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## The memory is in the details: Relations between memory for the specific features of events and long-term recall during infancy

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### ABSTRACT

The second year of life is marked by pronounced changes in the length of time over which events are remembered. We tested whether the age-related differences are related to differences in memory for the specific features of events. In our study, 16- and 20-month-olds were tested for immediate and long-term recall of individual actions and temporal order of actions of three-step sequences in an elicited imitation paradigm as well as for forced-choice recognition of the specific feature of the props used to produce the sequences. Memory for the props was related to long-term recall of the events only for the 20-month-olds. It accounted for unique variance above and beyond the variance explained by immediate recall of the individual actions and the temporal order of actions of the sequences. The different pattern of relations in the older and younger infants seemingly reflects a developmental difference in the determinants of long-term recall over the second year of life.

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### Introduction

During the first 2 years of life, infants make great strides in long-term recall. Whereas during the first year their memories are fragile and short-lived, by the middle of the second year they remember over long delays (see Bauer, 2006a, 2007, for reviews). One potential source of age-related differences in long-term recall is the specificity with which events are encoded and the extent to which details

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about them are preserved in long-term storage. The specific features of events are what differentiate one event from another and confer on memories their status as episodic (i.e., memories of unique events located in specific places and at specific times [Tulving, 1983, 1993]). The existing literature makes clear that there are age-related differences in infants' retention of at least one specific feature, namely, the temporal order of multistep event sequences (e.g., Barr, Dowden, & Hayne, 1996; Bauer, Wenner, Dropik, & Wewerka, 2000; Herbert & Hayne, 2000). In the current research, we examined infants' encoding and retention of another episodic feature, namely, the specific props used to produce events. The major question was whether memory for specific feature information related to the accessibility of memory traces over a delay.

There is a strong theoretical rationale for suggesting that age-related differences in long-term recall may be related to differences in memory for the specific features of events. For example, the trace integrity framework (Brainerd, Reyna, Howe, & Kingma, 1990) and fuzzy trace theory (Brainerd & Reyna, 1990) characterize formation and loss of memories in terms of featural integration and disintegration. In these conceptualizations, events are bundles of potentially encodable features. "Verbatim" features represent specific attributes of events such as the specific words spoken in a conversation and the font in which words on a list were presented. In contrast, "gist" features encode overall meaning. Integration of the feature types produces durable and distinctive traces (derived from gist and verbatim, respectively). Although it is thought that encoding of verbatim and gist occurs in parallel, verbatim features are more vulnerable to forgetting, leaving only the less distinct semantic representation. Thus, in this conceptualization, forgetting involves the loss of unique feature information. Age changes in resistance to forgetting are associated with developments in preservation of verbatim featural connections (see Brainerd & Reyna, 1990 and Brainerd et al., 1990, for discussions).

Specific features, such as who did what to whom and when, also are of special concern neurodevelopmentally because they seem to make high demands on relatively immature prefrontal and medial temporal structures. For example, encoding of information about the order in which an event occurred is impaired by lesions to dorsolateral prefrontal cortex (e.g., Petrides, 1995). Relating elements of events to one another—required for memory for order—also is impaired by hippocampal lesions (e.g., Eichenbaum & Cohen, 2001). There is electrophysiological and behavioral evidence that interaction between the dentate gyrus of the hippocampus and the CA3 hippocampal cell field supports recall of sequences (Lisman, Talamini, & Raffone, 2005). Damage to the prefrontal cortex also impairs retrieval. Retrieval deficits associated with prefrontal damage are especially apparent for (a) temporal order information (relative to item memory: e.g., Janowsky, Shimamura, & Squire, 1989; Shimamura, Janowsky, & Squire, 1990), (b) the specific features of events (the color of the font in which words were presented during encoding: e.g., Jacoby, 1991), and (c) the source of information in memory (Schacter, Wagner, & Buckner, 2000; Wheeler, 2000).

The neural structures implicated in memory for temporal order and for the specific features of events undergo a protracted course of development (see Bauer, 2006a, 2006b, 2007, for reviews). Briefly, portions of the medial temporal structures, including the cell fields of the hippocampus, mature relatively early (e.g., Seress & Abraham, 2008). In contrast, the prefrontal cortex and the dentate gyrus of the hippocampus are later to mature. It is not until 20 to 24 months of age that the numbers of synapses in these structures peak (Huttenlocher & Dabholkar, 1997), heralding their functional maturity (Goldman-Rakic, 1987). It is not until late during the preschool years and adolescence or early adulthood that adult numbers of synapses are apparent in the dentate gyrus and prefrontal cortex, respectively (Bourgeois, 2001; Huttenlocher & Dabholkar, 1997), indicating full maturity of the structures (Goldman-Rakic, 1987). The connections between the structures also are slow to develop (e.g., Durston et al., 2002; Schneider, Il'yasov, Hennig, & Martin, 2004). These findings are consistent with the suggestion that developments in the temporal–cortical network that take place throughout the first years of life will be accompanied by increases in memory for specific (episodic) features of events.

In accord with this conceptualization, there are pronounced age-related differences in recall of the temporal order in which events unfold. For example, in Bauer and colleagues' (2000) study, the majority of 16-month-olds remembered the temporal order of multistep sequences for 6 months, whereas the majority of 20-month-olds still showed evidence of ordered recall after 12 months. There also are age-related changes in memory for another episodic feature, namely, the specific objects used in events (e.g., Lechuga, Marcos-Ruiz, & Bauer, 2001). In Bauer and Dow (1994), 16- and 20-month-olds were

exposed to novel events and later tested for forced-choice recognition of the props used to produce them. Both age groups reliably selected the original props, thereby indicating memory for the specific event features. The 20-month-olds performed more systematically than the 16-month-olds ( $M_s = 81$  and 68% correct selections, respectively). This study provides evidence of developmental differences in memory for specific features of events. However, the design of the study did not permit testing of possible relations between memory for the specific event features and recall of the sequences they were used to create; that is, the elements were tested in separate experiments involving different infants.

In summary, the existing literature provides both theoretical and empirical motivation for investigation of a link between age-related changes in the specificity of memory of events and age-related differences in long-term recall of them. Specifically, we hypothesized that, relative to older infants, younger infants would encode and retain less information about the props used to produce event sequences and that their memories of the sequences themselves would be less long-lived. We further hypothesized that individual variability in encoding and retention of the specific feature of which props were used to produce events would predict recall of the sequences over a delay.

To begin to examine these hypotheses, in the current research we tested infants' encoding and long-term memory for the props used to produce multistep event sequences in the context of an imitation paradigm. We also tested infants' encoding and long-term memory for the individual actions and the temporal order of actions of the sequences. The imitation paradigm is well-suited to this investigation because it provides multiple measures of recall (e.g., actions, temporal order of actions) and can be adapted to examine the specificity of memory (e.g., Bauer & Dow, 1994). The paradigm also is widely accepted as a nonverbal measure of recall (e.g., Fivush, 1997; Mandler, 1990; Meltzoff, 1990; Nelson, 1995, 1997; Nelson & Fivush, 2000; Rovee-Collier & Hayne, 2000; Schneider & Bjorklund, 1998; Squire, Knowlton, & Musen, 1993).

The participants were 16 and 20 months of age. We selected these ages because by this point in development infants competently perform the imitation task under no-delay conditions (see Bauer, 1997, for a review). Age differences in performance nevertheless are apparent, with 20-month-olds remembering more than 16-month-olds (e.g., Bauer et al., 2000). All of the event sequences were three steps in length. Both 16- and 20-month-olds perform competently on sequences of this length (see Bauer, 1997, for a review). This suggests that they successfully encode the events, a prerequisite to tests of memory for them. All of the sequences were constrained by enabling relations: to reach a particular outcome or goal, one action in a sequence is both prior to and necessary for a subsequent action (see Bauer, 1992, for a discussion). This choice was made because 20-month-olds and younger infants do not yet perform reliably on test sequences that lack this temporal structure (Bauer, Hertsgaard, Dropik, & Daly, 1998; Bauer & Thal, 1990; Wenner & Bauer, 1999). In contrast, even during the first year of life, infants reliably reproduce the order of sequences constrained by enabling relations (e.g., Carver & Bauer, 1999).

## Method

### *Participants*

The participants were 18 16-month-olds (mean age = 16 months 2 days, range = 15 months 21 days to 16 months 12 days) and 20 20-month-olds (mean age = 20 months 8 days, range = 19 months 22 days to 20 months 14 days). An additional 5 infants were enrolled but did not complete both sessions. Infants were recruited from a departmental participant pool of families who at the time of their infants' births indicated their potential willingness to participate in research. All participants were full term ( $40 \pm 2$  weeks gestational age) and had no known mental or physical conditions or disorders. Most of the infants were living in middle- to upper middle-class families, and all were of non-Hispanic Caucasian descent. Infants received a toy at each session in appreciation of their participation.

### *Materials*

To test the possibility that differences in language ability between the younger and older infants might account for anticipated differences in performance, we asked infants' parents to complete the

MacArthur Communicative Development Inventory for Infants (for 16-month-olds, assesses comprehension and production) and for Toddlers (for 20-month-olds, assesses production only).

At each session, infants were presented with the six novel three-step sequences described in Table 1. All sequences were novel as assessed by parental report; the sequences had been used in prior

**Table 1**

Sequences and materials used.

Sequence	Props	Varying attribute	Version 1	Version 2
Make a dancing toy	“Put in the stick” (inserting stick into hole in base), “Hang up the dancer” (attaching dancer to Velcro spot on stick), “Make it dance” (pulling the string at the bottom of the figure, causing its legs and arms to move)			
	Stick	Color, material	Black, square, wood	Yellow, square, plastic
	Base	Color, shape	Red, round, plastic base with hole	Blue, rectangular, plastic base with hole
	Dancer	Color, shape	Tan and red, teddy bear, wood	Brown, police officer, wood
Go for a ride	“Set up the bottom” (unfolding the base), “Put on the ramp” (attaching the ramp to the base), “Go for a ride” (placing rider on ramp and allowing it to slide down)			
	Base	Color, shape	Yellow, triangular, plastic	Black, square, plastic
	Ramp	Color, shape	Red and green, rectangular, plastic	Clear, triangular, plastic
	Rider	Shape, material	Yellow, round, plastic bug	Yellow, lemon-shaped, sponge
Make a paddle rattle	“Put on the block” (putting block on paddle), “Cover it up” (inverting cover over block on paddle), “Shake it” (holding paddle by handle and shaking)			
	Block	Color, shape	Red, square, wood	Blue, round, wood
	Paddle	Shape, material	Green and white square, wooden paddle with handle	Green and white round, plastic paddle with handle
	Cover	Color, material	Clear, round, plastic	Orange, round, rubber
Play the drum	“Put in the hammer” (inserting hammer in slot in base), “Put on the top” (placing top on base), “Play it” (moving the hammer handle up and down to strike the cover)			
	Hammer	Color, shape	Red, round, metal	Metallic, square, metal
	Base	Shape, material	Black, triangular, wood	Black, round, plastic
	Top	Shape, material	Black, triangular, wooden top to fit base	Black, round, plastic top to fit base
Make a merry-go-round	“Make the top” (attaching two pieces together to make a top with a hole in the center, with shapes attached to the top with ribbon), “Put it on” (placing top on the base with the shapes hanging down over the side of the top), “Spin it” (hitting the shapes to make them spin around)			
	Top	Color, shape	Blue, octagon, plastic	Yellow, triangle, plastic
	Base	Shape, material	Red, round, wood	Red, square, plastic
	Shapes	Color, shape	White, triangles, wood	Brown, bears, wood
Play with tools	“Lift up the side” (pulling up a hinged side to form a base), “Put on the top” (placing flat piece on base, with wooden plug in flat piece), “Pound it” (using hammer to strike wooden plug)			
	Base	Color, material	Yellow and black, square, plastic	Red and black, square, wood
	Top	Color, material	Beige, square, wood	Blue, square, plastic
	Hammer	Color, shape	Green, mallet-shaped, plastic	Orange, hammer-shaped, plastic

research with infants in this age range (e.g., Bauer, Van Abbema, & de Haan, 1999). As reflected in Table 1, there were two versions of each sequence; the versions were distinguished by the attributes of the props used to complete them. As in Bauer and Dow (1994), the props varied perceptually yet filled the same roles in the sequences. The props used to perform each step of the sequences differed in color and shape, color and material composition, or shape and material composition; the props did not differ in size or function. Because the two sets of props did not differ in function, they could be used to produce sequences that were structurally identical to one another but with different surface instantiations (varying on two of three attributes: color, shape, and material composition). The version used to model the sequence for infants at Session 1 was the “base” version; the perceptually different but functionally equivalent version was the “variant.” Across participants, the two versions of the sequences served as bases and variants approximately equally often.

#### *Procedure: Session 1*

Infants participated in two sessions conducted by the same female experimenter. Sessions took place in a laboratory playroom and were recorded on DVD. After a brief warm-up period, infants took part in practice sequences and a prop familiarization procedure, followed by exposure to and test for immediate imitation of the test sequences. Finally, infants were tested for recognition memory for the props used to produce two of the sequences. Each phase is described below.

#### *Practice*

The experimenter presented two practice sequences designed to acquaint infants with the turn-taking nature of the elicited imitation task. For each practice sequence in turn, infants were allowed to interact with the materials. The experimenter then modeled the sequence two times in succession with narration. She then returned the materials to the infants and encouraged imitation. Infants' successful and approximate efforts at imitation were rewarded with social praise such as “Good job.” During the practice sequences, the experimenter reminded the parents of the procedure, encouraged them to ask questions of the experimenter, and obtained signed informed consent. Infants' parents remained with them throughout the session. They were asked not to suggest behaviors to their infants or to assist them in any way. Parents complied with this request.

#### *Prop familiarization*

After the practice sequences, infants were familiarized with the props for the variant version of the sequences they would see modeled. The purpose of familiarization with the variant props was two-fold: to reduce the likelihood that in the item selection procedure (see below) infants would (a) select the variant props based solely on their novelty (i.e., novelty preference) and, conversely, (b) select the base props solely because the variant props were novel (i.e., selection of base props based on exclusion of novel props) (see Bauer & Dow, 1994, for a discussion). Infants were successively presented with three trays in random order. Each tray contained six props; one tray contained the six props used to complete the first step of each sequence (i.e., stick, base ride, block, hammer, top, and base tools for the sequences make a dancing toy, go for a ride, make a paddle rattle, play the drum, make a merry-go-round, and play with tools, respectively [see Table 1]), one tray contained the six props used to complete the second step of each sequence, and one tray contained the six props used to complete the third step of each sequence. The version of the props with which a given infant was familiarized was determined based on the version to be used as the base during administration of the test sequences (see below). That is, infants who would have Version 1 of the props as their base were familiarized with Version 2 of the props and vice versa. The props were placed on the trays randomly. Infants were allowed to interact with the items on each tray for an infant-controlled period that ended when they touched or visually examined each item.

#### *Test sequence administration*

Following familiarization with the variant props, the test sequences were administered using the base props. The procedure was the same as that used for the practice sequences. That is, for each sequence in turn, infants were allowed to interact with the props for an infant-controlled baseline period

that ended when they engaged in repetitive exploratory or off-task behavior (e.g., Bauer, 1992). The experimenter then modeled the sequence two times in succession with narration (see Table 1 for the narration used). The props then were returned to the infants. Infants were encouraged to imitate the model: “Now it’s your turn to make/do [sequence name] just like I did.” Infants’ imitation was used as the measure of immediate recall.

Infants were presented with each of the six sequences in turn. Two sequences were presented in each of three conditions: standard, generalization, and specificity (condition was within participants). As reflected in the schematic of the procedure provided in Table 2, Panel A, the baseline, modeling, and immediate imitation phases of the procedure were the same for all three conditions. For each sequence in turn, infants were given the base props for an infant-controlled baseline period, after which the experimenter modeled the sequence two times in succession, after which the props were given to infants for an immediate recall test. For the standard and generalization conditions, after the immediate recall test, the experimenter modeled the actions once more with narration (remodeling). Remodeling of the two sequences in the specificity condition was deferred until after the item selection procedure (described next). With the exception of the timing of the remodeling, the procedure for the three conditions was identical. Assignment of sequences to conditions was counterbalanced across participants. The order of presentation of the conditions also was counterbalanced.

### Item selection

After all six sequences had been presented, immediate recall had been assessed, and the sequences in the standard and generalization conditions had been remodeled, infants were tested for identification of the props used to produce the two sequences in the specificity condition. The props used to produce each step of each sequence were presented in pairs composed of the base prop and its variant. For each pair, the base version of the prop was placed in one clear plastic container and the variant version of the prop was placed in a different clear plastic container. The containers were placed to either side of infants (left and right side placement of the base props was counterbalanced). Infants were encouraged to select the prop that had been used to produce the sequence with statements such as the following: “We used one of these to make a dancing toy. Show me which of these we used to make a dancing toy.” The item selection test was administered for each sequence in turn; the props for the different steps of the sequences were presented randomly with the constraint that they were not presented in sequential order.

Immediately after the forced-choice item selection procedure was complete, the examiner remodeled the two sequences in the specificity condition using the base props. Remodeling with the base props ensured that infants ended the session with accurate information regarding the props that had been used to produce the sequences.

**Table 2**

Schematic representation of the procedure in Session 1 (Panel A) and Session 2 (Panel B).

Session and phase	Condition ( $n = 2$ sequences per condition)		
	Standard	Generalization	Specificity
<i>Panel A: Session 1</i>			
Baseline	A, B	C, D	E, F
Modeling	A, B	C, D	E, F
Immediate imitation	A, B	C, D	E, F
Item selection	na	na	E– <u>E</u> , F– <u>F</u>
Remodeling	A, B	C, D	E, F
<i>Panel B: Session 2</i>			
Item selection	na	na	E– <u>E</u> , F– <u>F</u>
Delayed imitation	A, B	<u>C</u> , <u>D</u>	E, F

Note: Alpha characters represent unique sequences. Italics and underscore indicates the variant version of the props. Although in the schematic sequences are assigned to conditions, across participants, each sequence was used equally often in each condition and each version of the props was used as the base and the variant equally often. Note that in the standard and generalization conditions, there was no item selection procedure (na, not applicable).

By the end of Session 1, infants had been exposed to and tested for immediate recall of six sequences; they had seen all six sequences remodeled by the experimenter. The only difference across the three conditions was that for the two sequences in the specificity condition, infants also had been tested for recognition memory for the props used to produce the sequences.

At the end of the session, parents were instructed on the completion of the MacArthur Communicative Development Inventories and were asked to return them at the second visit.

### *Procedure: Session 2*

One month later, infants returned to the laboratory for the second session (mean delay = 30 days, range = 24–41). After a short warm-up period, infants were engaged in the item selection procedure in which they had taken part at Session 1, followed by testing of memory for the sequences in the standard, generalization, and specificity conditions. A schematic of the procedure is provided in Table 2, Panel B.

### *Item selection*

For each of the two sequences in the specificity condition in turn, infants were presented with a tray containing the three base props and three variant props; the props were arranged randomly. Infants were verbally reminded of the sequences with statements such as the following: “Last time you were here, we used some of these things to make a dancing toy. Remember which of these we used to make a dancing toy?” Infants then engaged in the forced-choice item selection task administered in the same manner as at the first session. This phase of the session constituted the test of delayed recognition of the base props used to produce the sequences at Session 1.

### *Memory for the test sequences*

Immediately after the forced-choice item selection procedure, infants were tested for memory for the six test sequences. For each sequence in turn, infants were presented with the props for the sequences along with a verbal reminder of the sequence such as the following: “You can use these things to make a dancing toy. Show me how you make a dancing toy.” Infants were allowed to interact with the props for an infant-controlled period. As reflected in Table 2, Panel B, for the four sequences in the standard and specificity conditions, the props given to infants were the same as those used to produce the sequences at Session 1 (base props). The procedures for the standard and specificity conditions replicated those used in prior studies of infants’ memory for event sequences after a delay (e.g., Bauer & Dow, 1994; Bauer et al., 2000) and provided a measure of long-term recall. The difference between the conditions was that in the specificity condition infants had been tested for immediate and delayed recognition of the props used to produce the sequences, whereas in the standard condition they had not. As such, the standard condition could be used to reveal effects of the delay without the potential for facilitation of, or interference with, memory created by exposure to the variant props.

For the two sequences in the generalization condition, the props presented to infants were not the base props they had used to produce the sequences at Session 1 but rather the variant props. The variant props were not entirely novel; infants had been familiarized with them at Session 1 (see prior familiarization subsection above). However, infants had not seen the props used to produce the sequences. This condition allowed us to assess whether infants would generalize to the variant props, thereby indicating that they found the variant props to be acceptable substitutes for those with which they had seen the sequences modeled (i.e., the base props). Thus, the manipulation served as an assessment of the strength of the test of infants’ memory for the base props versus variant props. The test would be considered as strong if infants demonstrated memory for the original base props (in the item selection task) yet used the variant props to produce the sequences (in the generalization condition).

### *Data reduction*

The experimenter coded each infant’s baseline, immediate recall, delayed recall, and force-choice item selection performance online; DVDs of the sessions were used for reliability purposes. For the

imitation task, the experimenter noted the occurrence of target actions and their order. For each sequence, an infant could produce three target actions (Step 1, Step 2, and Step 3) and two pairs of actions in the target order (Steps 1 and 2 and Steps 2 and 3). Although only one order of actions produced the end state, the infant received credit for performing the target actions in any order. However, as in prior related research (e.g., Bauer & Dow, 1994; Bauer et al., 1998, 2000), only the first occurrence of each target action was coded so as to reduce the likelihood that credit for recall of temporal order might be received by chance or trial and error. Thus, production of the string of actions 3–1–2–3 would result in a score of 3 for target actions (because all three actions were produced) but only 1 pair of actions in the target order (Steps 1 and 2); the infant would not be credited with the pair 2–3 because he or she already would have been credited with Step 3 (the first action). For the forced-choice item selection task, the experimenter recorded which prop the infant selected on each of the forced-choice trials (3 trials  $\times$  2 sequences).

A second coder independently coded the DVDs for 10 (26%) of the 38 infants. Mean percentage agreement between the coders on the number of target actions produced and the order of their production was 93% (range = 82–99). Mean percentage agreement between the coders on infants' choices in the item selection task was 96% (range = 92–100). For both tasks, when disagreements occurred between the coders, the observations of the primary coder (i.e., the experimenter) were used.

## Results

### *Relations with language variables*

We conducted correlational analyses to test for relations between infants' comprehension (16-month-olds only) and production (both age groups) and performance on the test sequences and in the forced-choice item selection task. No statistically significant correlations emerged. Language measures were not considered further.

### *Learning and memory of test sequences*

To determine whether infants learned and remembered the test sequences, and whether they generalized to the variant props at Session 2, we conducted 2 (Age: 16 months or 20 months)  $\times$  3 (Phase: baseline, immediate recall, or delayed recall)  $\times$  3 (Condition: standard, generalization, or specificity) mixed analyses of variance (ANOVAs) for each of the two dependent measures (phase and condition are within-participants variables). Tukey tests of significant difference were used to evaluate specific patterns of main effects involving more than two means ( $p < .05$ ). Descriptive statistics are provided in Table 3.

Because with one exception the findings for the two dependent measures (actions and pairs of actions or order) parallel one another, we present them together and note the exception. For both

**Table 3**

Means (and standard deviations) for 16- and 20-month-olds' performance on three-step sequences.

Condition	Phase	Dependent measure by age			
		16-month-olds		20-month-olds	
		Actions	Order	Actions	Order
Standard	Baseline	0.74 (0.59)	0.15 (0.29)	0.79 (0.69)	0.18 (0.34)
	Immediate	1.74 (0.99)	0.76 (0.66)	2.45 (0.72)	1.24 (0.54)
	Delayed	1.61 (0.65)	0.53 (0.47)	2.16 (0.65)	0.95 (0.62)
Generalization	Baseline	0.65 (0.52)	0.06 (0.17)	0.75 (0.64)	0.18 (0.34)
	Immediate	1.94 (1.03)	0.94 (0.58)	2.58 (0.75)	1.40 (0.62)
	Delayed	1.14(0.82)	0.39 (0.56)	1.95 (0.67)	0.85 (0.52)
Specificity	Baseline	0.79 (0.71)	0.12 (0.28)	0.88 (0.53)	0.13 (0.22)
	Immediate	1.97 (0.99)	0.82 (0.58)	2.38 (0.79)	1.30 (0.62)
	Delayed	1.25 (0.81)	0.36 (0.54)	2.13 (0.74)	0.93 (0.67)

Note: Standard deviations are in parentheses.



dependent measures, there were significant main effects of age,  $F_s(1, 36) = 14.72$  and  $27.10$ ,  $p_s < .0005$ ,  $\eta^2_s = .06$  and  $.06$ , for actions and order, respectively, and of phase,  $F_s(2, 70) = 97.14$  and  $87.37$ ,  $p_s < .0001$ ,  $\eta^2_s = .35$  and  $.34$ , for actions and order, respectively. These effects were qualified by Age  $\times$  Phase interactions,  $F_s(2, 70) = 5.72$  and  $6.05$ ,  $p_s < .005$ ,  $\eta^2_s = .02$  and  $.02$ , for actions and order, respectively. Follow-up one-way within-participants ANOVAs conducted at each age for each dependent measure indicated that both 16- and 20-month-olds learned and remembered the target actions and their order. That is, infants performed a greater number of actions and pairs of actions at immediate and delayed recall relative to baseline. Although they remembered the sequences over the delay, they also evidenced some forgetting: performance after the delay was lower than performance immediately after modeling (all  $p_s < .0001$ ,  $\eta^2_s = .40$ – $.73$ ). Follow-up one-way between-participants ANOVAs conducted for each phase for each measure indicated that 20-month-olds outperformed 16-month-olds at immediate recall and delayed recall (all  $p_s < .02$ ,  $\eta^2_s = .15$ – $.53$ ); differential performance by age was not found at baseline.

For the measure of individual target actions produced only, there was a significant Phase  $\times$  Condition interaction,  $F(4, 138) = 2.85$ ,  $p < .03$ ,  $\eta^2 = .01$ . Follow-up analyses for each phase provided no evidence of differential performance by condition at baseline, immediate recall, or delayed recall ( $p_s > .30$ ). Follow-up analyses for each condition revealed that performance at immediate and delayed recall exceeded that at baseline in all conditions. In the generalization and specificity conditions, there were decrements in production of the individual target actions from immediate to delayed testing; there was no evidence of forgetting of the target actions in the standard condition ( $p_s < .01$ ,  $\eta^2 = .33$ – $.40$ ).

In summary, infants learned and remembered both the actions and the temporal order of actions of the test sequences. In the standard condition, production of the individual target actions of the sequences did not differ from immediate to delayed recall. However, infants did evidence some forgetting of the temporal order of the sequences over the delay. In the generalization condition, infants generalized to the variant props at Session 2. The change in props extracted some “cost,” however, in that infants not only produced fewer pairs of actions at Session 2 relative to Session 1 (which could be due to forgetting as in the standard condition) but also evidenced a decrement in production of target actions (not seen in the standard condition). In the specificity condition, infants produced both fewer target actions and fewer ordered pairs of actions at Session 2 than they had immediately after modeling at Session 1. Testing for the specific features of the props, thus, apparently had a deleterious effect on memory for the individual actions of the sequences. As in Wiebe and Bauer (2005), the detrimental effects of additional props likely were the result of the interference that they create.

#### *Memory for props used to produce sequences*

Performance in the forced-choice item selection task was evaluated by comparing the percentage of time infants chose the base props with chance (50%) by age at each session. One-sample  $t$  tests indicated that neither the 16- nor 20-month-olds consistently chose the materials shown during the experimenter’s demonstration at either session (all  $p_s \geq .60$ ).

Although as a group infants did not consistently select the base props versus the variant props, there was evidence of systematic behavior within participants. Specifically, inspection of the data revealed that whereas some infants selected the base props, as instructed (e.g., “We used one of these to make a dancing toy. Show me which of these we used to make a dancing toy”), others seemingly were guided by a preference for novelty and selected the variant props. At Session 1, for both age groups, within-participants  $t$  tests revealed that the absolute difference between the number of base props selected and the number of variant props selected was reliably greater than 0 (the difference expected if selections were at chance),  $t(16) = 3.70$  and  $t(18) = 4.60$ ,  $p_s < .005$  (two-tailed), for younger and older infants, respectively (the data from one infant of each age were missing and could not be included in the analysis). The same pattern emerged at the second session,  $t(17) = 6.15$  and  $t(19) = 5.17$ ,  $p_s < .001$  (two-tailed), for younger and older infants, respectively. These analyses indicate that although as a group infants did not reliably select the base props, their behavior toward the props was nonrandom. The pattern is consistent with the suggestion that infants encoded specific features of the props at Session 1 and remembered them over the 1-month delay.

### Predicting immediate and long-term recall

The major question posed in this research was the relation between encoding (assessed at Session 1) and retention (assessed at Session 2) of the specific feature of which props were used to produce events and recall of the actions and the temporal order of actions of the events themselves. The question can be addressed concurrently, at each session, as well as over the delay. We confined the analyses to the sequences in the specificity condition because it was only those sequences on which we had measures of both recall of the sequences and forced-choice selection of the props. Because the strongest evidence of memory for the specific feature of which props were used comes from selection of the base props, we used the number of base props selected in the forced-choice item selection procedure as the predictor of recall of the actions and the temporal order of the events.

*Concurrent relations.* Within Session 1, across age groups, there was a relation between memory for the specific features of the props used to produce the events and the number of individual target actions produced immediately after modeling,  $r(34) = .33$ ,  $p = .05$ ,  $R^2 = 11\%$ . However, separate analyses for each age group revealed that the effect was apparent for the 20-month-olds only,  $r(17) = .47$ ,  $p < .04$ ,  $R^2 = 22\%$ . For the sample as a whole, there was no relation between selection of the base props and memory for the temporal order of the sequences. No relations emerged when the age groups were analyzed separately. Thus, at Session 1, for the older infants, there was a relation between memory for the actions of the events and for the specific features of the props used to produce them. The relation did not extend to the younger infants or to memory for the temporal order of the events.

Within Session 2, there were no concurrent relations between memory for the specific features of the props used in the events and memory for either the actions or the order of the actions, either for the age groups combined or for either age group separately.

*Cross-lagged relations.* Between sessions, for the sample as a whole, encoding of the actions and the temporal order of actions at Session 1 (as measured by immediate recall) did not predict recognition of the props used to produce the events after the 1-month delay. No relations emerged when the age groups were examined separately.

For the sample as a whole, the cross-lagged relations between encoding of the props used to produce the events at Session 1 (as measured by the forced-choice item selection at Session 1) and delayed recall (at Session 2) were significant,  $rs(34) = .42$  and  $.40$ ,  $ps < .05$ ,  $R^2s = 18$  and  $16\%$ , for long-term recall of the actions and order of the sequences at Session 2, respectively. However, separate analyses for each age group revealed that the correlations were carried by the older infants. That is, for the 16-month-olds alone, we found no significant relation between encoding of the specific features of the props used to produce the events and long-term recall of them. In contrast, for the 20-month-olds, encoding of the specific stimuli at the first session predicted delayed recall of the individual target actions and the temporal order of the sequences 1 month later,  $rs(17) = .71$  and  $.59$ ,  $ps < .001$  and  $.01$ ,  $R^2s = 50$  and  $35\%$ , respectively. Regression analyses revealed that encoding of the specific props used to enact the events predicted unique variance in long-term recall above and beyond that predicted by encoding of the actions and the temporal order of actions themselves. Specifically, immediate imitation of the individual target actions of the sequences at Session 1 predicted 21% of the variance in long-term recall of the actions. The addition of memory for the specific features of the props used to produce the events at Session 1 brought the variance accounted for to 48%,  $F(1, 16) = 9.96$ ,  $p < .006$ . Similarly, immediate imitation of the temporal order of actions at Session 1 predicted 23% of the variance in ordered recall 1 month later. The addition of memory for the specific features of the props used at Session 1 brought the variance accounted for to 39%,  $F(1, 16) = 5.37$ ,  $p < .05$ .

### Discussion

The current research was designed to address two questions. The first was whether there are age-related differences in 16- and 20-month-olds' encoding and retention of the specific props used to produce multistep sequences, such that older infants show more robust differentiation of them

from props that differ in appearance but that can be used to execute the same sequences. The second question was the nature of the relation between memory for the identity of props used to produce event sequences and recall of the events themselves. Within this larger question, the specific hypothesis was that memory for the props used to produce events would predict memory for the actions and order of the sequences after a delay. These questions are theoretically motivated. For example, the trace integrity framework (Brainerd et al., 1990) and fuzzy trace theory (Brainerd & Reyna, 1990) characterize formation and loss of memory traces in terms of featural integration and disintegration. In these conceptualizations, forgetting is thought to involve the loss of unique feature information. The resulting degraded traces are indistinguishable from those of other similar events, rendering them inaccessible. The questions also are important neurodevelopmentally in that recall of specific features seemingly places high demands on the relatively immature temporal–cortical network responsible for recall. As the network and structures within it develop, infants and children should be better able to encode, store, and retrieve the specific features that lend to memory traces their episodic quality (see Bauer, 2007, for a discussion).

The 16- and 20-month-olds tested in this research showed evidence of learning of multistep sequences and memory for them over a 1-month delay. They also showed evidence of memory for the specific feature of the props used to produce the sequences. The age groups did not differ in the robustness of their memories for the props. Nevertheless, memory for the events themselves and memory for the props used to produce them were related only in the 20-month-olds. Among the 20-month-olds, immediate recognition of the props used to produce the sequences at Session 1 predicted 50% and 35% of the variance in 1-month delayed recall of the actions and the temporal order of the actions of the sequences, respectively. Memory for the specific feature of the props contributed unique variance in long-term recall, beyond that explained by the level of encoding of the actions and the temporal order of actions of the sequences themselves. Similar relations were not observed among 16-month-olds.

The current research is not the first to assess 1- to 2-year-olds' memory for the props used to produce multistep sequences of action. Bauer and Dow (1994) conducted a similar investigation in pursuit of the question of the mechanism of generalization (see also Lechuga et al., 2001). Specifically, they asked whether generalization was born of forgetting (as it seemingly is in the conjugate reinforcement technique, with infants generalizing to novel mobiles only after they have forgotten the specific features of the original mobiles [see, e.g., Rovee-Collier, 1990, for a review]) or whether infants remember the specific props used to produce events even as they generalize to novel props. In the previous study, infants showed their memory for the base props by systematically selecting them to produce the target events. Yet in the current research, infants were as likely to select the variant props as the base props both immediately after producing the sequences and after a 1-month delay. It is likely that procedural variations between the experiments is the source of the different patterns of behavior. Specifically, in Bauer and Dow's (1994) study, infants were not tested for recognition of the base props until 1 week after experience of the events and production of them with the base props. In contrast, in the current experiment, infants' recognition was tested virtually immediately after infants produced the sequences. Given that infants had just used the base props to produce the events, and that the variant props were perfectly good substitutes (as evidenced by generalization to them), their novelty may well have overwhelmed the verbal instruction to, for example, "Show me which of these we used to make a dancing toy." Importantly, although infants did not necessarily select the base props, they nevertheless showed their recognition of the stimuli by systematically selecting either the base props or the variant props.

The finding of a relation between 20-month-olds' recognition of the props used to produce event sequences and their subsequent memory for the actions and the temporal order of actions of the sequences is consistent with the suggestion that one of the "ingredients" of successful long-term recall is memory for the details of to-be-remembered events. Although this premise has been tested in young children (e.g., Brainerd & Reyna, 2002) as well as in older children and adults (e.g., Odegard, Holliday, Brainerd, & Reyna, 2008), to our knowledge the current research is the first empirical test of the suggestion during infancy. The substantial unique variance explained by memory for the specific features of the props used to produce the events indicates the importance of additional work on memory for this episodic feature and others. Obvious questions include the robustness of infants' memories for

the specific features of events and the role in memory played by recognition or recall of other unique features such as who participated in the event and where the event took place. Infants have been shown to generalize their memories across changes in these features (who: Hanna & Meltzoff, 1993; where: Barnat, Klein, & Meltzoff, 1996; Klein & Meltzoff, 1999). Whether memory for them also plays a role in long-term recall is an important question. The current research strongly suggests that memory for at least one specific feature—the props used to produce events—is a critical element in the preservation of the integrity of a memory trace over the long term.

The current research also contains a strong motivation for further research on potential developmental differences in relations between memory for the specific features of events and memory for the events themselves. In the current study, there was evidence of age-related differences in long-term recall but no evidence of differentially robust memory for the specific props used in the events. Yet it was only among the older infants that memory for the specific features of the props were related to long-term recall of the sequences themselves.<sup>1</sup> In contrast, the younger infants experienced a utilization deficiency (Miller, 1990; Miller & Seier, 1994) of sorts. That is, they engaged in a mnemonic behavior—encoding and retaining the specific features of events—from which they derived no benefit to performance. A question for future research is whether this apparent utilization deficiency is preceded by a period in which infants even fail to encode the specific features of events, retain them, or both. At this time, we highlight the positive finding of a relation among 20-month-olds between memory for the specific feature of which props were used to produce event sequences and long-term recall of them. The finding is a step in explanation of development of long-term memory, namely, that long-term recall is facilitated by memory for specific features.

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<sup>1</sup> Nor did relations emerge in a separate experiment in which we tested 16-month-olds on shorter two-step sequences and tested memory for the props using a visual paired comparison procedure. These conditions might have been expected to produce a better “fit” to the capabilities of the younger infants in terms of a more developmentally appropriate sequence length (Bauer & Hertsgaard, 1993) and elimination of the challenges posed by explicit forced-choice item selection. Even under these conditions, however, no relations emerged for the younger infants (details available on request from the first author).

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