infants are more likely to look to the handle portion of the peeler immediately after looking at the hand than to look at the handle portion of the spoon, $t(1, 42)= -4.94$, $p<.001$, *95% CI* [-1.57, -.66]. No significant main effect of age was found. No interaction between the type of tool and the age of participants was found. A 2-way mixed ANOVA with the same between and within factors was also used to determine whether there was a difference in anticipations for the usable portion of both tools between age groups. No significant effects of tool or age were found, and no interaction between tool and age was found.

To answer the question, "Is there a difference in anticipations for the usable portions versus the handle portions of the spoon between age groups?" another 2-way mixed ANOVA analysis was used. Age group was again entered as a between factor. Anticipations toward the spoon's handle portion versus the spoon's usable portion was entered as the within participant factor. Partial eta squared was calculated as a measure of effect size. A significant main effect of the portion of the tool was found, $F(1, 40)=5.44$, $p=.025$, $\eta_p^2=.12$ ($M_{handle}=.44$, $SD_{handle}=.77$,

M_{usable}=1.16, SD_{usable}=1.44). Follow up analyses with a paired samples t-test indicate infants are more likely to look to the usable portion of the spoon immediately after looking at the hand than to look at the handle immediately after looking at the hand, $t(1, 42)= -3.455$, $p=.001$, 95% CI [-1.14, -.30]. No significant main effect of age was found, and no significant interaction between portion of the tool and age was found.

To answer this same question for the vegetable peeler, the same 2-way mixed ANOVA was used, but the within factor was defined as anticipations toward the peeler's handle portion versus the peeler's usable portion. A significant main effect of the portion of the tool was found, $F(1, 40)=9.14$, $p=.004$, $\eta_p^2=.186$ (M_{handle}=1.56, SD_{handle}=.1.37, M_{usable}=.74, SD_{usable}=.90). Follow up analyses of a paired samples t-test suggest that infants are more likely to look to the handle portion of the peeler immediately after looking at the hand than to look at the usable portion of the peeler immediately after looking at the hand, t(1, 42)=3.64, p=.001, 95% CI [.36, 1.27]. No significant main effect of age was found, and no significant interaction between portion of the tool and age was found. Results are also depicted in a graph (see Figures 8 and 9).

Discussion

This study investigated the early development of infants' tool use knowledge. Specifically, we were most interested in exploring what infants might know about the handle portions of tools, and how this could be exemplified in their visual and manual behaviors with different tools. This approach of looking specifically at the handle of tools is relatively new to the field with the exception of a pilot study done in our lab (Hirtle, et al., 2007) and was done to further enhance our understanding of cognitive and motor development in infancy. Infants were given the opportunity to visually and manually explore two types of tools, one seemingly familiar and one seemingly unfamiliar. Their first grasps of the tools during the manual exploration phases and their anticipations during the visual exploration phase were examined to gain insight into infants' understanding of tools and their uses.

Age was the only reliable predictor found that influenced the location of infants' first grasps of an adult spoon. Infants were much more likely to first grasp the handle rather than the usable portion of the adult spoon if they were 12.5-months-old than if they were 9.5-months-old. This finding corroborates our decision to examine these two age groups. This also further supports earlier research that most 12-month-old infants can feed themselves with a spoon (i.e. they exhibit more refined motor actions), but 9-month-old infants are not as skilled in this particular action (McCarty, et al., 2001). Age was not found to be a reliable predictor of the infants' first grasp location for any of the other tools. Phase, i.e. before and after watching the video, also was not found to be a reliable predictor of the infants' first grasp location. The interaction of age and phase was also not found to be a reliable predictor of the infants' first grasp location either. This lack of evidence in support of infants' first grasp location for the other tools (the baby spoon and two vegetable peelers) could indicate that infants at these ages are not yet able to integrate their knowledge of the affordances of tools in general in the planning of their grasping. Conversely, this could also signify that at this age infants simply do not have a general knowledge about the handles of tools to apply to tools they are less familiar with.

However, the latter explanation is much less likely considering previous research and parental reports of infants' familiarity, or experience, with each of these tools. Previous research evidences that infants are able to select the actions necessary to grasp objects (i.e. plan), but cannot actually perform the actions until somewhat later in development (Barrett, et al., 2008). Together, these results suggest that it may not be infants' ability to plan appropriate grasps that is lacking but rather their ability to execute their planning. Further, parental reports corroborate these findings. Parental reports demonstrate that infants have no manual experience and little to no visual experience with vegetable peelers (see Figure 10). This could help explain the finding that neither age nor phase could reliably predict where infants would first grasp the peeler, but does not explain infants' ability to make anticipations about the handle of the peeler. This is discussed later on.

Parental reports also show that 9.5-month-olds and 12.5-month-olds have different amounts of manual experiences with spoons. As demonstrated in Figure 11, parents reported that 9.5-month-old infants have much less experience with adult spoons than do 12.5-month olds. As demonstrated in Figure 12, parents reported that both age groups of infants have a variety of experience with baby spoons. Comparing the two graphs shows that infants have much more manual experience with baby spoons than adult spoons. Although parents reported more manual experience with baby spoons, a simple yet straightforward way to explain the first grasp results are the differences in shapes and sizes of the two tools. The adult spoon had a much clearer, distinct handle portion than did the baby spoon and both peelers (see Figure 2), indicating quite a conservative test of grasping for the handle.

It is unknown exactly how much experience is necessary to create a bias toward grasping a particular object, tool, or portion of a tool. We know from previous research that 13- to 18-month-old infants receiving training with a novel tool and action approximately 5 minutes per day in just one week is enough experience to subsequently increase action reproduction over 5 times more so than receiving no training or experience with the novel tool and action (Barrett, et al., 2007). In designing this experiment, we did not know the threshold for experience needed to influence grasping behaviors. However, taken together, these two studies indicate that bias is built over a long period of time and not over a single brief exposure. This also suggests that a bias toward grasping the handle of a tool requires some knowledge built up over time, because the brief exposure infants received in this study was not sufficient to create a handle-grasping bias among the infants.

As for infants' visual anticipations, results indicate that infants make anticipations of the hand grasping the handle of the unfamiliar tool (vegetable peeler) significantly more often than for the familiar tool (spoon). When comparing infants' anticipations of hands reaching for the handle versus the usable portions of both tools, the results illustrate that infants are more likely to make anticipations for the handle portion of the unfamiliar tool and are more likely to make anticipations for the usable portion of the familiar tool. Results are also depicted in Figures 8 and 9. The results did not show any effect of age, indicating that by 9.5-months-old infants are able to make these anticipations. Infants did not differ much in their average looking time throughout the eye-tracking portion of the study, with 9.5-month-olds looking 46% of the time and 12.5-month-olds looking 51% of the time. This is also corroborated by parental reports on infants' media experience demonstrating that both age groups do not differ much in how much television/video experience they experience in a typical week (see Figure 13).

Although this is essentially the exact opposite of our hypothesis, this finding is can be explained in several ways. In line with the original hypothesis, we expected that infants would make more anticipations towards the handle portion of the familiar tool, but the results show more anticipations for the usable portion. Not only did the infants make more anticipations toward the usable portion of the familiar tool, but most of their fixations were also in the usable portion AOI (see Figure 14). Although the graph shows infants fixating mostly on the hand AOI, this is easily explained by the fact that the hand was moving the entire time while the tools only moved for a small amount of time (when they were grasped). However, it seems unlikely that infants are truly anticipating that the hand in the videos will grasp the usable portion of the tool given that they themselves reliably first grasped the handle of the adult spoon in the grasping measures of the study. This may be explained by a nuance that we did not plan for: that infants at this age might have a tendency to look at the usable portion because that is where they expect food to be. The pilot study showed that by 6.5- to 8.5 months infants looked more at the handle of the familiar tool (Hirtle, et al., 2007), and in the current study infants made more anticipations toward the usable portion of the familiar tool.

One possible explanation is that by 12.5 months of age, infants in the current study have become less engaged in the question of where the hand will grasp the tool and might be wondering what will happen after the hand grasps the spoon. Another possible explanation for this is that our hypothesis was based off of pilot research on infants' fixations rather than anticipations. Despite these somewhat odd results for the familiar tool, it is also interesting to note upon the anticipation findings of the unfamiliar tool; infants made significantly more anticipations toward the handle of unfamiliar tool than the usable portion of the unfamiliar tool. As discussed earlier, infants did have more visual experience with vegetable peelers than they had manual experience.

In combination with the grasping results, this finding could potentially be indicative of infants' understanding about handles: that they can visually make anticipations regarding the handle of unfamiliar tools but that they cannot integrate this knowledge into their manual grasping behaviors at this same age, and perhaps more manual experience is needed to scaffold this process. In combination with the results about the anticipations for familiar tools, these findings may further indicate that infants' visual and manual behaviors towards the handles of tools are a result of a delicate balance between their visual and manual experiences with the tools. Because there is such a disconnect between the findings of the grasping and eye-tracking measures, perhaps in order to gain more insight into infants' understanding about the handles of tools, it is more important to parse out familiarity as visual familiarity and manual familiarity.

Despite these interesting findings, there are several limitations to the current study. The study did not provide a clearer understanding of the developmental trajectory for infants' understanding about the handles of tools that we hoped to gain. Because age was only a predictor of one type of tool for the grasping measures and age did not have effect on any anticipation measures, it is difficult to determine the specific developmental differences between the two age groups. Initially the study was intended to have 64 total participants, 32 in each age group. However, timing did not permit for this and the addition of more participants potentially may have influenced the findings. Another larger limitation of these findings is that the analysis of the grasping measures was limited to only infants whose first grasp location was at either the handle or usable portion of the tool across trials. This made the sample even smaller than it already was, and most likely had a negative impact on the results. Further research should aim to avoid these limitations.

Future research could expand upon these findings in several different ways. First, to improve the current study additional participants could be added to the sample. Additionally, it may be informative to analyze the entirety of the grasping measures, and explore how often infants grasped the handle portion in the 30 seconds he/she was given with each tool. To further explore the possible influence of visual and manual familiarity, it may be beneficial to include an additional unfamiliar tool to the current study. This tool would be completely novel to the infant, and could be a tool created in the lab such as the tool used in Barrett, et al. (2007). Determining how much previous visual and manual experience influences infants' subsequent behaviors towards the handles of tools could better instruction when teaching children how to use tools, and may even provide insight into how teach children with motor use disabilities. Although finding the exact amount and type of experiences necessary to teach efficient and effective handle use is unlikely, discovering more about the scaffolding and guidance needed is still relevant.

Yet another way that this research can be expanded upon in the future is developing a study in which infants watch a hand correctly grasping the handle of tools and incorrectly grasping other portions of the tools, similar to the functional and nonfunctional conditions in Hunnius and Bekkering (2010). If infants attended longer to the incorrect grasp than the correct grasp, this could indicate that the incorrect grasp is violating the infants' expectations about where the hand will grasp the tool. Last, a future study should include a wider range of age groups than the current study if both visual and manual behaviors are being explored as infants seem to perform differently for each at different ages.

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Figures and Tables

Figure 1. Infant and parent position during grasping measures; fingertip presentation of tools.

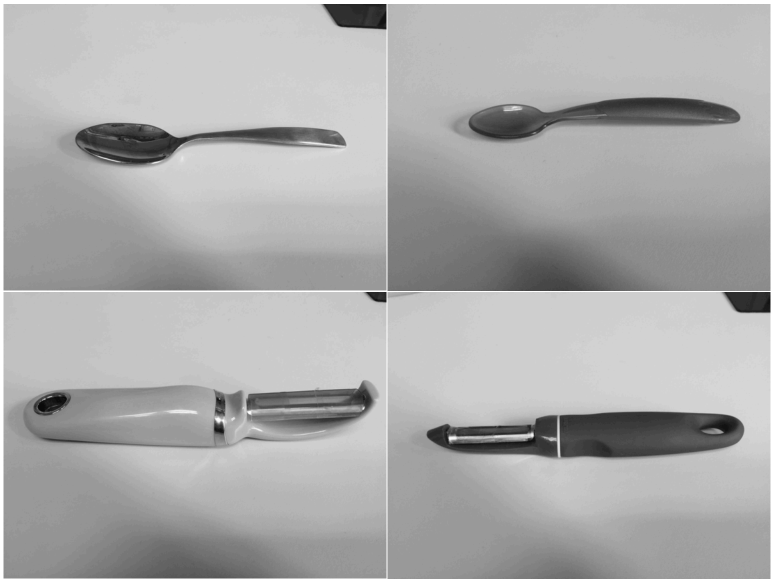

Figure 2. Spoons and vegetable peelers used in grasping measures.

Figure 3. Infant position during eye-tracking measures.

Figure 4. Spoons and vegetable peelers used in eye-tracking measures.

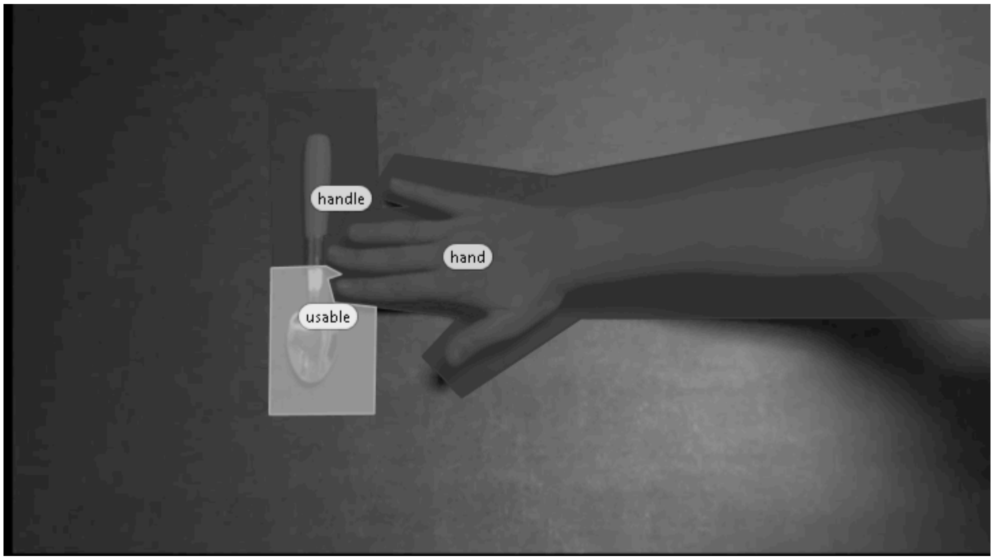

Figure 5. Areas of Interest (AOIs) for spoon.

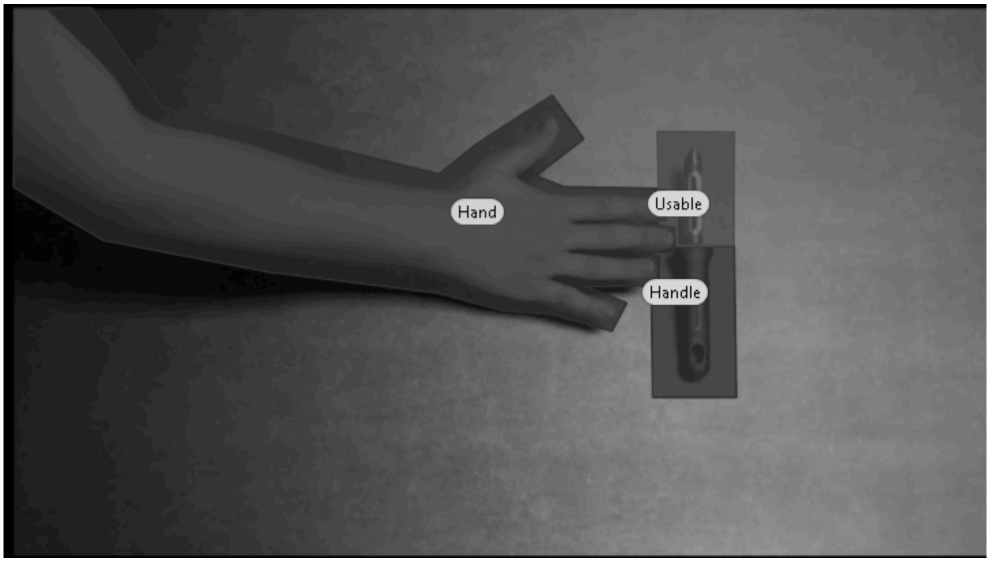

Figure 6. Areas of interest (AOIs) for peeler.

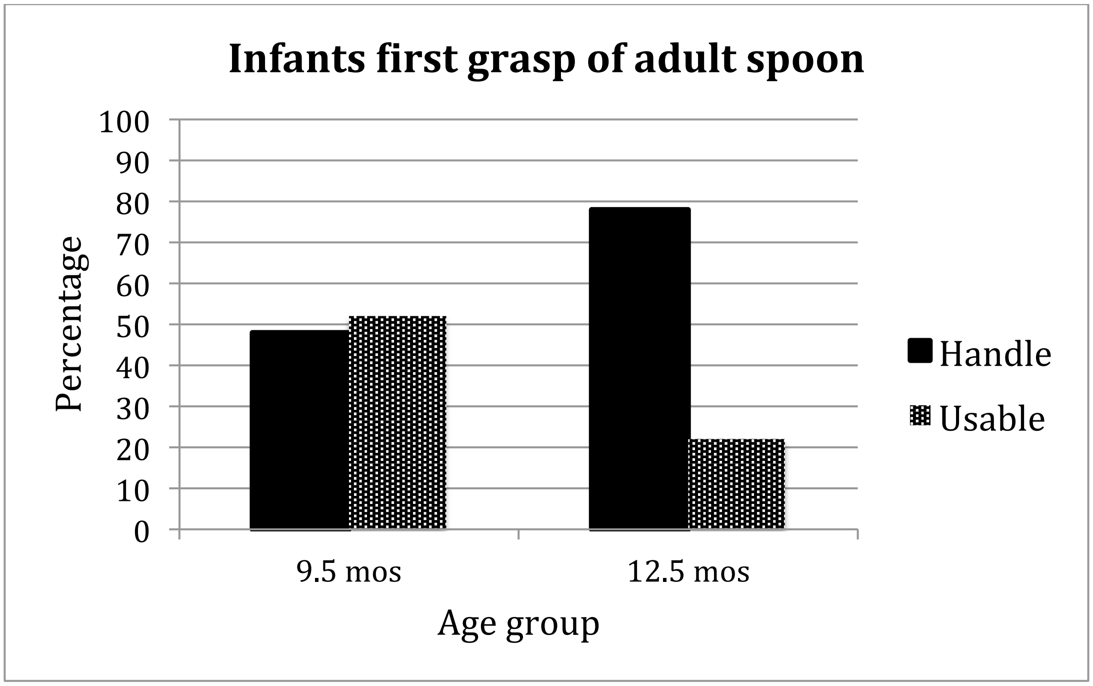

Figure 7. Percentage of infants first grasp of the adult, silver spoon (N_{9mos}=16, N_{12mos}=20).

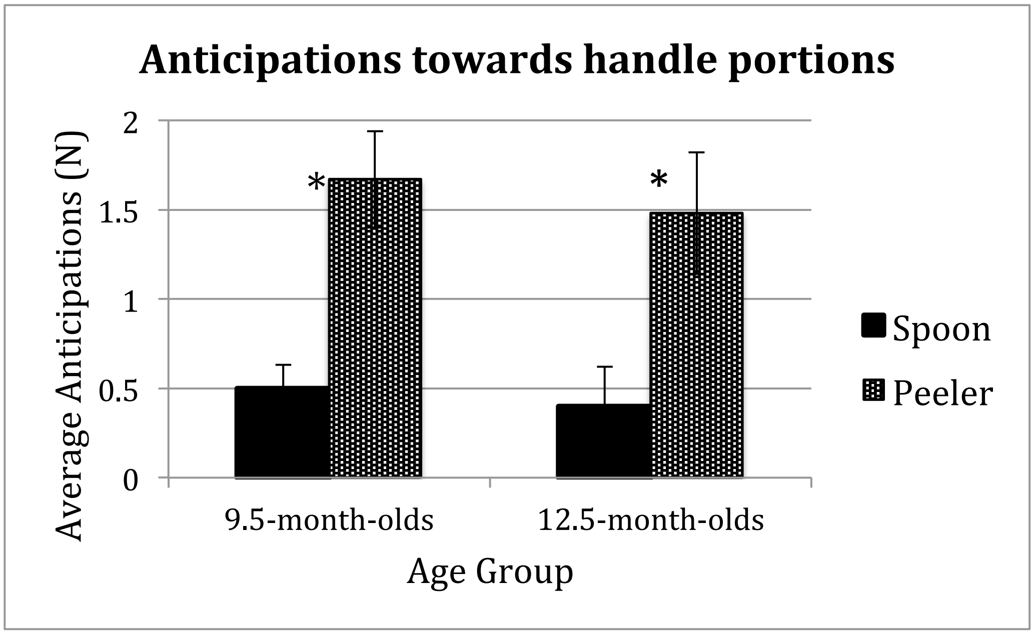

Figure 8. Number of infants' anticipations towards the handle portions of both tools.

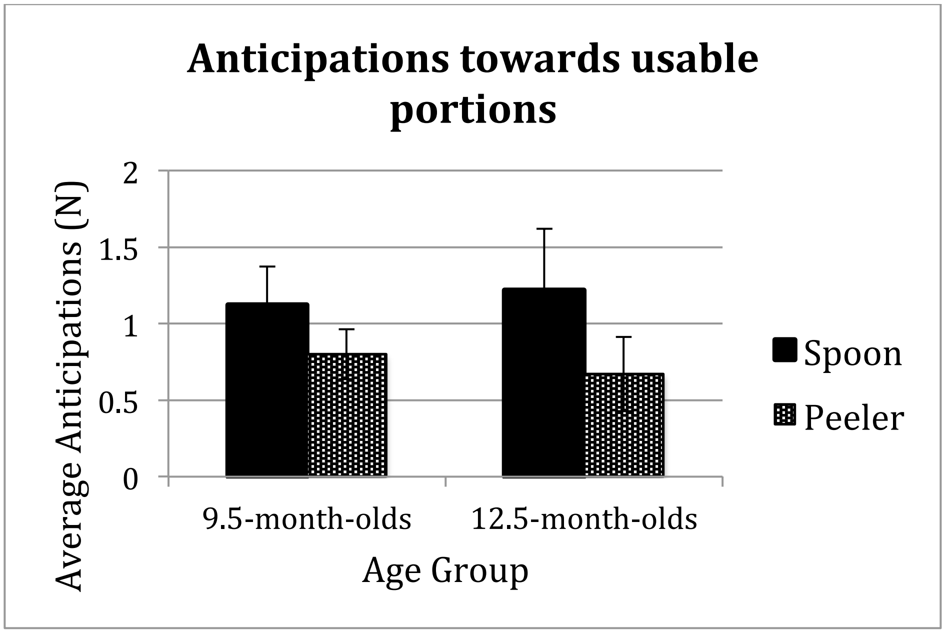

Figure 9. Number of infants' anticipations towards the usable portions of both tools.

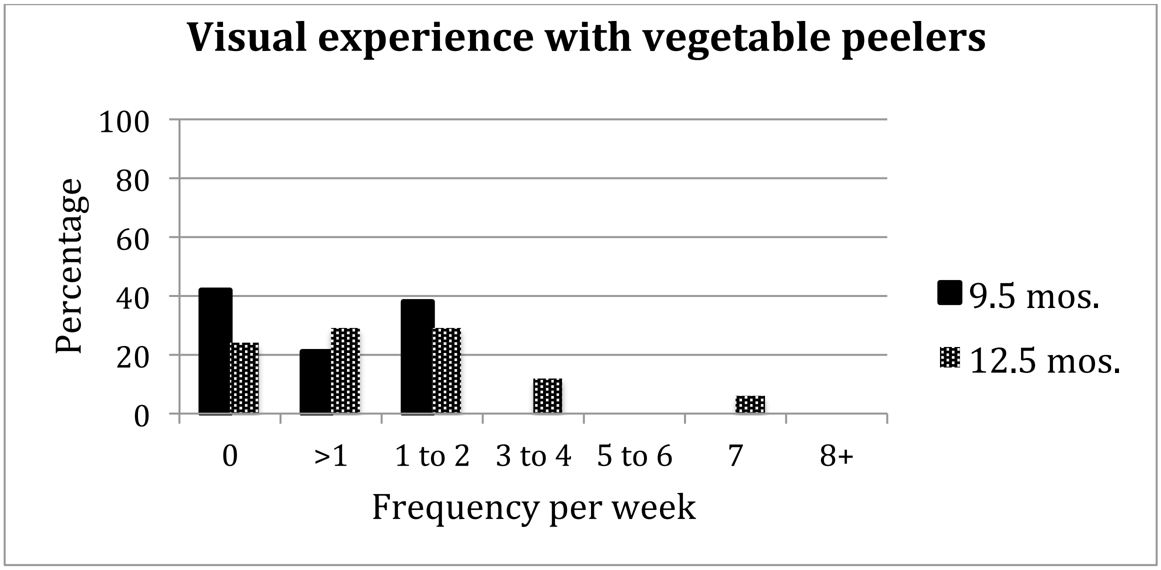

Figure 10. Infants' visual experiences with vegetable peelers.

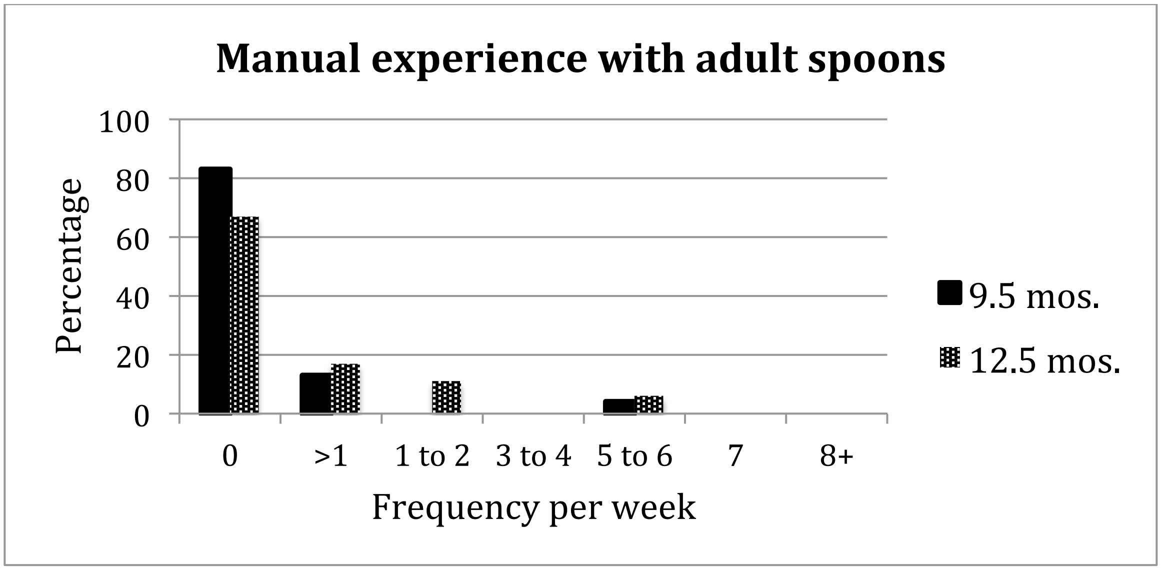

Figure 11. Infants' manual experiences with adult spoons in a typical week.

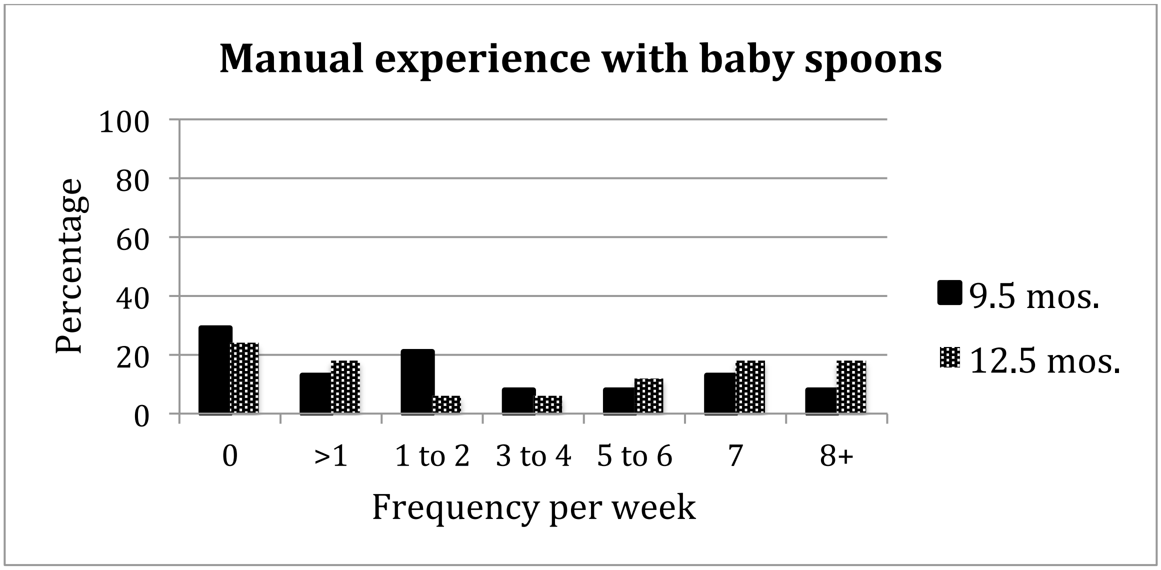

Figure 12. Infants' manual experiences with baby spoons in a typical week.

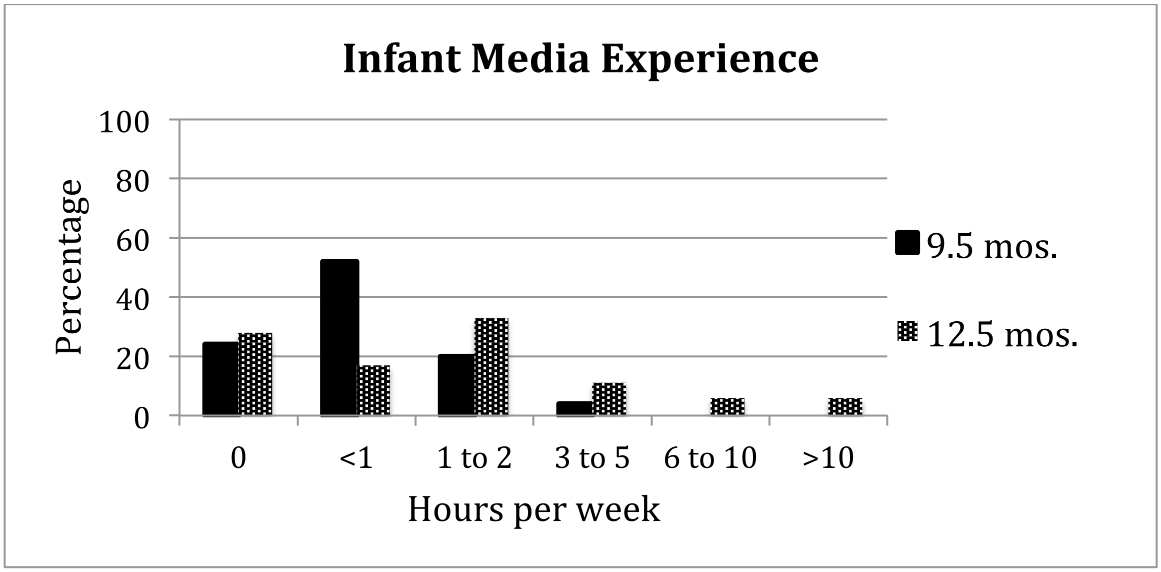

Figure 13. How often infants watch television and/or video in an average week.

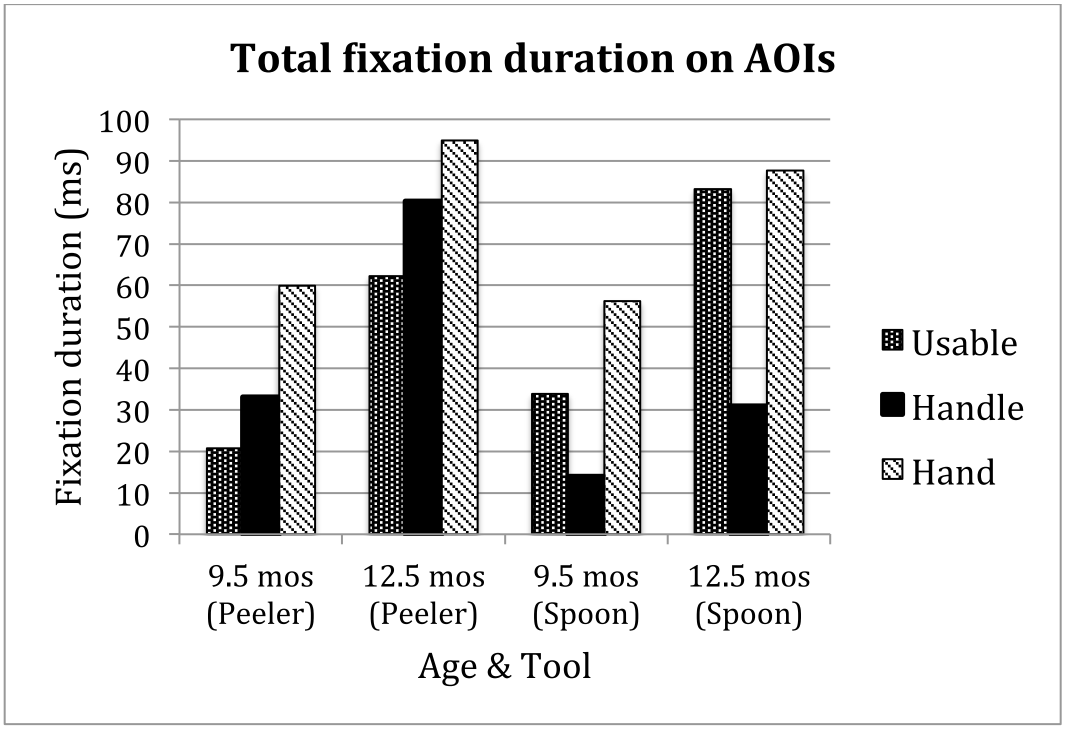

Figure 14. Infants' total fixation duration in milliseconds (all peelers combined and all spoons combined).

Group	N	Race	Age	Birth weight
9.5-month-olds	25 (females = 13)	W = 22 A = 0 B = 3	9 m, 23 d (*SD* = 9 d)	7 lb, 10.4 oz (*SD* = 1 lb 8 oz)
12.5-month-olds	18 (females = 11)	W = 16 A = 2 B = 0	12 m, 23 d (*SD* = 11 d)	7 lb, 11.2 oz (*SD* = 12.28 oz)

Table 1. Participant characteristics.