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Self-Directed Action Affects Planning In Tool-Use Tasks with Toddlers

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Abstract

Toddlers grasp a tool more effectively when it is self-directed (e.g., spoon) than other-directed (e.g., hammer), possibly because the consequences of self-directed actions are more obvious. When the negative consequences of an inefficient grip were made equally salient, the self- versus other-directed differences remained.

When solving problems, children early in life begin to rely on external objects to accomplish a goal. For example, 9-month-old infants grasp and pull a cloth to retrieve an out-of-reach toy (Willatts, 1984), 16-month olds use a handrail to cross a narrow walkway that they would otherwise be unable to cross (Berger & Adolph, 2003), and 1- to 2-year olds begin to use spoons to feed themselves (Connolly & Dalgleish, 1989). The perceptual features of the tool like shape, length, and orientation may be relevant to attaining a goal (Chen & Siegler, 2000; McCarty, Clifton, & Collard, 1999; Smitsman, 1997). Additionally, features of the goal may also affect one's ability to plan an action sequence (Boudreau & Bushnell, 2000; Lockman, 2000).

The extent of planning can also be affected by where the tool's action is directed (McCarty, Clifton, & Collard, 2001). McCarty and colleagues (2001) used children's selection of a radial grip on the tool's handle to indicate planning. The consistent selection of an efficient or radial grip on a tool rather than defaulting to the preferred hand can indicate the presence of advance planning in adults (Creem & Proffitt, 2001; Rosenbaum, Halloran, & Cohen, 2006; Cohen & Rosenbaum, 2004) and in children (Cox & Smitsman, 2006; McCarty et al., 1999; 2001). In McCarty et al. (2001), toddlers were more likely to plan actions involving self-directed tools (e.g., grasping a spoon to eat food, or using a hairbrush) than tools with externally-directed goals (e.g., grasping an empty spoon to "feed" a stuffed animal). This finding of planning more for tools that were self-directed as opposed to externally-directed was even true for tools that children have less experience with, such as hairbrushes. Children have better spatial orientation skills when relating objects to their own body than to other objects (Lockman & Ashmead, 1983; Rochat, 1998), and this distinction could impact performance in these tasks. Specifically, a child's greater familiarity with movements directed to one's own body may account for better

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planning when actions are self-directed. However, other factors may also play a role, including the explicitness of the goal state and the consequences of not planning.

To form a plan, one must represent the problem, set a goal, and build a strategy (Friedman & Scholnick, 1997). Plan formulation may be easier when the goal state is made explicit. The saliency of the goal can be increased by having a transformation or change in end state when the goal is accomplished. In some of the externally-directed tasks used by McCarty and colleagues (2001), the explicitness of the goal may have been unclear. For example, in the externally-directed spoon task, the goal was for the child to pretend to feed a puppet. There was no clear end-state, as the spoon and puppet looked the same before and after the goal was achieved. In contrast, the goal in the self-directed version of this task was for the child to self-feed. The end result of this action was that the food was no longer visible on the spoon and there was tactile and taste information about the presence of food in the mouth. Therefore, a lack of saliency of the goal for externally-directed tasks could hamper the toddler's ability to clearly form a goal and determine if it had been achieved.

Implementation of a plan follows the formulation stage, in which a strategy is executed, monitored, and repaired until the goal is achieved (Friedman & Scholnick, 1997). The more negative the consequences of not planning, the more likely one may be to plan an action in advance. Feedback (i.e., observing the consequences of one's own actions) plays an important role in developing new manual skills (Bruner, 1970), and may also influence whether one plans an action rather than responding in a habitual manner. In the externally-directed spoon task (McCarty et al., 2001) there were no negative consequences when children failed to use the most efficient grip in feeding the puppet. In contrast, there could be negative consequences when children failed to use the most efficient grip in the self-directed spoon task – they could spill the food when making adjustments to get the bowl of the spoon in the mouth. Negative consequences during one's actions could highlight the need and choice to plan ahead.

One purpose of the current study was to assess alternative hypotheses to the proposal that goal location (self- vs. externally-directed) is a major determinant of planning. If goal location is the best predictor of planning, then children should plan more consistently when the tool's action is directed toward the self than toward another object. However, this distinction may be confounded with clarity of goal state and consequences of grip selection. We designed two tasks (one externally-directed and one self-directed) in which it was clear to the child whether the experimental goal had been achieved via a change in end-state and there were obvious negative consequences if the wrong action was selected. We predicted that these factors would mitigate the effects of goal location on planning.

Preparation time, or the time it takes to contact the tool or object, is another useful measure of planning ability. Time to grasp an object has been used as a measure of planning in infants (Claxton, Keen, & McCarty, 2003), in toddlers (Boudreau & Bushnell, 2000), as well as in adults (Johnson-Frey, McCarty, & Keen, 2003; Marteniuk, MacKenzie, Jeannerod, Athenes, & Dugas, 1987). Boudreau and Bushnell (2000) found that when solving variants of means-end tasks, 10.5-month-olds took longer to make first contact with the pull-cord in the more cognitively complex 3-step means-end task than the less cognitively complex 1-step task. They argued that this provided evidence of a cognition/action tradeoff with the more complex cognitive task taking a longer reaction time.

Grip selection and preparation time have been used in conjunction as measures of planning in adults (Johnson, 2000; Marteniuk et al., 1987; Rosenbaum et al., 2006). Johnson (2000) found that when a reach for a dowel required an awkward grip, the time to contact was longer than for a non-awkward grip. To our knowledge, grip selection and preparation time have not been used in conjunction as measures of planning in children. McCarty et al. (1999) predicted that children would be slower to grasp a tool when selecting the optimal grip in a difficult tool orientation because this would require planning their actions well in advance of the grasp.

A second purpose was to measure latency to grasp as a measure of planning. In the present study we concealed the tool until it was within reach so that the action sequence could not be pre-planned out of reach. By measuring latency to grasp we could estimate children's movement preparation time. We predicted that grasp latencies would be longer whenever an optimal grip rather than a non-optimal grip was selected because of the increased thinking/planning time involved. We also predicted that children would have longer grasp latencies when the handle was on the side of the non-preferred hand because preplanning and inhibition of habitual movements might be necessary to select this hand for grasping.

Nineteen toddlers (9 males, 10 females, mean age = 19 months; range = 18 months, 0 weeks to 19 months, 3 weeks) were included in the data analyses. Fourteen additional toddlers were seen, 6 were excluded because they did not use the tools on enough trials, 6 refused the food task, 1 was excluded due to experimenter error, and 1 was excluded due to equipment failure. The names of the toddlers were obtained through state birth records.

Toddlers were presented with two tool-use tasks: a food task (self-directed) and a water task (externally-directed). For each task, the tool was presented on a wooden holder that supported both ends of the tool 14-cm above the table. The food task consisted of an infant's spoon with a 10-cm handle loaded with strained food (e.g., applesauce or peaches). The use of this tool was not demonstrated, but parents were asked to give their child a bite of food before the first trial to help the child feel comfortable eating food in this situation. The water task involved a small measuring cup (1/4-cup) filled with water and attached to the end of a 10-cm handle. When the child poured the water into the top of a rectangular funnel it caused a waterwheel to spin as it drained. The use of the tool was demonstrated by the experimenter before the start of the water task. Because we did not want to bias the child's grip during these demonstrations, the experimenter held the tools by the handle with a fingertip grip, a grip not regularly used by children at this age (cf. Connolly & Dalgleish, 1989). Failure to plan in both tasks had consequences because a liquid could spill and both tasks had a change in end state when the goal was achieved.

Children were seated in a booster seat across a table from the experimenter. Each session was videotaped with a camera placed to the side of the child and at the same height as the child, and a hundredth-seconds timer was superimposed onto the image. Before the start of each trial, a cardboard barrier masked the display to conceal the tool's orientation. Each tool was presented at the child's midline for up to 8 trials, with the handle's orientation alternating between the left and the right for an equal number of trials.

Half of the children were presented with either the food task or the water task first. However, if a child was not interested in grasping a tool when it was first presented, we progressed to the next tool and offered the rejected tool again later in the session. Because we did not rigidly adhere to the ordering of the tasks, we did not include this factor in the analyses.

The videotaped session was viewed off-line in slow motion, with the following variables scored for each trial: the tool; the orientation of the handle; whether the tool was grasped and by which hand(s); the type of grasp (defined below); whether an attempt was made to achieve the experimental goal; and the hand and grip used when the tool was applied. If the child did not reach, or knocked the tool off the holder and it landed in a different orientation, the trial was scored a mistrial.

Five grips were defined. A radial grip involves holding the handle with the thumb toward the head of the tool. An ulnar grip involves holding the handle with the thumb away from the head

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of the tool. A fingertip (or distal) grip is defined as holding the end of the handle with the fingers. A goal-end grip is defined as holding the action end of the tool. A two-handed grip is defined as simultaneously holding the handle in a radial grip with one hand and holding the action end of the tool with the other hand.

On a second pass through the session, several timing measures were coded for each trial. Trial onset was the first frame in which the tool became visible on the videotape as the opaque screen was lifted, which is when the tool first became visible to the child. Reach onset was the beginning of the forward/upward continuous movement of the reaching hand towards the tool. Grasp time was when the fingers started to close on the tool. Application time was when the water started to pour from the cup, or when the spoon was placed halfway into the mouth. The times were used to measure the duration of different components of the action. Preparation time is the duration between when the tool first became visible and when it was grasped. Application time is the time between when the tool was grasped and when the goal of the task was accomplished.

A second scorer coded the tapes for about half of the children to calculate inter-rater reliability (a total of 159 trials were coded twice). Overall, the observational measures had 98% agreement, with Kappa scores ranging from .74 to .99. For the timing measures, a 0.5 s window was used to code for agreement. Percentage of agreement for trial onset time, grasp time, and application time was 100%, 95%, and 91%, respectively.

Children picked up the tool and used it on 92% of the spoon trials (153/166) and 95% of the water trials (141/148). The most common grip used by the toddlers were radial (spoon = 142; water = 111). The next most common were the two-handed grips (spoon = 7; water = 24). In contrast, the ulnar, fingertip and goal-end grips were rarely observed (<3% for spoon; <4% for water). A two-handed grasp represents a strategy to quickly grasp a tool whose orientation has been hidden from view. In using both hands to engage in the grasp, the infant does not need to differentiate the orientation of the tool while preparing for and executing the reach. Hence, the two-handed grasp does not involve planned action in the same was as the radial grasp. Given the infrequent use of various types of non-radial grips, they were combined into one category of non-radial grasp.

The consistent use of radial grips across different orientations of the tool is thought to indicate advanced planning because the radial grip enables the child to apply the tool in an optimal manner in these tasks. A paired sample t-test was used on the percentage of radial grips. The percentage of radial grips in the food ($M = 0.93$, *S.E.* = 0.04) and water tasks ($M = 0.79$, *S.E.* = 0.06) significantly differed, $t(18) = 2.388$, $p=0.028$. Children used the radial grip more often in the self-directed food task than in the externally-directed water task, even when the clarity of goal state and negative consequences were made similar for both. These findings agree with those of McCarty et al. (2001), in which children of the same age (19 months) used a radial grip in the self-directed task significantly more often than in the externally-directed task. Making the end state of the other-directed goal clear and creating negative consequences for a non-radial grip, did not enable toddlers to chose the efficient radial grip.

For the duration time calculations, before the preparation time and application time were calculated, the data were examined for outliers. Data were eliminated from the normally distributed timing data using the 1.5XIQR rule (Moore & McCabe, 1993), which led to the elimination of 16 of 153 trials in the food task and 15 of 141 trials in the water task. A one-way repeated measures ANOVA was performed on preparation time and on application time. For preparation time, the mean for the food task was 2.3 s (S.E.=0.3) and for the water task was 2.6 s (S.E.=0.3). There was no effect of task, $F(1, 18) = 0.491$, $p > 0.05$. For application time, there was an effect of task, $F(1, 18) = 11.06$, $p < .001$. Children were faster in the application phase of the food task (M = 2.1 s, S.E. = 0.2) than in the water task (M = 3.8 s, S.E. = 0.6) perhaps because they were more familiar with that sequence of actions.

Because there was no difference between tasks in the preparation time, task will be collapsed for the remaining analyses. We predicted that children would be slower during the preparation phase when using a radial grip as opposed to the other non-radial grip options because it might take more planning. The mean preparation time was computed for the radial grasps and the other non-radial grasps. Five participants were not included in this analysis because they never used a non-radial grasp for either task. A oneway repeated measures ANOVA was conducted when children reached with a radial grasp (*M* = 2.14 s, *S.E.* = 0.16) and a non-radial grasp (*M* = 3.16 s, *S.E.* = 0.53). Unexpectedly, children were significantly faster using a radial grip on the tools than when using a non-radial grip, $F(1, 13) = 5.97$, $p < 0.05$. This may have been due to the large number of two-handed grips in the non-radial category (as opposed to one-handed ulnar grips) because mobilizing both hands to reach and grasp may take longer than employing only one hand.

We predicted that children would be slower during the preparation phase when the handle was on the side of the non-preferred hand. Because the majority of people are right-handed (Hardyck & Petrinovich, 1977), children should be slower to grasp the tool when the handle was oriented to the left than when it was oriented to the right. Mean preparation time was computed for the handle-left and handle-right orientations for each child. A oneway repeated measures ANOVA was conducted when the handle was to the left (*M* = 2.65 s, *S.E.* = 0.28) and to the right (*M* = 2.07 s, *S.E.* = 0.15). As predicted, children were faster in preparing a reach when the tool's handle was oriented toward the right hand, the one most people prefer to use F (1, 18) = 5.64, $p < 0.05$.

In conclusion, intelligent actions in toddlers include those that show proficiency in planning, problem solving, and learning. Around 18 months of age toddlers made more choices of the efficient radial grip when a tool's action was directed toward their body rather than toward another object. Even when negative consequences for using a non-radial grip were made obvious by having water spill out of a container, toddlers had more difficulty if the tool's action was other-directed. Throughout infancy the child engages in exploring his or her own body. As Rochat noted in his discussion of "The self in infancy" (Chapter 2 in The Infant's World, 2001), "The body is a privileged object of exploration in infancy…." Beginning with thumb-sucking in the fetus and newborn, self-directed actions are among the earliest actions in which the infant engages. Interacting with objects comes later, as reaching and grasping appear around 4 months of age. When first beginning to grasp objects, the object is usually brought to the mouth, and only later does the infant come to bang the object on a surface or against another object. The finding of McCarty et al. (2001) of a self-other distinction in planning a grasp appears to be a reasonable extension of the privileged self seen in early infant behavior. The difference between self and other-directed actions persists at least through the end of the second year of life. Data from the present study suggest that toddlers cannot bring the same problem-solving skills into play for other-directed actions even if negative feedback for errors is provided and goal salience is enhanced.

Finally, no difference was found in preparation time to pick up the tool for self-directed versus other-directed actions. Toddlers were, however, slower to plan and execute a reach when the tool was oriented toward the non-preferred left hand than when it was oriented toward the preferred right hand. This increased time could reflect problems of inhibiting the preferred hand, or perhaps generally slower movement with the non-preferred hand. The study of tool use by young children is a valuable way to study problem solving using easily measured overt behavior whose goals are usually transparent.

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