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EMPIRICAL ARTICLE



## Human Actions Support Infant Memory

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### ABSTRACT

Agents are important for structuring memory in adulthood. However, it is unclear whether this “social memory bias” stems from a reliance on agents in verbal narratives, or whether it reflects more fundamental preverbal memory processes. By testing 9-month-old infants in a non-verbal eye-tracking paradigm, we were able to effectively compare infant memory for events construed as the goal-directed action of an agent with those construed as the outcome of an inanimate object. Results demonstrate that preverbal infants’ memory increased for events including an agent as opposed to an inanimate object (Exp 1). Memory was also enhanced if infants were trained to perceive the inanimate object as an agent’s tool (Exp 2). Memory results were not dependent on attention differences to the events during encoding. Thus, these experiments suggest that the presence of a person in an event can alter foundational memory processes.

### Introduction

Agents and their associated actions are particularly important for structuring human memory. When adults and children verbally recall past events, their narratives are organized with respect to people and their actions (e.g., Foss & Bower, 1986; Stein & Trabasso, 1982; Trabasso, Stein, Rodkin, Park Munger, & Baughn, 1992) and children are more likely to recall everyday events that include goal-directed actions (e.g., Anderson & Conway, 1997). The propensity to structure verbal memories in relation to goals is so strong that older children will try to impose character intentions and thoughts even when remembering a scrambled nonsensical series of pictures (Poulsen, Kintsch, Kintsch, & Premack, 1979). However, it is unclear whether the agentive focus in memory is the consequence of a learned communicative form (i.e., language), resulting from a practice of using agents and their goals to structure verbal narratives, or whether the agentive focus reflects non-linguistic memory processes. Does the presence of another person in an event make it more memorable regardless of linguistic abilities, or are these effects on memory the result of using a verbal code to represent events?

There is a great deal of evidence linking narrative skill to developments in episodic memory in early childhood (Fivush, 2011; Reese et al., 2011). As children acquire the ability to use language to encode events, their episodic memory improves. The increase in general verbal

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#### Author Note

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abilities also appears to align with children's propensity to focus their verbal recall on agentive events. In fact, children age 4 and under do not show evidence of a "social memory bias" in their narrative memory (Poulsen et al., 1979) and they tend to mention agents only with respect to their external characteristics instead of goals and intentions (Nicolopoulou & Richner, 2007). It is possible that the development of verbal and narrative abilities leads to the increasing prominence of goal structure in children's episodic memory (Trabasso et al., 1992). However, because previous research has relied strongly on verbal methods to assess event memory, it is also possible that this work has underestimated early pre-linguistic memory and the role of agents in supporting it.

Indeed, the relation between goal knowledge and event memory may have earlier origins in development, coming online before the advent of children's productive language abilities. Though maturing language abilities may underlie both general and agentive memory capacities, research has demonstrated that even infants are able to retain specific event memories for long periods of time. For example, a large amount of work exploring infants' pre-linguistic memory for events involves memory for human actions. The most commonly used method for examining early non-verbal memory (known as *deferred imitation*) relies on infants' ability to encode an action sequence, maintain a mental representation of that information over time, and then reproduce the action at test (Bauer & Mandler, 1989; Meltzoff, 1985). These deferred imitation paradigms have uncovered impressive memory capabilities in infants, with evidence for robust recall in 3- to 6-month-olds (Barr, Dowden, & Hayne, 1996; Campanella & Rovee-Collier, 2005), after as few as one or two demonstrations (Bauer, 1992; Mandler & McDonough, 1995), and with maintenance of over a year if given intermittent reminders (Hartshorn, 2003).

Though no studies to date have explored the influence of social agents on human infant memory, recent research has demonstrated that non-verbal social memory biases are present in older children and other social primate species. For example, recent work by Howard, Riggins, and Woodward (2019) found that 3-year-old children were more likely to remember the information presented in a person-present versus a person-absent sequential picture event, demonstrating both behavioral (object reconstruction) and neural (event-related potential) differences across conditions despite no differences in attention. Similar findings are evident in chimpanzees, gorillas, and capuchin monkeys (Howard, Festa, & Lonsdorf, 2018; Howard, Wagner, Woodward, Ross, & Hopper, 2017). In these studies, subjects were familiarized to videos of a human hand or a mechanical claw building a simple block tower. Across all three species, subjects demonstrated better memory for the block tower built by the hand than by the claw. Taken together, these findings suggest that preschool children and other social species show better memory for the product of an agentive vs. non-agentive event when tested in nonlinguistic paradigms. However, subjects in each of these studies were either linguistically competent human children or were full-grown adults in their respective species with extensive social experience. Therefore, it is still unknown whether a social memory bias is present in preverbal human infants, and how previous experience might mediate this memory.

Though little is known about the effects of agents on infant memory, research shows that pre-linguistic infants in the first year of life are quite capable of disambiguating agentive from non-agentive actors in the moment (e.g., Gergely, Nádasdy, Csibra, & Bíró, 1995; Lakusta & Carey, 2015; Luo & Johnson, 2009). Their ability to distinguish between animate agents and inanimate objects influences assumptions of intentionality for each of these entities. For

example, looking-time studies have shown that 6-month-old infants expect humans (Daum, Prinz, & Aschersleben, 2008), but not inanimate objects (e.g., rods, occluders), to act in a rational, goal-directed manner (Woodward, 1998). Additionally, 10-12-month-old infants generate goal-based action predictions to human hands, but not mechanical claws (e.g., Adam et al., 2016; Cannon & Woodward, 2012). Interestingly, these looking patterns are altered when infants are given sufficient evidence that a seemingly inanimate entity is actually agentive in nature (see Baillargeon, Scott, & Bian, 2016 for review) or is a tool used by an agent to complete a goal (e.g., Gerson & Woodward, 2012). When provided with such agency cues, infants react to the inanimate object as if it was agentive, similarly expecting or anticipating goal-directed action (e.g., Adam, Reitenbach, & Elsner, 2017; Biro & Leslie, 2007; Csibra, 2008). Thus, even before children begin producing verbal narratives, they appear to encode and react to agentive versus inanimate events differentially.

There is reason to believe that the pre-linguistic abilities infants use when attending to agentive events may actually scaffold or support to later verbal encoding. For example, several studies show that infants can parse the components of agentive motion events that are represented in language, such as action sources, goals, and manners (e.g., Konishi, Pruden, Golinkoff, & Hirsh-Pasek, 2016; Lakusta, Wagner, O'Hearn, & Landau, 2007). Similar to verbal narratives of events (Jackendoff, 1990), looking-time studies also show that infants can categorize goals on a broad and abstract level (Lakusta, Spinelli, & Garcia, 2017) and are more likely demonstrate a bias toward attending to action goals as opposed to source or manners (e.g., Lakusta & DiFabrizio, 2017; Lakusta et al., 2007). These findings dovetail with the goal biases seen when older children are asked to verbally describe motion events (Lakusta & Landau, 2005), suggesting a connection between early attentional preference and subsequent narratives.

The current studies compare 9-month-old infants' memory for agentive versus non-agentive events in order to examine whether human action increases memory before mature linguistic abilities emerge. It also explored whether providing infants with agentive cues influences their attention to and memory for non-agentive tool events. Nine-month-olds were chosen as the target age range, as research has shown that they are old enough to understand human (agentive) actions as goal-directed (Woodward, 1998; see, Woodward, 2009 for review) though they do not automatically generalize this capacity to inanimate (non-agentive) objects such as claws (Cannon & Woodward, 2012; Kanakogi & Itakura, 2011; Woodward, 1998). In fact, it is not until infants are 12-months of age that they show signs of understanding that an inanimate object may be used as a tool by an unseen agent (e.g., Hofer, Hauf, & Aschersleben, 2005). Therefore, 9-month-old infants present an ideal population for exploring agentive vs. non-agentive memory while being able to use stimuli that are relatively matched in shape, size, and grasping abilities (a human hand and a claw).

In Study 1, infants were familiarized to matched video events where either a human hand or a mechanical claw sequentially constructed a block tower (similar to stimuli used in Howard et al., 2018, 2017). In Study 2, infants were trained to view the inanimate claw as the tool of an agent before watching the claw video. Across both studies, a novelty preference paradigm was employed after familiarization to examine infants' recognition memory for the event (Fantz, 1964; Pascalis & de Haan, 2003). In this way, we examined whether the presence of another person influences event memory very early in life.

## Experiment 1

Experiment 1 utilized an eye-tracking paradigm to test whether 9-month-old infants were more likely to remember a simple block tower built by a human agent or a mechanical claw.

### Methods

#### Participants

Forty 9-month-old infants ( $M = 8.93$  mos, Range = 8.48– 9.55 mos, 22 female) participated in Experiment 1. Sample sizes were determined based on recent work with similarly-aged infants that evidenced moderate effect sizes (e.g., Brandone & Wellman, 2009; Gerson & Woodward, 2012; Yoon, Johnson, & Csibra, 2008), and data collection ceased once this number was reached post-exclusionary criteria (below). All participants were reported as being born full-term (at least 37 weeks gestation). Infants were randomly assigned to the Hand ( $n = 20$ ,  $M = 8.96$  mos, Range = 8.48– 9.45 mos, 12 female) or Claw condition ( $n = 20$ ,  $M = 8.89$  mos, Range = 8.52–9.55 mos, 10 female). Based on parental report, 40% of the infants tested were White, 27% African American, 7% Hispanic, 4% Asian, 16% multiracial, 2% undefined, with 4% of parents choosing not to provide racial or ethnic information.

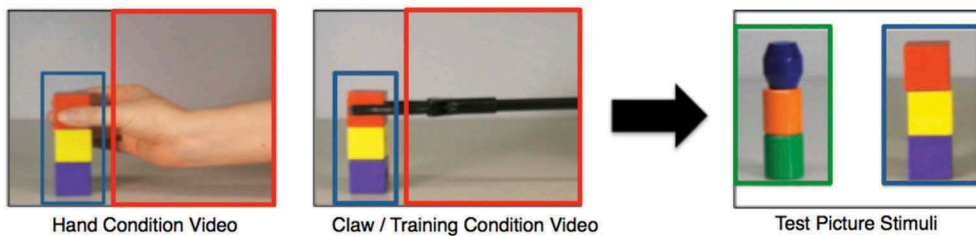
An additional six infants completed the study but were excluded from the final sample due to extremely low (less than 10 percent) eye-tracking data (Hand condition,  $n = 3$ ; Claw condition,  $n = 3$ ).

#### Procedure

**Setup.** All data were collected in a psychology laboratory at a large research University. Parents were briefed on the basic study procedures before proceeding through informed consent. During testing, infants were seated on a parent's lap, approximately 65 cm away from a 24" TFT monitor equipped with a Tobii T60XL corneal reflection eye-tracking system (accuracy 0.5°, sampling rate 60 Hz). A standard 9-point infant calibration was utilized. Infants were randomly assigned to the Hand or Claw condition. Data were collected and analyzed using Tobii Studio software (Tobii Technology, Sweden).

**Familiarization and test trials.** The current study employed a novelty-preference paradigm (also known as a visual paired comparison, or VPC, paradigm, see Fantz, 1964) to explore infant memory for agentive vs. non-agentive events. This type of paradigm tests nonverbal recognition memory by first familiarizing infants to an event, and then pairing information from the familiarized event with similar, but novel, information (see Pascalis & de Haan, 2003). Used extensively in the infant literature (e.g., Oakes & Kovack-Lesh, 2013; Robinson & Pascalis, 2004), the novelty-preference paradigm capitalizes on the fact that infants prefer to attend to novel stimuli (Pascalis & de Haan, 2003), a behavior only apparent if infants have adequately encoded and recognized the "old" or familiar stimuli.

In the first testing block, infants in both conditions viewed three initial familiarization trials followed by a test trial. After this first block, infants watched three additional blocks with the same stimuli that included one familiarization trial and one test trial. Therefore, all infants cumulatively watched six familiarization trials and four test trials.



**Figure 1.** Screen capture of videos shown in the agent and non-agent familiarization phase, along with a sample test picture. Shaded areas denote Areas of Interest (AOIs) for the builder (red), old tower (blue) and new tower (green).

During familiarization, infants in the Hand condition watched a 25-second long movie that depicted a human hand coming from the right side of the screen to sequentially place 3 square wooden blocks on the left side of the screen (see Figure 1). Infants in the Claw condition watched a matched event that depicted a claw (instead of a hand) sequentially placing the blocks. Both the hand and claw videos were filmed using a metronome set to 72 beats per minute to ensure equal speed of movement and movie length, and the sound of the metronome was present in each video.

During the test phase, infants viewed a still frame comprised of two side-by-side block tower pictures. Still pictures were used during the test phase, as research has found that infants of this age are able to easily transfer information from dynamic familiarization videos to static test images (e.g., Arterberry & Bornstein, 2002; Southgate & Begus, 2013). One picture depicted the block tower the infants had previously viewed in the familiarization video (the “old” tower). The second picture depicted a similar but novel block tower (the “new” tower). Each still test trial appeared on the screen for five seconds. The side that the old block tower appeared on (left or right) was counterbalanced across infants and trial.

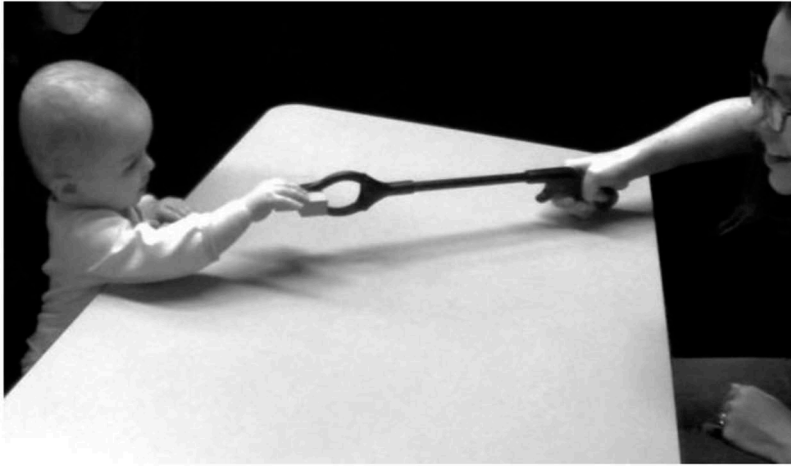
## Results

Preliminary analyses found no effects of gender, tower side, or trial number, therefore subsequent analyses were collapsed across these factors. Additionally, there was no significant difference in the percent time that infants watched the familiarization videos and test pictures in the Hand ( $M = 51.25\%$ ,  $SD = 22.63\%$ ) or Claw ( $M = 47.20\%$ ,  $SD = 20.38\%$ ) conditions, suggesting that infants in both conditions attended equally to the experimental stimuli ( $t(1, 38) = .59$ ;  $p = .56$ ,  $d = .18$ ).

## Test phase

Overall attention to the still picture test stimuli and specific areas of interest (AOIs) within the stimuli were examined. For each of the four test trials, AOIs consisted of the new (novel) and old (as seen in the familiarization videos) block towers. The AOIs for the block towers were equal in size and were equidistant from the middle of the screen (see Figure 1). The percent looking time for each AOI was calculated as [Overall time looking to AOI/Overall time looking to the screen].

A 2 (Condition: Hand, Claw) by 2 (Tower: Old, New) repeated measures ANOVA was run to examine the effect of agency on the percent of looking time to the old or new tower during



**Figure 2.** An infant aligning a reach for an object with the experimenter's claw during the experiment 2 training phase.

test. This analysis revealed a main effect of tower, demonstrating that infants looked for a larger percent of time at the new tower ( $M = 53.80\%$ ,  $SD = 16.18\%$ ) than the old tower ( $M = 32.18\%$ ,  $SD = 14.27\%$ ) when collapsed across conditions ( $F(1, 38) = 28.21$ ,  $p < .001$ , partial  $\eta^2 = .43$ ). In addition, there was a significant interaction between condition and tower ( $F(1, 38) = 5.88$ ,  $p = .02$ , partial  $\eta^2 = .13$ ). Post-hoc *t*-tests with Bonferroni corrections ( $\alpha = .025$ ) indicate that infants in the Hand condition looked significantly longer to the new block tower ( $M = 58.44$ ,  $SD = 15.02$ ) than the old tower ( $M = 26.95$ ,  $SD = 13.66$ ;  $t(19) = 5.67$ ,  $p < .001$ ) though no such difference was found when in the Claw condition (New tower:  $M = 49.15$ ,  $SD = 16.31$ ; Old tower:  $M = 37.40$ ,  $SD = 13.18$ ;  $t(19) = 1.97$ ,  $p = .06$ , see Figure 2). Additionally, a difference score was calculated (percent looking to new tower – percent looking to old tower) in order to directly compare the strength of novelty preference across conditions. An independent samples *t*-test indicates that children in the Hand condition evidenced a significantly larger difference in looking times to the new vs. old block tower ( $M = 31.49$ ,  $SD = 24.83$ ) than those in the Claw condition ( $M = 11.75$ ,  $SD = 22.62$ ;  $t(38) = 2.42$ ,  $p = .02$ ). Therefore, the findings suggest that infants in the Hand condition evidenced better memory for the previously seen block tower than those in the Claw condition.

These findings were supported by patterns at the individual level: In the hand condition, 19/20 infants demonstrated longer looking to the new vs. old block tower, a number that was significantly higher than chance ( $\chi^2(2, N = 20) = 16.20$ ,  $p < .001$ ). In contrast, 13/20 infants in the Claw condition evidenced a novelty preference, which was not significantly higher than would be expected by chance ( $\chi^2(2, N = 20) = 1.80$ ,  $p = .18$ ). Additionally, infants in the Hand condition were significantly more likely to show a novelty preference than were infants in the Claw condition ( $\chi^2(2, N = 40) = 5.62$ ,  $p = .02$ , see Figure 2).

### **Familiarization phase**

Though overall attention to the familiarization videos was equivalent, it's possible that the hand or claw in the video could alter *where* infants deployed their attention, subsequently influencing memory. For example, infants might be attracted to the novelty of the claw,



looking away from the tower and thus encoding less tower-relevant information. In order to evaluate this possibility, a 2 (Condition: Hand, Claw) by 2 (AOI: Builder (Hand or Claw), Tower) repeated measures ANOVA was run examining the effect of condition on the percent of looking time to the builder and tower during the familiarization video. Collapsed across conditions, infants attended to the builder ( $M = 52.69$ ,  $SD = 22.42$ ) significantly more than the tower ( $M = 29.46$ ,  $SD = 18.64$ ;  $F(1, 38) = 14.31$ ,  $p = .001$ , partial  $\eta^2 = .27$ ). However, no other significant main effects or interactions were found (all  $ps > .31$ ), suggesting no difference in the location of infants' attention based on condition.

Power analysis using G\*power software (Faul, Erdfelder, Buchner, & Lang, 2009) revealed that 20 infants per condition would provide sufficient power ( $>.80$ ) to detect a significant Pearson correlation between looking time at familiarization and test with a moderate effect size (see also Rakison & Benton, 2019). However, there were no significant correlations between the percent of time infants attended to the block tower or builder during the familiarization trials and later novelty preferences, either within or across conditions (all  $ps > .44$ ). Therefore, infants' patterns of attention during the familiarization phase did not predict later memory for the block tower.

## Discussion

In Experiment 1, infants in the Hand condition showed significantly stronger novelty preferences than those in the Claw condition. This suggests that stimuli designed to encourage thinking about a sequence in terms of a person's actions can increase memory in infants. Further, when looking at individual differences across conditions nearly all infants in the Hand condition showed a novelty preference, while only half of the infants in the Claw condition did so. These results were not due to attentional differences during familiarization. Infants in the both conditions attended to the relevant AOIs equally during familiarization and there were no correlations between looking times during familiarization and attention at test. Thus, our results suggest that the presence of an agent supports infants' memory, and, by extension that this aspect of human memory may have early ontogenetic roots.

Though infants can clearly differentiate between the actions of a hand and a claw, it's unclear whether our memory effect was due to the goal-directed behavior of the hand or whether any events that included a hand would be preferentially remembered regardless of intentionality. If infants are attuned to abstract analysis of hands as being agentive and goal-directed, we may see robust memory effects for other events including goals but omitting hands. Previous findings indicate that infants are adept at understanding hands and people as goal-directed (Woodward, 1998, 1999, 2003) but they can also view novel entities as goal-directed if given particular prior experience. For example, though 9-month-olds don't spontaneously view claws as goal-directed, they shift that perception if they first interact with a human demonstrator using a claw (Hofer et al., 2005). Similarly, 9-10-month-old infants do not identify the goal of a tool use event unless they first receive active training wherein they use the tool themselves (Sommerville, Hildebrand, & Crane, 2008).

Gerson and Woodward (2012) explored which particular experiences were necessary for 7- and 10-month-old infants to view inanimate claw events as goal-directed. Across a number of controlled conditions, infants were first familiarized to the ways a claw could move and grasp toys. Then, infants participated in a goal imitation task (Hamlin, Hallinan, & Woodward, 2008), watching an experimenter use the claw to grasp one of



two toys before imitating this grasp themselves. Seven-month-old infants only imitated the experimenter's goal when given prior experience aligning their reach with the claw tool (i. e., when the experimenter used the claw to pass an object to the infant). Simply seeing the claw move objects, observing the actor operate the claw, or touching the claw while it was not being used as a tool was not enough to facilitate goal imitation. Similarly, 10-month-old infants imitated the experimenter's goal only after active experience aligning their reach with the claw, not when observing the experimenter passing toys to another adult. Thus, allowing infants to compare their own reaching actions to that of the claw appears to be one way to facilitate infant's understanding of this inanimate object as a goal-directed tool.

If the memory results from Experiment 1 are due to the perceived goal-directedness of hands, then showing infants that claws can be used as goal-directed tools should alter the way they remember the claw event. In Experiment 2, we adapted the training procedure developed by Gerson and Woodward (2012) to expose infants to the claw as an agentive tool before proceeding through the memory paradigm from Experiment 1. In this way, we explored whether or not infants demonstrated a memory benefit when they were encouraged to think about a tool-use event as goal-directed.

## Experiment 2

Experiment 2 trained infants with an interactive claw paradigm to explore whether perceiving a mechanical claw as goal-directed would alter their memory for the product of a claw event.

### Methods

#### Participants

Twenty 9-month-old infants ( $M = 9.05$  mos, Range = 8.48– 9.48 mos, 9 female) participated in Experiment 2. All participants were full-term (at least 37 weeks gestation). All infants participated in a claw training phase before watching the eye-tracking videos (*Training Condition*). Based on parental report 71% of the infants were White, 5% African American, 5% Hispanic, 5% Asian, and 14% multiracial.

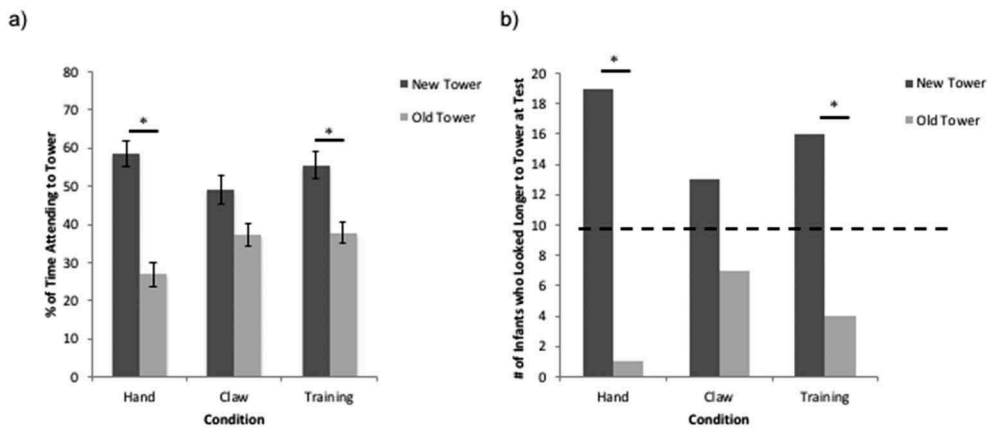
One infant completed the study but was removed from final sample due to extremely low (less than 10 percent) eye-tracking data.

#### Procedure

The procedure was identical to that in Experiment 1, except that infants proceeded through a claw training phase before watching the claw stimulus videos and test pictures.

During the claw training phase, infants entered the room and sat on their parent's lap directly across a 72 cm table from an experimenter. A video camera was situated behind the experimenter, focused on the infant. This phase was adapted from the method utilized in Gerson and Woodward (2012), which demonstrated to infants that the claw could be a tool used by a human agent and is not just an inanimate mechanical object.

Each infant completed 12 training trials. In each trial, the experimenter produced one of 6 brightly colored wooden toys in a randomized order, such that each toy was seen twice. The experimenter placed a toy on the table, said "Look the [toy's color] one!" to



**Figure 3.** Looking time data during test showing (a) the percent of time infants attended to the new tower versus old tower and (b) the number of individual infants who demonstrated a preference for the new tower versus old tower when compared to chance. The dotted line in (b) denotes chance, all error bars represent standard error, and \* denotes  $p < .05$ .

draw the infant’s attention to the toy, tapped the claw twice to draw the infant’s attention to the claw, then used the claw to reach for the toy. After reaching the toy, the experimenter used the claw to hand the toy to the infant across the table, while again labeling the toy’s color (“The [toy’s color] one!”). This type of object labeling, along with coordinated physical alignment of the claw and the infant’s own reach, has been shown to help infants understand the claw as a tool for goal-directed action (see Gerson & Woodward, 2012, 2014). The experimenter allowed the infant to reach and retrieve each toy (see Figure 3). The trial ended when the infant either retrieved the toy from the claw or the experimenter placed the toy in the infant’s hand. The side of the table (left or right) that each toy was placed, and thus the side toward which the claw reached, was switched with each trial. The order of the toy presentation was randomized across infants.

After proceeding through the training phase, infants viewed the claw familiarization videos and still test pictures as in the claw condition in Experiment 1.

### Results

Areas of Interest (AOIs) during both the familiarization and test phase were identical to those in Experiment 1.

Data from Experiment 2 were analyzed along with Experiment 1 in order to explore the influence of agentive training on infant’s attention and memory for a previously non-agentive event. Preliminary analyses found no effect of gender, tower side, or trial number, therefore subsequent analyses are collapsed across these factors. As in Experiment 1, there was no significant difference in the percent time that infants watched the familiarization videos and test pictures across conditions ( $F(2, 58) = 1.12, p = .33$ , partial  $\eta^2 = .04$ ).

### Test phase

As in the Hand condition in Experiment 1, infants in the Training condition attended significantly more to the new block tower ( $M = 55.51, SD = 15.76$ ) than the old block

tower at test ( $M = 37.32$ ,  $SD = 13.98$ ;  $t(19) = 2.78$ ,  $p = .01$ , see [Figure 3](#)). This result stands in contrast to children in the Claw condition of Experiment 1, where there was no significant difference between looking to the old vs. new tower. When measured in this manner, infants in the Training and Hand condition appeared to show a significant novelty preference (suggesting better memory for the event), while those in the Claw condition did not.

An attentional difference score was calculated for the Training condition (percent looking to new tower – percent looking to old tower). Interestingly, a series of planned contrasts with Bonferroni corrections demonstrated that the difference score in the Training condition ( $M = 18.24$ ,  $SD = 29.15$ ) was not significantly different from the difference score in either the Hand condition ( $M = 31.49$ ,  $SD = 24.83$ ;  $t(38) = 1.55$ ,  $p = .13$ ) or the Claw condition from Experiment 1 ( $M = 11.75$ ,  $SD = 26.62$ ;  $t(38) = .73$ ,  $p = .47$ ). Therefore, though the pattern of significance in the Training condition of Experiment 2 was similar to that of the Hand condition in Experiment 1, there was no distinction between the Training and Hand or Claw conditions in relation to the magnitude of this difference.

On an individual level, 16/20 infants in the Training condition looked longer to the new tower vs. the old tower at test, a number which (as per the Hand condition though not the Claw condition in Experiment 1) was significantly higher than chance ( $\chi^2(2, N = 20) = 3.96$ ,  $p = .04$ ). However, a direct comparison across condition shows that this number was not significantly different than the number of infants who demonstrated longer looking to the new tower in the Hand ( $\chi^2(2, N = 40) = 2.06$ ,  $p = .15$ ) or Claw conditions ( $\chi^2(2, N = 40) = 1.12$ ,  $p = .29$ ). As in the first set of analyses, infants in the Training condition looked similar to those in the Hand condition in terms of patterns of significance, though this number was in the middle of (and not significantly different from) infants in either the Hand or Claw conditions.

It is possible that the training phase in Experiment 2 was not equally effective for all infants. In prior work, coordination between the infants' actions and the tool has been the key for infant's later understanding of a tool event as being goal-directed (e.g., Gerson & Woodward, 2012). Therefore, as a follow up, we coded the extent to which infants' actions were coordinated with those of the claw. Infant reaching behaviors during the training phase were coded using Mangold Interact coding software (Mangold, 1998). Reaches were coded as either aligned (infant aligned their reach with the claw, taking the toy directly from the claw), non-aligned (infants did not align their reach with the claw, refusing to take the toy until the claw put it down in front of them) or as no reach (infant did not reach for the toy) for each of the 12 training trials. Four infants were removed from this analysis because the video recording angle did not allow for coding at this level of detail. On average, infants aligned their reach with the claw on 84% of the trials, reached for the toy but did not align their reach on 5% of the trials, and did not reach for the toy at all on 11% of the trials. All infants (100%) reached for and grasped the toy on at least 4 of 12 training trials.

Correlations were run in order to explore the relationship between infant reaching behaviors during training and the extent to which they attended to the new block tower at test. Post-hoc power analyses using G\*power software revealed that a sample size of 16 infants with a moderate effect size were sufficient to reveal a significant Pearson correlation with a power of .78. Results demonstrate that there was a significant positive correlation between the number of aligned reaches during training and the percent of time infants attended to the new block tower at test ( $r = .46$ ,  $p = .04$ ). Furthermore, there

were significant negative correlations between the number of times infants failed to align their reach or did not reach at all and the percent of time infants attended to the new block tower at test (not aligned:  $r = -.53$ ,  $p = .02$ ; no reach:  $r = -.57$ ,  $p = .01$ ).

Since infants who were highly aligned also showed a stronger novelty preference, a follow up analysis was conducted on only those infants who aligned 100% of the time during training ( $N = 11$ ). A series of independent sample t-tests with Bonferroni corrections demonstrated the difference scores of infants who aligned on all trials during training ( $M = 34.30$ ,  $SD = 25.41$ ) was not significantly different from the difference score in the Hand condition ( $M = 31.49$ ,  $SD = 24.83$ ;  $t(29) = .29$ ,  $p = .77$ ), but was significantly higher than the difference scores in the Claw condition ( $M = 11.75$ ,  $SD = 26.62$ ;  $t(29) = 2.29$ ,  $p = .03$ ). Thus, those infants who most effectively aligned their reaches with the claw were more likely to show a novelty preference at test than those who did not, suggesting better memory for the event. Furthermore, those “highly aligned” infants were indistinguishable from infants in the Hand condition, and showed a significantly stronger novelty preference than those in the Claw condition.

### **Familiarization phase**

As in Experiment 1, a 2 (Condition: Hand, Claw) by 2 (AOI: Builder, Tower) repeated measures ANOVA was run examining the effect of condition on the percent of looking time to the builder and tower during the familiarization video. Once again, we found that infants attended more overall to the builder ( $M = 53.14$ ,  $SD = 21.02$ ) than the tower ( $M = 28.29$ ,  $SD = 17.31$ ;  $F(1,57) = 28.25$ ,  $p < .001$ , partial  $\eta^2 = .33$ ). There were no significant correlations between attention to the builder or tower during the familiarization videos and later novelty preferences either within or collapsed across conditions (all  $ps > .38$ ). Therefore, as in Experiment 1, infant attention during encoding did not appear to differ depending on condition.

### **General discussion**

The current studies examined the influence of agency on preverbal infant memory, motivated by findings that infants remember human action robustly (Barr et al., 1996; Campanella & Rovee-Collier, 2005) though children do not focus on agentive actions in their verbal descriptions until much later in life (e.g., Trabasso et al., 1992). This begs the question, does human action increase pre-linguistic memory, or do agentive memory effects only appear as children structure the world according to narratives?

By testing 9-month-old infants in a non-verbal eye-tracking paradigm, we were able to effectively compare infant memory (measured via novelty preferences) for events construed as the goal-directed action of an agent with those construed as the outcome of an inanimate object. In Experiment 1, we found that infants who viewed a human agent completing an action showed a significantly stronger novelty preference than those who viewed a claw completing the same action. This was not due to the agent being more visually engaging: infants watched the familiarization event for the same amount of time across conditions, and fine-grained attention analyses suggest they also attended equally to the “builder” and block towers before test. Experiment 2 further underscored the fact that this memory bias was based on the goals of the agent and not simply the external features or attention-grabbing ability of the agent. Here, infants trained to view the claw as a tool

used by an agent subsequently showed a stronger novelty preference for the non-agent video. Furthermore, infants who better aligned their own goal with the claw during training showed better memory for the claw video, suggesting an important connection between goal-directed event construal and memory.

These findings dovetail with the research exploring verbal memory in older children and adults. When using paradigms that ask children to verbally describe or remember a sequence of events, there is often a bias toward focusing on agents and their goals (Lakusta & Landau, 2005, 2012; Trabasso et al., 1992). Furthermore, children are likely to verbally remember agentive words (e.g., “baby”, Nairne, VanArsdall, Pandeirada, Cogdill, & LeBreton, 2013) or words previously associated with agentive abilities (e.g., “likes music”, Aslan & John, 2016) more than non-agentive words. In adults, this “animacy advantage” on memory has been demonstrated repeatedly (for a review, see Nairne, VanArsdall, & Cogdill, 2017) and does not appear related to attention, arousal (Popp & Serra, 2018), or encoding effort (Bonin, Gelin, Laroche, Méot, & Bugaiska, 2015) across word types. Rather, it’s been postulated that preferentially remembering animate or agentive information may be particularly important for human survival, as it helps to recall potential predators, prey, and social partners (New, Cosmides, & Tooby, 2007). Our findings suggest that this may be the case as, similar to adult verbal recall, associating information with agency increased subsequent memory, independent of attention. Thus, these results suggest that human action may be particularly important for structuring memory early in ontogeny, before children have the ability to verbally recount information.

To some extent, this may not come as a surprise, as research has demonstrated that infants are adept at distinguishing between agentive and non-agentive entities from the first year of life, and their perception of agency alters their comprehension of and expectations for events (see Baillargeon et al., 2016). Furthermore, agentive information, particularly that pertaining to an agent’s goals, alters the way infants segment (Baldwin & Baird, 2001; Monroy et al., 2019; Stahl, Romberg, Roseberry, Golinkoff, & Hirsh-Pasek, 2014) and chunk (e.g., Bauer & Mandler, 1989) events. This segmentation is consequential: infants’ ability to parse events in relation to an agent’s goals is connected to subsequent memory. For example, an occlusion presented at the goal boundary of an event (e.g., when an agent has completed one action and is about to move on to another) decreases memory in infants more than an occlusion presented mid-goal, and objects presented at crucial goal boundaries are remembered more robustly than those presented mid-scene (Sonne, Kingo, & Krøjgaard, 2017). Thus, one of the potential mechanisms underlying our social memory bias may be the cognitive structure that agents provide, allowing infants to package information in accordance with a hierarchical goal.

The imitation literature further underscores the importance of goal structure on early event comprehension, demonstrating that infants are sensitive not just to the low-level perceptual aspects of an event, but to the intentions behind and agent’s actions. For example, infants understand (Brandone & Wellman, 2009; Daum et al., 2008) and are more likely to reproduce the overall goal of a failed action after a brief delay as opposed to the manner in which the action was demonstrated (Meltzoff, 1995). By the preschool years, this understanding influences the way children recall an event: 3-year-old children are more likely to imitate an action sequence accordance with an actor’s goals as opposed to the demonstrated sequential order (Loucks & Meltzoff, 2013; Loucks, Mutschler, &

Meltzoff, 2017). As such, infants in the current study may evidence more robust memory in agent-related conditions primarily because chunking an event in accordance with the agent's goals provides a structure that aids in both the encoding and recall of an event.

It is important to note that the current study does not answer questions concerning which particular aspects of an agentive event make it more memorable when compared to a non-agentive event. Though research has explored what agentive cues are necessary for infants to view an object as an agent (e.g., Csibra, 2008) or to induce tool action imitation (e.g., Gerson & Woodward, 2012), the current studies were not focused on disentangling all possible markers. Future studies could explore how various agentive cues present in the video (e.g., self-propelled movement, action effects) alter later recognition or recall for event information. Similarly, various claw training procedures could be employed to see what types of hands-on experience alters infant perception of and memory for claw actions (similar to Gerson & Woodward, 2012).

As one example, the current studies contained cues to both agency and intentionality, making it difficult to determine which is most influential for event memory. Research shows that agency and intentionality are so intertwined that the latter is often used as evidence in favor of the former. For example, infants assume human agency as the causal force behind objects that appear to move spontaneously, break apart, or play music (e.g., Muentener & Carey, 2010; Saxe, Tenenbaum, & Carey, 2005; Saxe, Tzelnic, & Carey, 2007), actions that would be difficult for an inanimate object to complete in isolation. Similarly, infants expect human agents (and not inanimate objects such as claws) to drive creations of regular patterns or intentional order (Ma & Xu, 2013; Newman, Keil, Kuhlmeier, & Wynn, 2010). Some have even suggested that it is inherently more difficult to construe events as both agentive *and* unintentional, arguing for an “intentionality bias” that is pervasive across development (Rosset & Rottman, 2014). Therefore, future studies could disentangle the influence of agency vs. goal structure by exploring memory for matched events where a person is present but the intentionality varies (e.g., knocking blocks over to create a tower as opposed to placing them).

Our findings do suggest that minimally-agentive hand actions are enough to elicit social memory biases, where as previous research has focused heavily on how pedagogical cues, such as directed language or eye gaze, can alter preverbal memory (see Gergely & Csibra, 2006; Shneidman & Woodward, 2016). For example, 9-month-old infants differentially remember events in accordance with the communicative intent behind actions (Yoon et al., 2008). This work highlights the nuanced effects of social cues on early event memory, however it does not speak to the significance of having a social context present vs. absent during encoding. The current studies suggest that even mentally construing an actor as agentive can have effects on preverbal memory. Therefore, though differences within a social context might alter the focus of infant memory, the presence of a social context *at all* may globally increase recall.

Cross-species studies provide additional support that the presence of an agent may tap fundamentally different process than that used for social cue comprehension. For example, though nonhuman primates understand agents as being goal-directed (Burkart, Kupferberg, Glasauer, & van Schaik, 2012; Kano & Call, 2014) and demonstrate better memory for agentive vs. non-agentive events (Hopper, 2010; Howard et al., 2018, 2017), their sensitivity to social cues is more limited than human children (Herrmann, Call, Hernández-Lloreda, Hare, & Tomasello, 2007). Some have argued that it is our human



ability to quickly learn from social contexts (pedagogical or otherwise) that provides the foundation for our rich and varied culture (Whiten, 2005). Therefore, the present study not only allows for a new perspective on the influence of social context on memory, but also a new understanding of what it means to be such a uniquely social species.

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