THE DEVELOPMENT OF ORIENTING OBJECT FEATURES
DURING HAND TO MOUTH TRANSPORT IN INFANTS

AN ABSTRACT
SUBMITTED ON THE SEVENTH DAY OF JULY 2015
TO THE DEPARTMENT OF PSYCHOLOGY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
OF THE SCHOOL OF SCIENCE AND ENGINEERING
OF TULANE UNIVERSITY
FOR THE DEGREE
OF
DOCTOR OF PHILOSOPHY

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Abstract

The development of orienting object features during hand to mouth transport was studied in a group of infants between 6-12 months of age (N=60). The task was to bring a bottle to the mouth. The bottle was presented in six different orientations (up, down, toward, away, left, and right). To measure head movement, a 3D motion capture system (Qualisys) was used. The results revealed that older but not younger infants are able to plan actions based on the functional end of an object. Older infants take less time, are more successful at directing the nipple to the mouth, initially grasp the bottle in an efficient manner more frequently, and move the head less than younger infants. More broadly, the results offer insights into how infants become more efficient in feeding tasks as they get older.
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Acknowledgements

I would like to thank my advisor, Dr. Jeff Lockman for his outstanding mentorship throughout my graduate school career. I appreciate his guidance, patience, and flexibility. I could not ask for a better advisor. A big thank you also goes to my favorite colleague, Dr. Sascha Kahrs for his friendship and all of his assistance. My ability to collect baby data and his ability to analyze it made our working relationship very symbiotic. I am also grateful to Brittany DeVries and Madeleine Schwartz for their long hours of coding behavioral data. Many thanks also to my dissertation committee, Dr. Mike Cunningham, Dr. Dave Corey, and Dr. Ed Golob for their input and thoughtful suggestions. Thanks also to my dad, Johnny Jung for believing that I can do anything. I am forever grateful for all of the hard work and sacrifices he made immigrating to the United States to give us a better life. Also, I would like to thank my husband, Dr. Chris Linn for his unconditional support. He walked this path before me and provided me with good advice and encouragement. I am very thankful that we met a week before I started graduate school. Finally, I thank the children and families who were involved in this project. None of this would be possible without their participation.
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**Introduction**

When transporting an object to the mouth, individuals often must orient the object in such a way so that the functional end of the object contacts the mouth. For example, when using a spoon, the goal is for the individual to bring the bowl of the spoon to the mouth. In the same vein, drinking out of a travel mug requires the proper alignment of the spout to the mouth. The ability to perform these kinds of feeding tasks efficiently underlies many forms of adaptive behaviors and requires planning, possibly mental rotation, and understanding of object properties when relating an object to a target location. In the present study, we investigate the development of orienting object features when transporting objects to the mouth. In particular, we examine how infants bring particular parts of familiar objects (e.g., nipples on baby bottles) to their mouths.

**Hand-to-Mouth Behavior**

Fetuses as young as 14 weeks of gestation have been observed through ultrasound imaging to bring their hand to their mouths (Gesell & Ilg, 1937; Sparling, Van Tol, & Chescheir, 1999). In addition, infants as young as 1-3 days are capable of bringing their hands to their mouths (Blass, Fillion, Rochat, Hoffmeyer, & Metzger, 1989). In this work, Blass and colleagues intraorally administered small amounts of a sucrose solution to newborns in order to induce hand-to-mouth contact. They found that the sucrose solution calmed the newborns and caused sustained hand-to-mouth contact. However, when a pacifier was placed in the newborn’s mouth, the hand activity stopped.
A longitudinal study by Lew and Butterworth (1997) examined older infants between 2-5 months age. Pacifier-like objects with handles were placed in infants’ hands. The infants were then free to explore the objects for 5 minutes. The researchers found that 2-3-month-olds are able to bring objects to the face; however, it is not until they are 4 months of age that they are able to bring the object immediately to the mouth. In addition, Lew and Butterworth also found that it is not until 5 months of age that some infants show anticipatory mouth opening when an object approached their mouths.

**Reaching and Grasping**

Many researchers have looked at planning behavior in infants while reaching and grasping. In a reaching task, children must relate their hand to an object. An efficient reach is one that involves anticipatory hand adjustments in order to match the properties of the target object before the hand touches the object. For instance, Lockman, Ashmead, and Bushnell (1984), found that 9-month-olds but not 5-month-olds make appropriate anticipatory hand adjustments when trying to grasp dowels displayed in different orientations. Rotating the hand before actual contact with the object can be taken as evidence of anticipatory visuomotor coordination with respect to orientation. This finding suggests that while eye-hand coordination exists in young infants, it is limited at first to anticipation for the location of an object at 5 months and only later emerges for the orientation of the object by 9 months.

Other investigators have obtained related findings. Von Hofsten and Fazel-Zandy (1984) found that some anticipatory hand movements appeared in infants as young as 5 months when reaching for rods presented in different orientations. However, at the
younger age the adjustments were not complete. Von Hofsten and Fazel-Zandy found that infants showed better adjustments at grasping for the rods as they got older.

In a subsequent study, Witherington (2005) examined infants longitudinally from 5 months to 7.5 months of age on a similar task. Infants were presented a reaching task where an object was oriented horizontally or vertically. The results suggested that between 5 and 7 months, there is a qualitative transition to prospective grasp control. During this transition, infants go from using reactive tactual control to using prospective visual control.

Other work by McCarty and Ashmead (1999) and McCarty, Clifton, Ashmead, Lee, & Goubet (2001) examined the role of visual input in reaching and grasping objects of different orientations. McCarty and Ashmead presented infants that were 5, 7, and 9 months of age with a rod that was either horizontally or vertically oriented. Kinematic measures showed that 5-month-olds used a more inefficient reaching path than the older infants, indicating that older infants were capable of reaching for the rod with fewer hand movements. In this study, the rod also was either illuminated or darkened during reach. The results showed that infants were capable of making contact with a darkened object, but the 9-months-olds were more likely to grasp the darkened object after making contact with the object than the 5- and 7-month-olds. The researchers found that reaches for a darkened object had shorter durations and had fewer movements than reaches for an illuminated object. McCarty and Ashmead concluded that if visual information is available, infants took more time to process the sensory information to make corrective movements.
In subsequent work, McCarty, Clifton, Ashmead et al. (2001) set out to assess how infants use vision to guide prospective movements of the hand for grasping objects of different orientations. They performed three experiments where 1) the sight of hand was removed with 7.5-month-olds, 2) the sight of object was removed near the end of the reach with 5-, 7-, 9-month-olds, and 3) the sight of the object was removed before the beginning of the reach with 9-month-olds. Similar to Witherington (2005), they found evidence that 7- and 9-month-olds are able to make anticipatory hand adjustments, but this was not found in 5-month-old infants. A developmental difference was found between the 5-month-olds and the two older groups (7-month-olds and 9-month-olds). McCarty, Clifton, Ashmead et al. concluded that sight of hand was not necessary to guide the hand to the orientation of the object for infants that are 7 months of age or older. Similarly, infants did not need to see the object before reaching. They were able to remember the orientation of the object before the object was darkened.

Together, these studies show that infants in the first year of life show planning behavior when reaching and grasping an object positioned in a particular orientation. Infants in the second half-year are able to show prospective adjustments when relating the hand to the orientation of an object (Lockman et al., 1984; McCarty & Ashmead, 1999; McCarty, Clifton, Ashmead et al., 2001; von Hofsten & Fazel-Zandy, 1984; Witherington, 2005).

**Self-directed feeding actions**

Self-directed feeding tasks have additional cognitive demands relative to bringing an empty hand to the mouth or reaching and grasping an object. Not only does one have to reach and grasp an external object, one must relate the handheld object to the self. As
noted, hand-to-mouth behavior occurs in fetuses as young as 14 weeks of gestation (Gesell & Ilg, 1937; Sparling et al., 1999) and prospective reaching and grasping occurs in infants as young as 5 months of age (von Hofsten & Fazel-Zandy, 1984). However, infants do not master self-directed feeding actions until much later in infancy.

Spoons are familiar objects to older infants and toddlers. A feeding task, however, presents several challenges for a young object user. First, infants have to reach and grasp a spoon. Next, they have to orient the spoon to hold the food. Then they have to transport the spoon and bring the bowl of the spoon to the mouth. Getting the spoon loaded with baby food from a dish, then transporting the bowl of the spoon to the mouth are sequences of organized actions not mastered until the second year of age (Connolly & Dalgleish, 1989). In this study, Connolly and Dalgleish longitudinally examined the development of spoon use in toddlers 11-23 months of age. Toddlers use a radial grip the majority of the time where the bowl end of the spoon faces the thumb. As noted, when bringing the hand to the mouth infants as young as 5 months of age show some evidence of anticipatory mouth opening when bringing a pacifier to the mouth (Lew & Butterworth, 1997). Connolly and Dalgleish (1989) also found evidence of anticipatory mouth opening as infants brought spoons toward their mouths, however the older toddlers were more consistent by opening their mouths predominately when the spoon was half way between the bowl and mouth. The younger toddlers showed more variability to where and when they opened their mouths, but also opened their mouths earlier than the older toddlers in anticipation of the spoon contacting the mouth.

Other work on spoon use includes a study by McCarty, Clifton, and Collard (1999). In this study, the researchers presented 9-, 14- and 19-month-old infants with a
feeding task using a spoon loaded with food. The researchers evaluated children’s strategies as they grasped spoons in a feeding task. The handle of the spoon was initially oriented either left or right with respect to the infant. The results showed that younger children would use their preferred hand, but this would sometimes produce an awkward grip for feeding. Additionally, when an awkward grasp was initially used, the 9-month-old infants used a feedback based strategy, where the handle of the spoon was only reoriented when the food had reached the mouth. The 14-month-old infants would also reach with the preferred hand. When reaching with the preferred hand caused an awkward grasp, the 14-month-olds, however, used a partially planned strategy where they would adjust the spoon after it had been grasped, but before it reached the mouth. Finally, the 19-month-old infants used a fully planned strategy where they anticipated the problem, reached with the appropriate hand, and achieved an efficient grip when placed in either left or right orientation.

In sum, although children are able to bring objects to their mouths as young as 4 months of age (Lew & Butterworth, 1997), the work on spoon use indicates that the planning and coordination of grasping and orienting a spoon efficiently does not occur until later in the second year (Connolly & Dalgleish, 1989; McCarty et al., 1999).

**Mental Rotation**

Mental rotation is potentially an important part of coordinating prospective movements in self-directed feeding tasks. Infants need to identify the current orientation of an object (e.g., a spoon or a bottle) and rotate it so that the functional end faces the target (e.g., the mouth). A few studies have looked at mental rotation in infants and toddlers outside of feeding situations. Due to the age of the participants, these studies
have relied on the violation-of-expectation method, where infants will look longer at events that violate their expectations. One of the first studies on mental rotation by infants was done by Rochat and Hespos (1996), who presented events in which an object shaped like the letter “Y” rotated through a 120° arc and continued to rotate 60° more behind an occluder. At the end of the event, the object was either in a probable or improbable orientation. Infants as young as 4 months looked longer at the improbable than at the probable outcome, suggesting that they demonstrated some forms of mental rotation in infancy.

In later work, Moore and Johnson (2008) habituated 5-month-olds to an object that rotated 240°. Infants were then presented test trials where they viewed either the object they were habituated to or the mirror image of the object. In the test trials, the object continued to rotate through the previously unseen 120° from the habituation trials. Male infants looked longer at the mirror image of the object. Female infants looked at both of the test stimuli about equally. This suggests that 5-month-old males were able to mentally rotate an object.

In another study on early mental rotation, Quinn and Liben (2008) habituated 3- to 4-month-old infants to an object that looked like the number “1” or the mirror image. The habituation trials consisted of seven stationary images presented in identical pairs of the object rotating in steps of 45°. Test trials paired the novel rotation of the habituated stimulus with its mirror image. Similar to Moore and Johnson (2008), the results showed that the males, but not the females looked longer at the mirror image compared to the familiar stimulus, suggesting that male infants as young as 3 months have some ability of mental rotation.
Moore and Johnson (2011) used the same methods as in Moore and Johnson (2008), but in this study they tested 3-month-old infants. In line with the 2008 study, females showed no preference for one stimulus over the other. However, 3-month-old male infants looked longer at the familiar test stimuli. Although this pattern is a reverse of what was found in 5-month-olds, the researchers suggested that since there was a reliable preference for one stimulus over another, male infants as young as 3 months in age have the capability of mental rotation.

Schwarzer, Freitag, Buckel, and Lofruthe (2013) presented a mental rotation task to 9-month-old infants using the same stimuli as Moore and Johnson (2008, 2011). Half of the sample had 7 weeks of crawling experience on average. The other half had no experience crawling. The results showed that infants with crawling experience looked significantly longer at the novel stimulus than the non-crawlers. This suggests crawling experience facilitates infant’s mental rotation abilities.

In a follow up study, Schwarzer, Freitag, and Schum (2013) had infants participate in a manual exploration task in addition to testing crawling vs. non-crawling abilities in infants. The manual exploration task involved giving infants objects to play with. Infants were scored on exploratory behaviors such as manual rotations, transfers, and fingerings. Similar to their prior work (Schwarzer, Freitag, Buckel, et al., 2013), the results showed that infants who had crawling experience looked longer at the novel stimulus than the familiar one, regardless of their manual exploration scores. However, the non-crawlers showed a difference in looking patterns between the novel and familiar stimuli based on their manual exploration scores. Non-crawling infants who scored low on manual exploration tended to show preference for the familiar stimulus. Non-
crawling infants who scored higher on manual exploration scores looked significantly more at the novel stimulus, suggesting that manual experience contributes to mental rotation abilities.

Finally, in recent work, Möhring and Frick (2013) tested 6-month-old infants’ ability to mentally rotate objects. Unique to this study compared to previous work on mental rotation was that half of the infants were allowed to touch and manually explore the asymmetrical object and the other half were only allowed to observe the asymmetrical object. During test trials, infants watched the object move straight down behind an occluder. When the occluder was removed, it revealed either the original object or the mirror image. They found that infants who were given prior manual experience with the object looked longer at the mirror image. Infants who only observed the object previously showed no preference between possible or impossible events. Similar to findings by Schwarzer, Freitag, and Schum (2013), these data indicate that infants are better at mental rotation when they are able to manually explore an object.

Together, these studies suggest that on some level infants as young as 3 months of age are capable of mental rotation. However, the reviewed work on infant mental rotation is based on the habituation and violation of expectancy procedure, where infant’s looking behavior is used as an index of infant’s capacity for mental rotation. These looking measures, however, do not address how manual action and mental rotation are combined when performing many critical adaptive tasks including feeding.

**Summary**

Collectively, the review of the literature reveals that fetuses and newborn infants are capable of bringing their hands to their mouths. Also, infants in the first year use
prospective movements when reaching and grasping for an object (von Hofsten & Fazel-Zandy, 1984; Lockman et al., 1984; McCarty & Ashmead, 1999; McCarty, Clifton, Ashmead et al., 2001; Witherington, 2005). In addition, planning in self-directed feeding tasks comes later in development during the second year (Connolly & Dalgleish, 1989; McCarty et al., 1999). Finally, infants as young as 3 months of age have some capacity for mental rotation which is important for orienting objects. Feeding tasks require the incorporation of these different behaviors such as reaching and grasping, bringing objects to the mouth, and possibly mental rotation. The present study addresses how infants coordinate these different actions by examining how they orient and use objects adaptively for feeding.

The Current Study

We focused on infants and how they bring particular parts of familiar objects (e.g., bottles) to the mouth. Very few studies have looked at bottle use in infants. Gessell and Ilg (1937) found that some infants are able to hold a bottle as early as 5 months of age. They also found that most infants are able to master this task by 9 months of age. Infants around 7-8 months of age may cry or vocalize when seeing a bottle being prepared for feeding, and will calm when the bottle is given to them. Finally, Gessell and Ilg found between 7-9.5 months of age infants can grasp and bring a bottle to their mouth and even adaptively tilt the bottle depending on how full it is. Although Gessell was one of the first researchers to quantify when bottle-feeding behavior occurred, he did not address the strategies infants used to bring the bottle to the mouth.

Bottles can be thought of as a tool to facilitate drinking and feeding. When the infant holds the bottle in the hand, it becomes an extension of the hand. In order to use
this drinking tool adaptively, infants must incorporate this tool into existing motor
patterns and anticipate the functional consequences of the new additions to their hands in
order to operate efficiently in their environment. In the current study, we use a task that
was based in part on one that was originally implemented by Piaget (1954) with his infant
son, Laurent. Piaget studied Laurent longitudinally between 7-9 months of age. He
presented Laurent with a baby bottle in various orientations. When Piaget handed
Laurent a bottle backwards with the bottom facing the infant, he observed that around 7-8
months of age Laurent turned the bottle around if he noticed the nipple in the
background. However, he was not successful if he did not see any part of the nipple and
only the base of the bottle was visible.

Piaget and Inhelder (1969) suggested that the 7- to 8-month-old infant did not
attribute a constant form to the bottle, meaning that the infant does not perceive the object
to stay the same after it has been rotated to where the nipple is out of view. According to
Piaget, it is not until around the age of 9 months when infants begin to gain object
permanence can they easily turn the bottle even if the nipple is not visible. Infants are
starting to recognize specific qualities about objects and begin to display goal-directed or
means-ends behavior based on prior experience with particular objects.

Other researchers, however, dispute Piaget’s claims that infants do not understand
constant form until the age of 9 months. Kellman and Spelke (1983) conducted a series
of experiments in which 4-month-old infants were habituated to diagonal rods whose top
and bottom were visible, but the middle of the object was occluded by another object. If
the upper and lower portion of the rod moved in unison behind the occluder, when shown
the dishabitation stimuli with the occluder removed (either a continuous rod or two
separate rods) the infants looked longer at the “broken” rod, which was the more novel stimulus. The Kellman and Spelke study thus suggests infants as young as 4 months are able to perceive constant form of an object despite the occlusion of part of the object. This should be the case with a familiar object such as a baby bottle with which infants typically have manual exploration experience.

The baby bottle was chosen for this study because infants must orient it in such a way so that the functional end the bottle (i.e., the nipple) contacts the mouth. The ability to perform this kind of task underlies many forms of adaptive behaviors and requires planning, possibly mental rotation, and understanding of object properties when relating the bottle to a target location (i.e., the mouth). We investigate how infants bring the nipple of the bottle to their mouths when the bottle is placed in different orientations.

We chose to present the bottle in six different orientations (up, down, left, right, toward, and away), because they pose different processing demands. For instance the toward orientation has the least manual rotation demands compared to the other orientations such as the away orientation which requires a 180° rotation. Also, infants may have an advantage with some of the orientations over others due to familiarity and experience. The toward and up orientation of the bottle can be considered canonical orientations, because infants typically see the bottle presented in these two orientations. The left and right orientations are not conventional, however the nipple is in plain view for the infant to solve the task. The down and away orientations are probably the most unfamiliar of the six orientations presented, and may be most challenging for infants.

We also chose to study 6- to 12-month-old infants based on prior literature suggesting that 7- to 9-month-olds can reach and grasp for a bottle (Gessell & Ilg, 1937).
and 9-month-olds gain insight about object permanence (Piaget & Inhelder, 1969). By sampling 6- to 12-month-old infants, we hoped to observe bottle-use behavior before and after it is mastered.

We also examine motor planning in how infants grasp familiar objects that are to be transported to the mouth. We investigate whether infants take into account “end-state” comfort (Rosenbaum et al., 1990) – choosing a grip that may be awkward initially but at the goal state will be comfortable. As noted earlier in the review of the literature, prior work with spoons suggests that young children do not fully take into account end-state comfort planning during reaching until 19 months of age (McCarty et al., 1999). When performing a self-feeding task, children at 19 months of age will notice the orientation of the spoon handle and grasp the spoon in order to achieve end-state comfort, even if it is with the nondominant hand. In this study, we used a familiar feeding task with infants to see if this ability would be evident earlier in development.

Finally, we investigate the role of experience in motor skill development. In a recent review article Adolph, Kretch, and LoBue (2014) discuss the role of experience in the development of locomotion. They suggest that through locomotor experience, infants learn how to perceive locomotor affordances. Through experience infants identify the relevant parameters for a particular action and adjust according to their capabilities (e.g., limb length, muscle strength, and balance control). Experienced crawlers and walkers will rarely commit errors and attempt to cross when approaching a cliff. In the present study, we examine the role of experience with bottles and study whether errors committed are due to lack of experience with these common objects.
**Design and Hypotheses**

To investigate how infants transport a particular part of an object to the mouth, this study looked at how infants (ages 6-12 months) orient a baby bottle to their mouths. We chose a sample of 60 infants based on our previous studies that yielded 225-340 observations per study (Jung, Kahrs, & Lockman, 2015; Kahrs, Jung, & Lockman, 2012, 2013). Standard errors for parameter estimation were small enough to allow detections of age trends.

In this study, a baby bottle was presented to the infants in six different orientations (up, down, left, right, toward, and away). The bottle was initially located at the infant’s midline, approximately 20 cm away from the infant, so that we could study planning by examining infants’ anticipatory adjustments of the bottle during the transport of the bottle to the mouth.

The primary hypothesis of this study was that older infants would be more efficient in bringing the bottle to the mouth. We hypothesized that older infants would consistently bring the nipple end of the bottle to their mouth on the first attempt. As infants get older and have more experience with bottles, we predicted that they would show more planning behavior by orienting or rotating the functional end of the object to their mouths. We also predicted that younger infants would be successful at bringing the nipple to the mouth for familiar orientations (up and toward), but not for the unfamiliar orientations (down and away).
In addition, we hypothesized that infants who have more experience with bottles are more likely to be successful and orient the bottle correctly when they bring the bottle to their mouths. The mental rotation literature suggests that infants who have manually explored an object are better at mental rotation (Möhring & Frick, 2013). Also for a different motor system, crawlers and walkers who were experienced rarely erred when approaching a cliff (Adolph et al., 2014). We predicted that infants with more manual bottle experience would be better at manually rotating and orienting the functional end of the bottle to their mouths.

We hypothesized that younger relative to older infants will not be consistent in how they grip the bottle. The younger infants will show more grip patterns. Based on work by Connolly and Dalgleish (1989) and McCarty et al. (1999) in which older toddlers consistently used a radial grip to grasp a spoon, we predicted that the older infants in our sample would take into account end-state comfort when gripping the bottle by using a radial grip in which the thumb faces toward the nipple end of the bottle.

Next, we predicted that all infants in our sample would display anticipatory mouth opening, however we hypothesized that younger relative to older infants would open their mouths earlier in relation to the location of the nipple en route to the mouth. As noted, 5-month-old infants show anticipatory mouth opening with pacifiers (Lew & Butterworth, 1997) and older toddlers are more consistent when bringing a spoon to their mouths and younger toddlers display anticipatory mouth opening earlier in transport (Connolly & Dalgleish, 1989). Likewise, we predicted that this would be the case in bottle use.

Finally, we hypothesized that younger relative to older infants show more movement in bringing the nipple to the mouth. In prior work (Kahrs et al., 2013), infants
6-15 months of age were given a hammer like object and were encouraged to bang with it. The older infants banged more efficiently by moving their arms less than the younger infants. We predicted that older infants would be more efficient and show less movement than younger infants.

To address these questions, we used both video and motion capture data. Video data were used to examine how long infants took to complete the task, whether they were successful, what strategies infants used to bring the bottle to the mouth, and whether infants displayed anticipatory mouth opening. Motion capture data were used to examine head movements of infants. Overall, we expected older infants to display more planning behavior and mental rotation and account for the orientation of the bottle before bringing it to the mouth.
Method

Participants

The sample consisted of 60 children (32 males, 28 females; 41 Caucasian, 7 Hispanic, 4 African American, 2 Asian, 6 more than one race), ranging from 6 to 12 months of age (see Figure 6 for age distribution of the sample). An additional 4 participants were excluded because of fussiness or they did not complete at least 3 trials. The participants were recruited from local childcare centers, through online community advertisements, and from local baby festivals. Parents were asked to schedule the lab visit at a time where their infants were hungry and most willing to take a bottle. During the lab visit, parents were given a questionnaire to determine how much experience infants have with pacifiers and bottles (see appendix). Based on parent responses from the questionnaire, 54 out of 60 infants were breastfed and 54 out of 60 infants used a pacifier. (The six infants who were not breastfed have used a pacifier and the six infants who did not use a pacifier were breastfed.)

Apparatus & Design

The infant was given either a 60 ml Similac Advance Ready to Feed formula bottle (14.5 cm x 4.5 cm) or a Medela 80 ml breastmilk storage bottle (15 cm x 4.5 cm; Figure 1). The Medela breastmilk storage bottle was used to accommodate infants who did not drink formula.
In order to track the movement of the bottle in relation to the mouth, reflective markers were placed on the infant’s forehead in three locations (right temple, center of the forehead, and left temple) and on the base of the bottle in three locations (Figures 2a & 2b). In addition, a reflective marker was placed above the upper lip for a 5-10 second trial, which allowed us to track the location of the infant’s mouth (Figures 2c & 2d).

The infant’s movements were filmed at 240 Hz using a 3D optical motion capture system (Qualisys) involving eight infrared cameras (ProReflex MCU 240) positioned in a semicircle around the front of the table (Figure 3). An external trigger was used to start and stop recording. Additionally trials were filmed at 30 Hz with a video camera (Hi8 SONY Handycam) to record infant’s behavior.
Figure 2. (a) Kinematic markers were placed on infant’s forehead and base of the bottle. (b) 3-D view of motion capture data of the head and bottle markers. (c) One marker was placed briefly above the upper lip to interpolate mouth position during test trials.

Figure 3. 3D motion capture system set up.
Procedure

Infants were brought into the lab by a parent or guardian. They sat on their parent’s lap at the table. The infants were presented a baby bottle at their midline for six trials. In random order, the bottle was initially presented in one of six positions: nipple facing up, facing toward the infant, facing down, facing away from the infant, facing left, and facing right (Figure 4). Each trial lasted for 10 seconds or until the infant had brought the nipple of the bottle to the mouth. Additional blocks of trials were attempted as long as the infants were not fussy. Parents were also given a questionnaire to determine how much experience infants have with pacifiers and bottles (see appendix).
Figure 4. The six orientations of the bottle presented to the infant.
Dependent Measures

Behavioral coding was completed using Datavyu by two independent observers. Both observers coded 60% of the trials (203 out of 337), which yielded 20% of the trials (69 out of 337) that were coded by both observers. The observers coded several behaviors. They coded strategies used, grip patterns, changes in grip, timing of mouth opening, initial success, overall success, and trial duration. Inter-rater reliability was established with Cohen’s Kappa for categorical data and intraclass correlation coefficients (ICC) for continuous data. Cohen’s Kappa for the categorical data averaged .82. The ICC for the continuous data averaged .85.

Strategies used.

The strategies infants use to get the bottle to the mouth were coded. They include reaching for the bottle with the hand and bringing the mouth to the bottle. Reaching was coded when the infant uses a hand to grasp the bottle. Bringing the mouth to the bottle was coded when the infants leaned toward the bottle without the use of their hands.

Initial grip of the bottle.

For trials in which infants reached and grasped the bottle, how infants initially grasped the bottle was coded. Grips were coded unimanual if one hand was used and bimanual if two hands were used. In addition, the type of grip was coded. The two main types of grips that were coded are the radial and ulnar grip. A radial grip was defined as holding the bottle with the thumb facing toward the nipple; an ulnar grip was defined as holding the bottle with the thumb facing away from the nipple (Figure 5).
Changes in grip.

For trials that infants reached for the bottle, any changes in grip after the initial grasp were also coded until the infant brought the bottle to the mouth. The number of grip changes indicates the number of adjustments infants made to bring the bottle to the mouth.

Initial success.

The part of the bottle that is initially brought to the mouth was coded (nipple, bottom, side). In addition, the trial was coded as initially successful if the nipple made
initial bottle-to-mouth contact. The trial was coded as initially unsuccessful if the bottom or the side of the bottle made initial bottle-to-mouth contact.

**Overall success.**

If infants were not initially successful, the coders continued to code behavior to see if infants would make adjustments after bringing the bottle to the mouth. The trial was coded overall successful if the nipple was brought to the mouth at the end of the trial. The trial was coded as overall unsuccessful if the bottom or the side of the bottle was brought to the mouth at the end of the trial.

**Trial duration.**

Trial duration is the amount of time the infant used to bring the bottle to the mouth. This duration started either when the infant started to bring the bottle to the mouth or when the infant started to move the head toward the bottle. Trial duration ended when the bottle reached the mouth.

**Timing of mouth opening.**

The duration in which the infant opened the mouth was coded. The timing onset was coded as when the mouth started opening. The timing ended when the bottle reached the mouth.

**Motion capture measurements**

**Head movements.**

The distance the head moved was measured by using the three markers placed on the infant’s head. The three markers were used to interpolate the location of the mouth. Based on the location of the mouth, we were able to measure how stable the target (i.e., the mouth) for this task remained.
We proposed using other motion capture measurements examining the trajectories based on the bottle location. Unfortunately, due to methodological limitations, we were not able to obtain valid and reliable data. The trajectories of the nipple location were based on the interpolation of the three markers at the bottom of the bottle. For many trials one of the markers was occluded, which introduced error to the interpolation of the nipple location.
Results

Data were collected from 60 children with a minimum of 3 trials each yielding a total of 337 trials. Since there were a minimum of three trials per participant and age is a continuous variable, Generalized Estimating Equations (GEE) was used, which is a way to perform repeated measures multiple regression. GEE is an extension of generalized linear models, allowing for the analysis of non-normally distributed, correlated data. A backward stepwise procedure was used where all independent variables and interactions were entered into the model, then taken out when found not to be significant.

Independent variables include age and initial presentation of bottle orientation (up, toward, down, away, left, right), and bottle experience (the difference between current age and age when bottle-feeding started). Based on the literature that indicates sex differences in mental rotation (Moore & Johnson, 2008, 2011; Quinn & Liben, 2008), sex was only entered into the initial model of overall and initial success. We did not enter race/ethnicity or pacifier experience into our models because there were too few ethnic minorities or infants without pacifier experience to analyze for these predictors.

We first discuss more general indicators of efficiency in the bottle task, such as trial duration, overall success, and initial success. Then we consider specific components of the task and examine strategies used including how infants grasp the bottle, how early do they show anticipatory mouth opening, and how much they move the head. These strategies potentially contribute to task efficiency.
**Trial Duration**

As noted, trial duration is the amount of time the infant used to bring the bottle to the mouth. In this analysis, we removed outliers (defined as all trials where the trial duration exceeded 1.5 times the interquartile range [Moore & McCabe, 1999]) and used only the trials where infants successfully brought the nipple to the mouth (215 out of 337 trials, N=60). We used only successful trials as a conservative measure to ensure that infants were performing the intended task and not performing other exploratory behavior. Trial duration was regressed onto age and bottle orientation using a gamma distribution with a log link function and an exchangeable correlation matrix. A significant main effect of age was obtained (Wald $\chi^2_1=12.50, p<.001$; Figure 6), indicating that older children take less time and are faster at bringing the bottle to the mouth than younger children, regardless of bottle orientation. (No significant effects involving bottle experience [$p=.77$] or Age x Bottle Experience [$p=.581$] were obtained in the initial model. Similar results were obtained when only outliers were removed and both unsuccessful and successful trials were used [307 out of 337 trials, N=60; Wald $\chi^2_1=5.43, p=.02$; Figure 7].)
Figure 6. Trial duration as a function of age. Each data point represents one trial. Trials where infants were initially successful were included. No two children were the exact same age, so the data at any given age come from a single child.
Overall Success

We next analyzed overall success in the bottle task. Infants were considered to be successful in this task if the nipple end of the bottle reached the mouth by the end of the trial. Overall success during bottle-to-mouth contact was regressed onto age and bottle orientation with GEE using a binomial distribution with a logit link function and an exchangeable correlation matrix. A significant main effect of bottle orientation (Wald $\chi^2 = 71.00, p < .001$), and a significant Age x Bottle Orientation interaction (Wald...
\( \chi^2 = 47.74, p < .001 \) were obtained (Figure 8). (No significant effects involving sex

\([p = .444], \) bottle experience \([p = .89], \) or Age x Bottle Experience \([p = .878] \) were obtained.)

Post-hoc analyses of the slopes of the regression lines indicated a significant slope

for the down \((b = .023, t = 3.43, p < .001; \) Figure 8b) and away \((b = .018, t = 2.81, p = .006; \) Figure 8d) orientations. With increasing age, infants were more likely to be successful when using a bottle regardless of the initial orientation of the bottle. Younger infants, however, had the most difficulty when the bottle was presented in the down and away orientation.
Figure 8. Probability of overall success.
**Initial Success**

We next looked at infants’ first attempt at bringing the bottle to the mouth. Infants were considered initially successful if the nipple end of the bottle was the first part of the bottle that contacted the mouth. Initial success during bottle-to-mouth contact was regressed onto age and bottle orientation with GEE using a binomial distribution with a logit link function and an exchangeable correlation matrix. A significant main effect of age ($\chi^2_1=3.89, p=.049$) and bottle orientation ($\chi^2_5=30.02, p<.001$), and a significant Age x Bottle Orientation interaction ($\chi^2_5=14.76, p=.011$) were obtained (Figure 9). (No significant effects involving sex [$p=.489$], bottle experience [$p=.95$], or Age x Bottle Experience [$p=.834$] were found.)

Post-hoc analyses of the slopes of the regression lines indicated a significant slope for the down ($b=.026, t=3.66, p<.001$; Figure 8b) and away ($b=.021, t=3.09, p=.002$; Figure 9d) orientations. As infants got older they were more likely to be successful when using a bottle regardless of the initial orientation of the bottle. Similar to the results in overall success, younger infants had the most difficulty when the bottle was presented in the down and away orientation.
Figure 9. Probability of initial success.
**Strategies Used**

Next, we examined the strategies infants used in bringing the bottle to the mouth. Infants were observed using one of two strategies. The first strategy was reaching for the bottle with the hand and bringing it to the mouth. The other strategy was that infants leaned forward and essentially brought their mouth to the bottle without reaching. GEE were employed to analyze “strategy used” with a binomial distribution and a logit link function and an exchangeable correlation matrix. Age and bottle orientation were entered into the model to predict strategy used. (Trials in the up and down orientation were excluded in this analysis because there was not enough variability in these orientations for the model to run. For instance in the up orientation only 1 out of 59 trials and the down orientation only 1 out of 53 trials resulted in the infant leaning the mouth towards the bottle.) A significant main effect of bottle orientation (Wald $\chi^2_3=12.83$, $p=.005$) and a significant Age x Bottle Orientation interaction (Wald $\chi^2_3=11.64$, $p=.009$; Figure 10) were found. (No significant effects involving bottle experience [$p=.684$] or Age x Bottle Experience [$p=.781$] were obtained.)

Post hoc comparisons of the estimated marginal means for bottle orientation indicated that the mean score for the toward orientation was significantly different than the away, left, and right orientation. Pairwise comparisons of the estimated marginal means revealed that the toward (M=.69) orientation was significantly different from away (M=.85, $p=.008$), left (M=.91, $p<.001$), and right (M=.92, $p<.001$) orientation. When the bottle was oriented directly toward infants, they were more likely to lean in with their whole body than for the away, left, and right orientations.
Additionally, a test of the slopes revealed a significant slope in the away orientation \((b=0.12, t=2.18, p=0.024; \text{Figure 10b})\). With increasing age when the bottle was presented in the away orientation, infants were more likely to grasp for the bottle. This suggests that infants take different actions based on the orientation of the bottle.

Figure 10. Probability of reaching (1) or leaning (0) towards the bottle.
Initial Grip of the Bottle

We next examined how infants initially grip the bottle for trials in which infants used the strategy of reaching. For trials in which infants reach and grasp the bottle (304 out of 337, N=60), how infants initially grip the bottle was coded. We considered how many hands infants used and what type of grip infants used.

Bimanual vs. unimanual grip.

Grips were coded unimanual if one hand was used and bimanual if two hands were used to reach for the bottle. We examined bimanual vs. unimanual grips of the bottle with GEE using binomial distribution with a logit link function and an exchangeable correlation matrix. Age and bottle orientation were entered into the model to predict one- or two-handed grips. A significant main effect of age was obtained (Wald $\chi^2_1=9.06, p=.02$; Figure 11). As infants got older they were more likely to use bimanual grips than unimanual grips. This result is consistent with previous findings that infants return to using bimanual grips near the end of the first year (Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1996; Fagard & Pezé, 1997; Gesell & Ames, 1947; Goldfield & Michel, 1986). In particular, Corbetta and Bojczyck (2002) found infants use bimanual grips when they are learning to walk, which occurred on average around 11 months of age in their sample. (No significant effects involving bottle experience [$p=.688$] or Age x Bottle Experience [$p=.665$] were obtained.)
Radial vs. ulnar grips.

For trials in which infants used distinctively radial or ulnar grips (227 out of 337 trials, N=58) where infants grabbed the barrel of the bottle with the thumb faced toward (radial) or away (ulnar) from the nipple, we examined which grip infants were likely to use. Other grips that were excluded were ones in which the infants initially grasped the nipple or the bottom of the bottle. GEE was used to analyze the grip type with a binomial distribution with a logit link function and an exchangeable correlation matrix. Age and bottle orientation were entered into the model to predict infant grip type. A significant main effect of bottle orientation (Wald $\chi^2_5=28.32, p<.001$) and Age x Bottle Orientation were obtained (Wald $\chi^2_5=13.79, p=.008$; Figure 12). The interaction was largely due to how infants at different ages grasped the bottle when it was presented in the away
orientation. Additionally, a test of the slopes revealed a significant slope in the away orientation ($b=.019, t=2.16, p=.029$ Figure 12d). With increasing age, when the bottle was presented in the away orientation, infants were more likely to grasp the object with a radial grip (Figure 12d) and for the down orientation, infants across age primarily use an ulnar grip (Figure 12b). The older infants use a radial grip in the away orientation, which is consistent with planning and taking into account end-state comfort. (No significant effects involving bottle experience [$p=.588$] or Age x Bottle Experience [$p=.454$] were obtained.)
Figure 12. Probability of using a radial (1) or ulnar grip (0).
**Changes in Grip**

We next examined whether infants make adjustments in their grip after initially grasping the bottle. Behaviors that occurred between the initial grasp and when bottle first contacts the mouth were coded. These behaviors include any changes to location or adjustments of the grip during the transport phase. The frequency of changes in grip was regressed onto age and bottle orientation with GEE using a gamma distribution with a log link function and an exchangeable correlation matrix. We predicted a significant Age x Bottle Orientation interaction in which older infants will make more anticipatory adjustments for certain bottle orientations (upside down and facing away) than younger infants, however, only a trend of the main effect of bottle orientation (Wald $\chi^2 = 9.95$, $p = 0.077$) and Age x Bottle Orientation interaction (Wald $\chi^2 = 9.98$, $p = 0.076$; Figure 13) were obtained. The trends were largely due to the bottle in the down orientation (Figure 13b). With increasing age, infants tended to be more likely to grasp the bottle and make adjustments in the down orientation than in the up, toward, away, left, and right orientation. (No significant effects involving bottle experience [$p = 0.593$] or Age x Bottle Experience [$p = 0.997$] were obtained.)
Figure 13. Number of grip changes as a function of age.
Anticipatory Mouth Opening

We next examined whether the timing of anticipatory mouth opening would change with age. Anticipatory mouth opening was measured by the amount of time the mouth was opened before the bottle reached the mouth. In this analysis, we removed outliers (defined as all trials where the trial duration exceeded 1.5 times the interquartile range) and used only the trials where infants successfully brought the nipple to the mouth (220 out of 337 trials, N=60). Similar to the trial duration analysis, we used only successful trials as a conservative measure to ensure that infants were performing the intended task and not performing other exploratory behavior.

Anticipatory mouth opening was regressed onto age and bottle orientation using a gamma distribution with a log link function and an exchangeable correlation matrix. To account for the differences in total trial duration, we entered trial duration into the model as a covariate. Only a nonsignificant trend of the main effect of age emerged (Wald $\chi^2_1=3.76, p=.053$; Figure 14). Older children spent less time engaging in anticipatory mouth opening than younger children, suggesting that they were more efficient and expended less effort in keeping the mouth open during hand to mouth transport. Although Connolly and Dalgleish (1989) used approximate spatial data to measure anticipatory mouth opening, our temporal data are consistent with their finding that for the younger children, anticipatory mouth opening occurs earlier in the transport than older children. (No significant effects involving bottle experience [$p=.77$] or Age x Bottle Experience [$p=.581$] were obtained in the initial model. Similar results were obtained when only outliers were removed and both unsuccessful and successful trials were used [311 out of 337 trials, N=60; Wald $\chi^2_1=3.859, p=.049$; Figure 15].)
Figure 14. Mouth opening as a function of age. Trials where infants were initially successful were used.
Finally, we examined how much infants moved the head during the task. Out of 337 behavioral trials, we obtained 115 trials of motion capture data of head movement (N=43). The distance the mouth moved was regressed onto age and bottle orientation with GEE using a gamma distribution with a log link function and an exchangeable correlation matrix. A significant main effect of age (Wald $\chi^2=3.89$, $p=.049$) was obtained (Figure 16). As infants got older they moved their head less, suggesting that they are keeping the target of the task (i.e., the mouth) in a relatively stable position. (No

Figure 15. Mouth opening as a function of age. Trials where infants were initially successful and unsuccessful were used.

Head Movement

Finally, we examined how much infants moved the head during the task. Out of 337 behavioral trials, we obtained 115 trials of motion capture data of head movement (N=43). The distance the mouth moved was regressed onto age and bottle orientation with GEE using a gamma distribution with a log link function and an exchangeable correlation matrix. A significant main effect of age (Wald $\chi^2=3.89$, $p=.049$) was obtained (Figure 16). As infants got older they moved their head less, suggesting that they are keeping the target of the task (i.e., the mouth) in a relatively stable position. (No
significant effects involving bottle experience \([p=.445]\) or Age x Bottle Experience \([p=.448]\) were obtained.)

Summary

Taken together, the results from the various analyses indicate changes in efficiency and planning behaviors as infants get older. Older infants take less time to successfully bring the bottle to the mouth. Older infants were also able to account for the different orientations of the bottle and were successful at orienting the nipple of the bottle
to the mouth. Older but not younger infants showed prospective adjustments when grasping a bottle, particularly for the away orientation. Older infants also decrease the cognitive and motor demands of the task by moving the target of this task (i.e., the mouth) less. This suggests that older infants are able to plan actions based on the functional end of the bottle, a skill that the younger infants have not yet mastered.
Discussion

The results of the present study revealed that older infants become more efficient in transporting a bottle to the mouth. Regardless of bottle orientation, older children take less time bringing the bottle to the mouth than younger children. The present study also suggests that infants around the end of the first year of age begin to display sensitivity to features of an object’s orientation. The younger infants in our sample had difficulty orienting the nipple to the mouth when the bottle was presented in unfamiliar orientations (i.e., down and away). Older infants, however, were successful at orienting the nipple to mouth regardless of bottle orientation.

Past research on reaching (Lockman et al., 1984; McCarty & Ashmead, 1999; McCarty, Clifton, Ashmead et al., 2001; von Hofsten & Fazel-Zandy, 1984; Witherington, 2005) indicates that by 9 months of age, infants are able to show prospective movements when relating the hand to the orientation of an object. The present study extends these previous findings by demonstrating that older infants employ different actions in a feeding task based on the orientation of the bottle.

Strategy Use

Overall, infants use different strategies for different bottle orientations. They are more likely to lean towards the bottle when it was presented in the toward orientation compared to other orientations. And for the away orientation, older infants were more likely to reach for the bottle than lean towards the bottle. A closer look at the data
provides additional information about strategy use in transporting objects to the mouth. The unimanual vs. bimanual reaching analysis revealed that older infants return to bimanual grips, which is consistent with previous findings on reaching (Corbetta & Bojczyk, 2002; Corbetta & Thelen, 1996; Fagard & Pezé, 1997; Gesell & Ames, 1947; Goldfield & Michel, 1986). Some have ascribed this change in reaching to the onset of walking behavior, which requires infants to master upright balance control (Corbetta & Bojczyk, 2002). Infants do this by holding both arms in the air when they are learning to walk. Although we do not have data about the onset of locomotion in our sample, changes that occur at a motor level may contribute to cognitive or planning abilities, similar to findings that suggest crawling behavior is linked with mental rotation abilities (Schwarzer, Freitag, Buckel, et al., 2013; Schwarzer, Freitag, & Schum, 2013).

Our findings also suggest that older infants plan for end-state comfort when reaching for a familiar object in certain orientations. During the second half year, infants increasingly take into account end-state comfort while reaching for the bottle in the away orientation, but still fail to do so when reaching for the bottle in the down orientation. Unlike previous literature on spoon use that indicates that children fully take into account end-state comfort at 19 months of age when bringing a spoon to the mouth (McCarty et al., 1999), we found evidence of end-state comfort occurring in bottle use with infants around the end of the first year. This may be because infants are given liquids from birth and are first given solid food around 4-6 months of age (Kuo, Inkelas, Slusser, Maidenberg, & Halfon, 2011), suggesting that they are first introduced to a bottle before they are given a spoon.
Most of the work describing end-state comfort in infants uses handled objects (i.e., spoons, hammer, and hairbrush) presented in the left and right orientation (McCarty et al., 1999; McCarty, Clifton, & Collard, 2001). In grasping handled objects, using a radial grip is considered the more comfortable grip. In our work, we used an object without a handle and presented the object in more orientations. Little is known about infant planning for end-state comfort in grasping objects that are upside-down. Looking at our results from the radial vs. ulnar grip analysis, almost all infants used an ulnar grip in the down orientation. It may be that for an upside-down bottle, the radial grip is too awkward and uncomfortable and that infants use a two-step approach by initially using an ulnar grip then adjusting their grip to a radial one when drinking from a bottle.

In fact, when we examined the number of grip changes after the initial grip, we obtained a nonsignificant trend suggesting that in the down orientation, older infants initially use an ulnar grip then adjust the bottle by changing to a radial grip. It is not clear if adults would behave in a similar way under similar conditions. To the best of our knowledge, grasping patterns during bottle use (e.g., with bottled water or juice) have not been fully studied in adults.

In related research, a study with adults has shown that when asked to turn over an upside-down glass to fill it with water, 94% of participants will use a radial grip which is initially awkward, but comfortable when holding the glass upright, which suggests they were sensitive to end-state comfort (Fischman, 1997). However, an uncovered glass is different than a bottle. Bottles are typically filled with liquid, which might introduce different demands on the task (e.g., added weight or concern for not spilling liquid). For an upside-down bottle, it may be more adaptive to disregard end-state comfort at first and
use an initially comfortable grip (i.e., ulnar grip) to make sure one has a stable grasp on the bottle, then readjust to a radial grip for drinking from the bottle. As noted, our findings indicate a trend that older infants are adjusting their grip after using an ulnar grip.

**Anticipatory Mouth Opening**

Infants in our sample all showed evidence of anticipatory mouth opening which extends previous findings that 5-month-old infants open their mouths in anticipation for an object that is approaching the mouth (Lew & Butterworth, 1997). Also, we found a trend that anticipatory mouth opening occurs earlier in the transport for younger children, which is consistent with previous findings with spoon use (Connolly & Dalgleish, 1989). Older infants spent less time engaging in anticipatory mouth opening than younger infants, suggesting older infants expend less energy and display greater efficiency than younger infants.

**Head Movement**

Finally, older infants relative to younger infants show greater efficiency by moving the head less when bringing the bottle to the mouth. This finding is consistent with findings that older infants move less when banging a hammer-like object (Kahrs et al., 2013). Presumably, older infants move the head less to reduce the cognitive and motor demands of the task. In other words, older infants simplify the problem by reducing the degrees of freedom associated with the task. If the target (i.e., the mouth) of the task is kept relatively stable, less effort is required to perform the task. Also, planning demands are reduced.
Developmental Challenges

Why do younger infants have difficulty orienting the nipple end of a bottle to the mouth? Our findings are consistent with Piaget (1954) on a similar task, where his infant son was not successful at 7-8 months of age if the nipple was occluded. According to Piaget and Inhelder (1969), infants younger than 9 months of age lack object permanence and it is possible that infants in our sample did not attribute common form to the bottle. This explanation is unlikely, however. Our results demonstrate that younger infants were unsuccessful in bringing the nipple to the mouth when the bottle was facing down, even though the nipple was in sight.

Perhaps the capacity for mental rotation can explain the age differences. Although our task does not directly test mental rotation, planning and formulating an appropriate action plan for getting the bottle to the mouth may require mental rotation abilities. Consistent with findings that prior manual experience with an object facilitates mental rotation abilities (Möhring & Frick, 2013; Schwarzer, Freitag, & Schum, 2013), older infants have much more manual experience with bottles than younger infants which may explain why older infants better account for the different orientations of the nipple than younger infants.

We suggest that the development of planning in a feeding task can also be understood with respect to perception-action theory (see Gibson, 1979). This approach suggests that object manipulation can be viewed as an important means of seeking information about affordances in the environment. Affordances refer to action possibilities within the environment. It is known that infants are capable of detecting manual affordances of objects. For example, 9-month-old infants will finger textured
surfaces more than smooth ones, shake objects that make sound, squeeze flexible objects more than hard ones, or bang hard objects more than soft ones (Bourgeois, Khawar, Neal, & Lockman, 2005; Bushnell & Boudreau, 1993; Gibson & Walker, 1984; Lockman & McHale, 1989; Palmer, 1989; Ruff, 1984).

The perception-action approach views object manipulation as a continuously developing ability in which perception and action guide one another. Through manual exploration of handheld objects, infants are gaining knowledge about objects, which is then applied to their actions. These actions in turn provide additional information, which can be used to further refine future actions. What is thought of as trial and error behavior in the younger infants can be considered as opportunities for perceptual learning. Through experience and exploration, children develop the ability to anticipate the functional consequences of new additions to their hands in order to operate efficiently in their environment to perform these adaptive feeding tasks.

**The Role of Experience**

As noted in the results section, bottle experience was initially entered into the regression model. However, it did not emerge as a significant factor in any of our analyses. Due to the lack of variability in our sample, we were unable to specifically address the role of experience with bottle use. All of the infants in this sample had a minimum of 20 days of experience using a bottle (M=220 days, SD=70). Baby bottles seem to be ubiquitous in our culture. Breast milk pumps have become such a common parental aide that even children who are fed only breast milk have some experience with baby bottles. Future work with cultures that do not use baby bottles could better address what role experience plays in the development of orienting bottles during feeding.
Sex Differences

Some studies on infant mental rotation have found sex differences (Moore & Johnson, 2008, 2011; Quinn & Liben, 2008), while others have not (Möhring & Frick, 2013; Rochat & Hespos, 1996; Schwarzer, Freitag, Buckel, et al., 2013; Schwarzer, Freitag, & Schum, 2013), with male but not female infants evidencing the ability to engage in mental rotation of stimuli. We initially entered sex into our regression models, but it did not emerge as a significant factor in any of our analyses. We may have not detected any sex differences because the infants in our sample were older than the infants in the Moore and Johnson (2008, 2011) and Quinn and Liben (2008) studies. It should be noted, however, that age differences in our sample relative to previous work with younger infants, are associated with manual experience. Experience in manipulating objects has been shown to enhance subsequent attempts at mental rotation (Möhring & Frick, 2013; Schwarzer, Freitag, & Schum, 2013).

Limitations

The motion capture markers on the bottle introduced some limitations in obtaining data about the trajectory of the bottle. One limitation was that a marker on the bottle would often become occluded by the infant’s hand, which interrupted the interpolation of the nipple’s location and thus made the bottle’s trajectory data unreliable. Denser information about the bottle’s trajectory may yield more details about how infants rotate the bottle and whether they become more efficient in doing so. In a related vein, infants during the same developmental period show gains in efficiency when performing other instrumental tasks. Prior work with 6- to 12-month-old infants showed that older
infants banged more efficiently by using a more straight up and down pattern than younger infants who use a more circular up and down pattern (Kahrs et al., 2013).

In addition to not obtaining information about the bottle’s rotation, we also did not obtain spatial data about anticipatory mouth opening. Based on work by Connolly and Dalgleish (1989) where they spatially coded anticipatory mouth opening as the location of the spoon when the mouth first opened relative to the mouth, we proposed analyzing mouth opening by tracking the distance between the bottle and the mouth as the mouth starts to open. Although we were able to obtain temporal data, spatial data may have provided additional insights into the development of anticipatory mouth opening.

To address some of the limitations concerning marker occlusion, motion tracking without markers is available for adult subjects. This technology is employed commercially in video games (Microsoft Kinect). The technology uses infrared light to detect depth patterns, and locations of body parts are then inferred based on a large data set of adult motion capture images (Shotton et al., 2013). Although this technology can accommodate different adult body types and sizes, algorithms used to detect infants and toddlers are currently unavailable. Researchers are now developing algorithms to use markerless motion tracking for infants (B. A. Kahrs, personal communication, June 19, 2015). Motion tracking without markers is less obtrusive and holds more ecological validity, because infants could act on the object without being distracted by the markers.

**Implications and Future Directions**

The current work indicates that older infants are able to detect the functional end of an object and plan their actions according to the orientation of the object. Our data
suggest that this could be due to developmental changes in motor behavior and planning and/or age-related experience with manual behavior. The findings provide insight to how children master a self-feeding task where they reach for a very familiar object and engage in a well-practiced skill (hand-to-mouth transport). This work could lead to the development of early assessments of adaptive manual behaviors in infants and thus guide the timing of intervention efforts of infants who have developmental delays.

The current work may also be relevant for understanding the development of many adaptive behaviors such as self-dressing tasks which require understanding important features of an object’s orientation in relation to the body. For instance, efficiently putting on gloves or shoes requires detecting the orientation of the glove’s thumb or the large toe end of the shoe, then matching that orientation with the correct limb. Additionally, putting a hat on the head requires understanding that the concave surface, not the convex surface, is what is placed on the head. Future work with these kinds of self-directed tasks can provide insights into how children master tasks where one has to orient objects relative to the body. These types of tasks are considered important preschool achievements.

Conclusions

In conclusion, the present results indicate a change in object-to-mouth behavior between 6 to 12 months of age. Not only are older infants more successful at bringing the functional end of a bottle to the mouth, they are more efficient at doing so than younger infants. Older infants complete the task in less time and move their head less than younger infants, suggesting greater efficiency and less energy expenditure in accomplishing this fundamental task. When examining whether infants are successful at
bringing a bottle with a nipple to the mouth, our findings also indicate that older but not younger infants show more prospective adjustments. Older infants demonstrate this by grasping the bottle with consideration to end-state comfort for certain orientations. We suggest that age-related changes in a common feeding task can be attributed to developmental changes at a motor and cognitive level and/or age-related manual experience with objects. Overall, our findings help us understand how infants develop the ability to orient the functional end of an object to a goal, a critical achievement of adaptive behavior.
Appendix

Pacifier/Bottle Questionnaire

1) Has your child ever been fed with a bottle?

2) If yes, at what age did bottle-feeding start?

3) If both nursing and bottle-feeding are used, how often does your child receive a bottle?

4) Has your child ever used a pacifier?

5) If yes, how often does your child receive a pacifier?
References


Biography

Wendy Jung is a doctoral candidate in the Psychology Department at Tulane University. She was born in Taiwan, raised in Louisiana. She attended The University of Texas at Austin where she received a Bachelor of Science in Human Development and Family Sciences. Upon graduating from UT Austin, she came home to New Orleans and pursued a career in early childhood education. While working as a preschool teacher, she obtained a Master of Education in Curriculum and Instruction at the University of New Orleans. She later returned to graduate school and obtained a Master of Science in Psychological Sciences from Tulane University. Previously, her research has used motion capture technology to examine how young children fit objects into apertures. In the future, she plans to teach teachers on how to apply developmental science to early education.