Goals influence memory and imitation for dynamic human action in 36-month-old children

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Loucks, J. & Meltoff, A. N. (2013). Goals influence memory and imitation for dynamic human action in 36-month-old children. *Scandinavian Journal of Psychology* 54, 41–50.

Adults' memory for action is organized according to a hierarchy of goals. Little previous research has examined whether goals also play a crucial role in young children's memory for action, and particularly whether goal information is privileged over veridical sequential order information. The current experiment investigated 3-year-old children's (N = 40) memory for naturally occurring interleaved action sequences: Sequences in which an actor switched back and forth between carrying out actions related to two distinct goals. Such sequences allowed a test of whether children's action representations prioritize a goal interpretation over veridical sequential information. Children's memory for the action events was assessed by deferred imitation, 5-min after the demonstration had ceased. Results indicated that children's memory prioritizes goals over veridical sequential order – even to the extent that the actual sequential order is distorted in memory. These findings deepen our understanding of action processing and memory with implications for social-cognitive development.

Key words: Memory, imitation, human action, goals, intentions, hierarchical organization, representation.

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INTRODUCTION

Humans are highly social creatures. Processing the actions of other individuals takes up a significant portion of the daily mental life of adults. Efficient interpretation and accurate memory of others' actions is required for interacting in social settings, engaging in cooperative activities, helping others, and profiting from pedagogical encounters. For most adults, action perception and interpretation does not require explicit mental effort – people can pick out actions from impoverished perceptual input (e.g., point-light displays, Johansson, 1973). However, in naturally occurring social interactions action sequences are rather complex stimuli. Everyday actions are typically carried out rapidly, without pausing between distinct actions, and can involve multiple goals interleaved in one dynamic action stream (multi-tasking). Given such complexity and the ease with which action is perceived and comprehended, a powerful cognitive system is likely at play (Baldwin, 2005; Prinz, Beisert & Herwig, 2013).

Action processing is arguably even more crucial for infants and young children than for adults. Children must rapidly acquire information about actions and their causal effects on the world by watching others – learning by observation and imitation (Meltzoff, Kuhl, Movellan & Sejnowski, 2009). The development of action processing is deeply intertwined with early social-cognitive development, and much developmental work focuses on this relation (e.g., Baldwin & Baird, 1999; Meltzoff, 2007; Phillips & Wellman, 2005; Woodward, 2009).

One aspect of action processing which remains largely unexplored in children is *memory* for complex action sequences involving multiple interwoven goals. Given the fact that human action is rapid, evanescent, and complex, it seems likely that it is selective – only certain details are actually encoded and stored in memory, while others are lost. In addition to *what* information is stored, there is a question of *how* that information is stored. How are memory representations of complex action sequences organized?

Goal coding in early development

Information pertaining to the goals or intentions of the actor are encoded by children and adults (Baldwin, 2005; Heider, 1958; Malle, Moses & Baldwin, 2001; Meltzoff, 1995; Schult & Wellman, 1997). Observers seem less concerned about how actions are carried out than about the underlying goals and intentions. If you were to ask your friend at a dinner party to pass the salt, you would be less concerned with whether the salt was lifted or pushed across the table, and more concerned simply that the salt is indeed transferred.

Developmental research supports the notion that goals are encoded in memory from infancy. Infant looking-time paradigms show that by 6 months of age infants selectively encode the goal of reaching-to-grasp actions (Woodward, 1998). Infants' imitation of other people's actions is also influenced by goals. When presented with an actor trying unsuccessfully to manipulate an object, 18-month-old infants do not duplicate what the actor did – instead, they successfully re-enact the goals and intentions of the actor (Meltzoff, 1995). Similarly, if presented with goal-relevant and goal-irrelevant actions, 3-year-olds will selectively imitate goal-relevant actions (Williamson & Markman, 2006). At this age, representations of action goals are also hierarchical in nature (Bekkering, Wohlschläger & Gattis, 2000; Gleissner, Meltzoff & Bekkering, 2000).

Segmenting the action stream

Research on adults' segmentation of action is also relevant to memory organization. Since human action is largely continuous in nature, a crucial component of comprehension involves segmenting the continuous flow of motion into discrete units (Baird & Baldwin, 2001; Newtson, 1973; Zacks, Tversky & Iyer, 2001b). Adults are remarkably consistent in explicitly identifying the boundaries or "breakpoints" of action – points that mark the completion of one goal and the initiation of another (Zacks, 2004). People spontaneously segment action in real-time as they view

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others' behavior (Saylor & Baldwin, 2004; Zacks, Braver, et al., 2001a), and even preverbal infants are sensitive to the breakpoint structure of action (Baldwin, Baird, Saylor & Clark, 2001; Saylor, Baldwin, Baird & LaBounty, 2007).

Evidence also indicates adults represent action as a partonomic hierarchy of goals. That is, when observers are asked to segment continuous action into units of varying size, they parse action into several levels: Coarse units (e.g., cleaning the kitchen), finer units from which each coarse unit is composed (e.g., washing dishes and throwing out the trash), and into even finer nested units still (e.g., grabbing a dish, running it under water, putting it in the tray, Zacks et al., 2001b). This kind of structure provides the observer a way of chunking information at differing levels of granularity for differing purposes – for example, inferring the actor's immediate goals ('intentions-in-action,' Searle, 1983) versus longer-term goals, plans, and intentions (Searle's 'prior intentions').

The process of segmentation influences memory, as breakpoints provide an anchor with which observers can organize action information. In adults, action at breakpoints is remembered more accurately than action at non-breakpoints (Newtson & Engquist, 1976; Schwan & Garsoffky, 2004), and action sequences that are interrupted at breakpoints are remembered more accurately than sequences interrupted at non-breakpoints (Boltz, 1992). Observers whose segmentation agrees with others' segmentation have better memory for action details (Zacks, Speer, Vettel & Jacoby, 2006), and the way observers approach the task of segmentation affects their memory for action (Lassiter, Geers & Apple, 2002; Lassiter, Geers, Apple & Beers, 2000; Ratcliff & Lassiter, 2007).

Recent research also indicates that the hierarchical processing of action influences memory for events. Hard, Recchia, and Tversky (2011) investigated adults' viewing durations to slideshow sequences of action, and found that viewing time increased at breakpoints and as a function of hierarchical level. Longer viewing occurred at breakpoints of higher-level action units relative to nested sub-action units, and viewing time at breakpoints was significantly correlated with observers' later recall of the action sequences. Thus, hierarchical encoding enhances memory for specific action details.

Theoretical issues in the representation of action: two ways to organize action memory

We have shown that (a) goals are central aspect of observers' representation of action, and (b) action segmentation is based on the hierarchical identification of action goals. Given this as background, it seems plausible that representations of action in memory would reflect the process of hierarchical segmentation according to goals. One possibility is that individual actions (e.g., selecting a mug, grasping a tea kettle) would be stored in a way that relates actions to one another via the representation of an inferred, higher-level goal (e.g., preparing a cup of tea).

A second possibility is that memory for action might reflect the veridical sequential structure of the action. Because the causal efficacy of many actions depends on strict adherence to a particular sequence of actions, at some level encoding of sequential information is essential. For instance, pouring a glass of soda can only be fulfilled if one removes the cap from the bottle *before* attempting to pour the liquid into the glass, and an observer who witnessed the reverse order of actions would not infer a higher-level goal of getting a drink. Indeed, theories of adult episodic memory emphasize the importance of temporal order in memory organization (Conway, 2009), and sequential information plays an important role in action and event processing more generally (Avrahami & Kareev, 1994; Baldwin, Andersson, Saffran & Meyer, 2008; Swallow & Zacks, 2008).

For many action events, hierarchical goal structure and sequential structure coincide – for instance, making a bed by executing all sub-actions in sequential order. In these cases, memory organization could easily represent the goal hierarchy using a sequentially organized base of sub-actions, and there would be no cost to either the goal inferences or the sequential information. Crucially, however, there are action events in which goal structure is at odds with the observed sequential structure. A carpenter might be hammering nails into a board, and then stop to take a quick sip of coffee, before resuming the hammering of nails. How would a naïve observer parse and remember such a sequence? Everyday goals are often executed in a non-linear fashion: We are interrupted, we are distracted, we multi-task. What does an observer make of the tangled action stream in such cases?

When goal inferences and sequential information do not coincide in the flow of action, which information takes precedence in the memory representation? If action memory is organized primarily with respect to the hierarchical goal structure of the action, then coding of sequential relations may be distorted in memory. Alternatively, action memory may be organized primarily according to the veridical sequential structure of the action, which in some cases would yield a similar cost to the representation of higher-level goals. Figure 1 depicts these contrastive organizational schemes. Our hypothesis is that goal organization dominates sequential organization, with implications for children's memory for social-cognitive events.

Goal organization

Previous research supports the hypothesis that goal inferences take precedence in memory. Lichtenstein and Brewer (1980) found that adult observers were more likely to verbally recall higher-level action units than units lower in the goal hierarchy. They also found that adults displayed relatively poor verbal recall for action units that occurred at times outside of their canonical sequential positions, and tended to misremember these units as having occurred in the standard canonical position. Zacks *et al.* (2001b) found similar effects of hierarchical representation in explicit verbal recall of action events.

However, evidence that *explicit* verbal recall follows hierarchical goal structure is not definitive, because linguistic representations of events may be distinct from the actual underlying representation of the action. Brewer and Dupree (1983) alleviated this concern to some degree by extending the findings of Lichtenstein and Brewer (1980) with a visual recognition task. A limitation of this study, however, was that the stimuli used were edited videotapes that did not flow like natural action events (i.e., involved inserted blank screens).

Developmental research is useful in this regard as it often works around explicit verbal responses. Bauer and colleagues explored so-called "enabling relations" in action – when the execution of

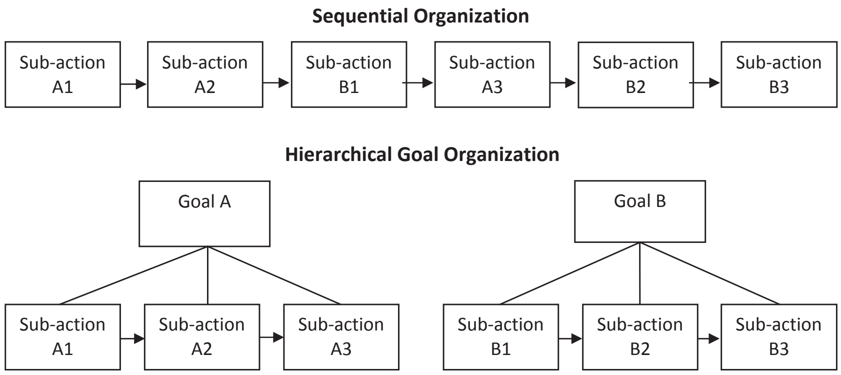

Fig. 1. Schematic examples of sequential organization and hierarchical goal organization for the memory of an interleaved action sequence. Note that sequential organization reflects the veridical order of observed sub-actions, while goal organization involves shifting the position of sub-actions A3 and B1.

one action enables the execution of a subsequent action (Bauer, 1992; Bauer & Mandler, 1989, 1992; Bauer & Shore, 1987). They argued that enabling relations are represented as a unitized chunk in children's memory, thus reducing memory load. A typical enabling relation used in such studies was 'make a rattle', which involved putting an object into a cup, inverting another cup on top of this cup, and shaking the cups together with the object inside. Bauer presented 20- and 25-month-old infants with an action sequence in which an action unrelated to an enabling relation was inserted in between the enabling relation, for example, putting a sticker on the rattle. In their imitation, children were most likely to reproduce the enabling relation sequentially and the interrupting action either before or after the relation, suggesting unitized organization in memory according to causal structure.

Although Bauer and colleagues have argued that this effect reflects chunking in memory, several alternatives have not yet been ruled out. Children might find the enabling relations inherently more interesting. Children may also accurately remember the sequential order, but because of poor inhibitory control be unable to inhibit executing the inherently more interesting next step in the relation (see Barr & Hayne, 1996, for further points).

Of even greater importance for the purposes of the current research, Bauer and colleagues' line of research was restricted to mechanical action structures. For example, proper rattle construction relies on knowledge of solidity and containment (Hespos & Baillargeon, 2001; Spelke, Breinlinger, Macomber & Jacobson, 1992): The to-be-rattled object must be put inside an appropriate container. It is thus unknown whether children's memory is more generally organized according to inferred higher-level goals, which do not always involve mechanical causal relations and may be more arbitrary and conventional. Consider the case of making a salad, or cleaning a room, or decorating for a social event, all of which have a discernible goal and involve sub-actions, but can be accomplished flexibly in several orders. Because such goals are more abstract in nature, they are not always identifiable from an analysis of the component actions themselves.

Aims of current study

The purpose of the current research was to explore whether young children's memory for complex, dynamic action events is organized primarily with respect to hierarchical goal structure or veridical sequential structure. We hypothesized that children's memory for action prioritizes goal organization. Our test of this hypothesis involves having young children watch an adult engaged in multitasking. We used interleaved action sequences: Sequences in which actions related to one goal are interrupted by actions related to a second distinct goal. Critical for theory is the fact that in such sequences, the veridical sequential structure is discordant with the hierarchical goal structure, and thus memory organization based on sequential structure differs from organization based on inferred higher-level goals (see Figure 1). When young children observe an interleaved action sequence, do they represent the sequence in memory according to veridical sequential order or according to goals?

We designed a paradigm that capitalized on children's tendency to imitate or re-enact action scenes from memory (Meltzoff & Williamson, 2010). Children observed an adult demonstrate an action sequence in which actions from one goal were interleaved with actions from a distinct second goal. We predicted that children would be more likely to re-enact the sequence by spontaneously grouping actions together according to hierarchical goals, rather than imitating the veridical sequence, relative to appropriate controls.

METHOD

Participants

Participants included 40 3-year-old children (20 boys). The children were tightly clustered around their 3rd birthday, mean age = 35.95 months, range = 35 to 37 months. Ten children (five boys) were randomly assigned to each of the four conditions. All children were typically developing and from the Seattle metropolitan area. Participants were recruited from a computerized database maintained by the university. Based on parental report of race/ethnicity, 31 children were classified as White, three as Asian/Pacific Islander, one as African American, and five as mixed or unlisted race; four of the 40 self-classified as being of Hispanic ethnicity. An additional 11 children were tested but excluded from the final sample for the following reasons: Poor compliance with experimental instructions and imitation during the warm-up sets ($N = 6$), too shy ($N = 1$), equipment failure ($N = 2$), and experimental error ($N = 2$).

Stimuli

Stimuli included four sets of objects: Two warm-up sets and two test sets. The first warm-up set was the *Catapult*, and included a wooden dowel, a flat green stick, and a small wooden sheep. The second warm-up set was

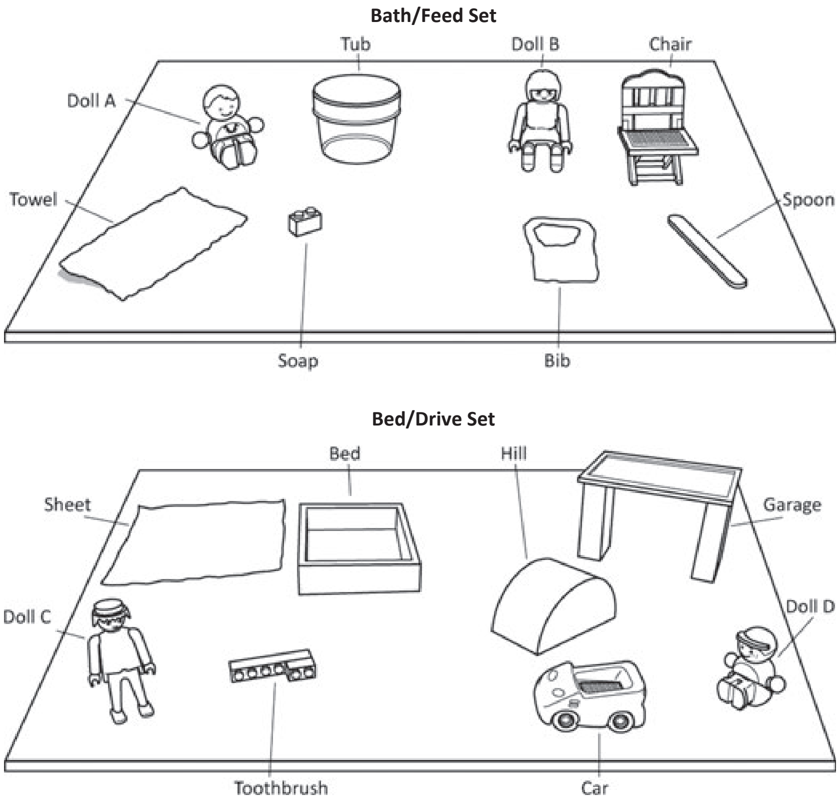

Fig. 2. The two test sets. In the text, the *Bath/Feed* set is referred to as Set A, and the *Bed/Drive* set is referred to as Set B. Labels in figure correspond to sub-action descriptions used in Table 1. For size reference, Dolls A and D are 4 cm tall, Doll C 7 cm tall, and Doll B 5 cm tall.

the *Obstacle Course*, and included a human doll, a thick wooden block, a green wooden staircase, a square blue wooden block, and a thin red wooden block.

As depicted in Figure 2, the test sets were Set A (the *Bath/Feed* set) and Set B (the *Bed/Drive*) set. Each of these involved objects used to complete two familiar, independent goals. Each test set was arranged on a black board, to ensure the standard placement of items across children. The objects were arranged on the boards as they appear in Figure 2.

Design

Equal numbers of male and female children were randomly assigned to one of the four conditions. Three of these conditions involved demonstrations: the interleaved, grouped, and activity control conditions. The baseline condition involved no demonstrations – children were simply given the materials to play with in order to assess their spontaneous tendency to produce and sequence target actions in the absence of any adult demonstration. Across all four conditions which test materials (set A or B) were presented first was fully counterbalanced across children. Which goal activity was demonstrated first (e.g., Set A: *Bath* vs. *Feed* and Set B: *Bed* vs. *Drive*) was also fully counterbalanced within the three demonstration conditions.

Procedure

All children were tested in a university laboratory room. Children were tested at a black table, with the experimenter seated adjacent to the child, on the child's left. Each session was digitally recorded for subsequent offline coding. Parents observed the session via camera in an adjoining room or if need be were seated in the corner of the room and asked to remain quiet and neutral. Children were given minimal verbal information about the task – that the experimenter would be bringing out toys and then either providing demonstrations (the three demonstration conditions) or giving them to the child to play with (baseline condition).

The general procedures common to all groups are described next. The commonalities exist for the warm-up phase, and for how the demonstrations, memory delays, and subsequent response periods unfolded. Note that the baseline condition involved no demonstrations and no memory delays.

Warm-up phase. The two warm-up sets preceded the test demonstrations. The *Catapult* set was brought out first. For this set, the experimenter demonstrated crossing the green stick perpendicular over the wooden dowel, putting the sheep on the low end of the green stick, and hitting the high end of the green stick to launch the sheep upwards. The *Obstacle Course* set was brought out next. For this set, the experimenter demonstrated making the doll jump over the thick wooden block, walking up the green staircase, hopping onto the blue block, and laying down on the red block.

Demonstrations. A set of test materials was put on the table, and the experimenter said, "OK [child's name], watch this," and then carried out the relevant demonstration. The experimenter maintained a positive expression throughout all steps of the sequence and no language was used. Once the experimenter had completed the demonstration, he said, "OK, I'm all done!" The mean length of the demonstration for Set A was 28.56 seconds ($SD = 2.40$) and for Set B 31.43 seconds ($SD = 2.68$).

Memory delay. After each test set's demonstration, a 5-min delay period was inserted. The experimenter said, "Before you get a turn, I'm going to put these away for a little bit, and we'll do something else. Then you'll get a turn in a little while." The set was then placed out of sight. The delay activities included coloring a picture and looking at a picture book. The coloring activity was always the first activity. After the delay, the set was brought back, and the standard response period commenced.

After this the demonstration for the next test set began, followed by another 5-min delay, and then the response period for that set.

Response periods. The board with the test set was slid toward the child with the prompt "OK, [child's name], now it's your turn." A 60 s response period began when the child first touched a toy in the set (or ended when the child completed the sequence or indicated that they were finished and would engage no more with the objects). If the child was tentative to engage with the display, the experimenter encouraged the child with neutral phrases, such as "It's OK – it's your turn now." If the child asked questions about particular objects or about what to do, the experimenter responded in a friendly way, and simply said, "Um, I don't know." The children's behavior during the response periods was digitally recorded, and this constituted the raw behavioral record for subsequent scoring.

Details of demonstration conditions. All demonstration conditions involved showing the same 12 sub-actions, and only differed in their sequencing of these sub-actions. Table 1 provides a description of the sub-actions. Each sub-action was assigned a notational code, shown in Table 1, for use in describing the demonstration sequences below. Next we describe the sequencing involved in each condition.

Interleaved condition. This was the experimental condition of chief interest. It embodied the adult switching from one goal to another in an interleaved fashion. Thus, for Set A, children saw a demonstration of 1-2-A-3-B-C (or A-B-1-C-2-3). For Set B, children saw a demonstration of 7-8-X-9-Y-Z (or X-Y-7-Z-8-9). Note that these demonstrations involve switching the positions of two sub-actions from their standard grouping, as indicated by the underscoring in the sequences above (e.g., 3 and A are switched). The hierarchical goal organization and veridical sequential organization are in conflict. Children can thus reveal their memory for the observed events by how they choose to re-enact what they saw in the response period.

Grouped condition. In the grouped condition children saw intact goal sequences. The actions related to each goal were grouped together without any switched or displaced actions. Thus, for Set A, children saw a demonstration of 1-2-3-A-B-C (or A-B-C-1-2-3), and for Set B saw a demonstration of 7-8-9-X-Y-Z (or X-Y-Z-7-8-9). We predicted that hierarchical goal organization would be prioritized in memory such that children's recall in the interleaved and grouped goal conditions would not differ.

Activity control condition. The purpose of the activity control was to rule out the possibility that seeing the sub-actions in the interleaved (and grouped) conditions might simply trigger children to "run off" a completed script. Scripts are representations of well-practiced or habitual activities that specify the typical actions or events that are likely to occur for an activity, and research indicates that they play a role in adults' encoding and recall of events (Bower, Black & Turner, 1979; Schank & Abelson, 1977). Because the goals used in the demonstrations were familiar, children in the interleaved condition might recall grouped goal sequences not because they are accessing their representation of the just-demonstrated event, but because they are accessing a previously formed script that was triggered by seeing one or more particular sub-actions. This control condition tests this possibility, and is based on the adult manipulation control introduced to assess intention understanding (Meltzoff, 1995) and deferred imitation (Meltzoff, 1988) in infants.

In the activity control condition the adult demonstrated target actions related to the same goals, but demonstrated them in (a) the reverse order, and (b) in a scrambled fashion. Importantly, children *see the exact same sub-actions* as they do in the interleaved and grouped demonstrations. If seeing one or more of these sub-actions simply triggers a whole script, it should be triggered in this condition as well. For Set A, children saw a demonstration of 3-C-2-B-1-A (or C-3-B-2-A-1), and for Set B children saw a demonstration of 9-Z-8-Y-7-X (or Z-9-Y-8-X-7). Children thus observed all of the sub-actions that could trigger the scripts, but did not see a sequence of events that could elicit a higher-level goal inference, because the event was so thoroughly scrambled as to not be "meaningful" in terms of a hierarchically organized goal. We predicted that in the interleaved condition, but not in the activity control condition, children would use the inferred goals to reorganize what was actually seen. All of the same sub-actions were demonstrated to children, but we did not think they could "make sense" of the adult's demonstration in terms of hierarchical goal structure.

Baseline condition. Children in this condition were not shown any demonstrations, and were simply presented with the warm-up and test materials in the same manner as the other conditions, but without the prior modeling of what to do with the objects. Everything about the procedure was identical, save that the demonstration phase and subsequent memory delay was omitted. The purpose of this condition was to control for the possibility that the stimuli *spontaneously* elicited the behaviors that we predicted we would observe only in the experimental conditions. We predicted that children would perform few target actions in this condition, and few grouped goal sequences.

Table 1. *Sub-actions for the test sets*

Set	Goal	Action	Notation
A	Bath	Put doll A in tub	1
		Scrub doll A's head with soap	2
		Dry off doll A's head with towel	3
	Feed	Put doll B in chair	A
		Put bib over doll B's head	B
		Feed doll B with spoon	C
B	Bed	Brush doll C's teeth with toothbrush	7
		Lay doll C in bed	8
		Cover bed with sheet	9
	Drive	Put doll D in car	X
		Push car over hill	Y
		Push car into garage	Z

Scoring

Children's behavior during the response periods were scored from the video records. Because the response periods from all four groups were identical and there was no identification of the child's condition on the recording, scoring could be performed with the observer blind to condition. The 40 children (two response periods each) were scored in a random order by a trained observer.

The coder provided a record of all of the actions that the child performed with the objects, including target sub-actions (1, B, etc.) and non-target actions (e.g., putting the car on top of the garage). For sub-actions 2, 3, C, and 7, as long as the relevant object was brought to the relevant body part it was scored as a target sub-action. For sub-action 9, the act was scored if the sheet covered at least 50% of the bed. For sub-action Z, the target act was scored when the car passed through the vertical supports of the garage. The coder also provided a record of the sequence in which all of these actions were performed. From these raw sequences, the main dependent measures were derived. A second coder, also blind to children's test condition, scored 25% of the sample for reliability purposes (results below). Any disagreements were resolved through discussion.

Goal grouping score. The goal grouping score was defined as the number of grouped goal sequences performed across both test sets by each child. A grouped goal sequence was when sub-actions for a particular goal were executed in exact sequential order – for example, performing 1-2-3 for the *Bath* goal, or X-Y-Z for the *Drive* goal. Importantly, if the child performed any of the target actions out of order, it was not counted as a grouping sequence. In addition, if the child corrected a mistake in sequencing (e.g., put the doll in the bed, then took the doll out to brush its teeth, then put the doll back in the bed), this also was not counted as goal grouping. Reliability on goal grouping identification was high (Cohen's kappa = 0.92).

A child received a score of 1 for each grouped goal sequence. Because there were 4 goals (*Bath, Feed, Bed, Drive*), scores thus ranged from 0 to 4. A child who grouped none of the sub-actions together as a goal on either of the test sets received a score of 0, and a child who grouped all sub-actions together for each goal on both sets received a score of 4.

Target act score. The target act score captured how many of the 12 sub-actions listed in Table 1 were recalled across both test sets, regardless of sequencing. A child received a score of 1 for each target sub-action recalled. Because there were 4 goals with 3 sub-actions each, scores on this measure ranged from 0 to 12. The target act score evaluates how many sub-actions children imitated without regard for sequence, and thus children in the activity control condition might well recall and imitate the sub-actions, because they saw each of them; however, we predicted they would not group them together in a goal sequence. Reliability on target act identification was high (Cohen's kappa = 0.91).

First-activity score. The first-activity score reflected the extent to which children recalled the set of materials the experimenter engaged with first in his demonstrations. For each test set, a child received a 1 if the first target sub-action they performed was from the same goal that the experimenter first engaged with in his demonstration. For instance, if the experimenter began his demonstration with a *Drive* sub-action, and the child's first performed sub-action was from the set of *Drive* actions (see Table 1 for sub-actions), the child would receive a 1 for that set. There were two sets of materials used (Sets A and B), thus, scores on this measure ranged from 0 to 2. A score of 2 indicates accurate recall of the first activity engaged with on both sets; a score of 1 was 'chance' in that the child had a binary choice on each set, and would be expected to get one correct if guessing randomly. Coders did not disagree on this measure (Cohen's kappa = 1).

RESULTS

Main analyses

Preliminary analyses revealed no significant gender or order effects (which set or goal presented first), so the main analyses collapsed over these factors. Table 2 provides the raw distribution of goal grouping scores. As predicted, the grouping scores differed as a function of condition and support the predictions of hierarchical goal organization (Figure 1). A one-way ANOVA on goal grouping scores revealed a significant effect of condition, $F(3,36) = 19.99$, $p < 0.001$, $\eta^2 = 0.63$, and Tukey post hoc tests showed that the interleaved ($M = 2.3$, $SD = 1.34$) and grouped conditions ($M = 2.1$, $SD = 1.10$) did not differ, but that both produced significantly higher goal grouping scores than the activity control ($M = 0$, $SD = 0$) and baseline ($M = 0.1$, $SD = 0.32$) conditions (ps < 0.001), which did not differ from one another.

Table 2. *Distribution of goal grouping scores as a function of condition*

Condition	Goal grouping score 0	1	2	3	4
Interleaved	2	0	2	5	1
Grouped	0	4	2	3	1
Activity control	10	0	0	0	0
Baseline	9	1	0	0	0

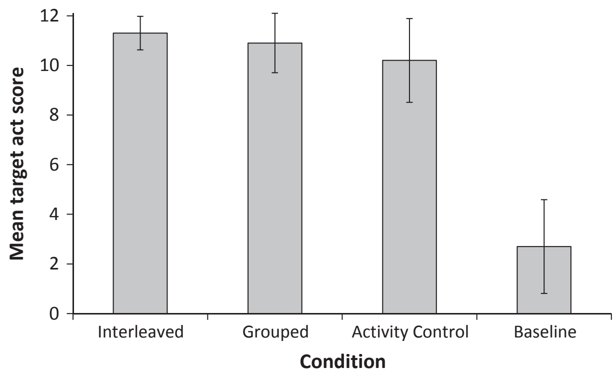

Fig. 3. Mean target act scores, that is the number of sub-actions performed (maximum 12), for each condition.

The low level of goal grouping in the activity control condition suggests that goal grouping in the interleaved condition was *not* the result of sub-actions triggering pre-formed scripts for these events (see Discussion for further elaboration). The low level of goal grouping in the baseline condition further suggested that the stimulus array did not possess demand characteristics that spontaneously elicited this kind of grouping behavior.

Figure 3 displays the mean target act scores. A one-way ANOVA revealed a significant effect of condition, $F(3,36) = 80.04$, $p < .001$, $\eta^2 = 0.87$, and Tukey posthoc tests revealed that children in the three demonstration conditions did not differ in terms of the number of target actions recalled, but that children in these conditions produced significantly more target acts than the baseline condition (all ps < 0.001). Thus, children's memory across demonstration conditions did not differ in terms of the raw number of target acts recalled. In addition, the low number of target acts in the baseline condition indicates that and the objects themselves did not pull for certain actions in and of themselves.

Finally, we also analyzed children's first-activity scores for the three demonstration groups (the baseline condition was not analyzed, because with no demonstrations there were no first activities). The scores were: interleaved ($M = 1.5$, $SD = 0.53$), grouped ($M = 1.6$, $SD = 0.70$) and activity control ($M = 1.1$, $SD = 0.58$). A one-way ANOVA indicated that the three demonstration groups did not significantly differ in terms of first-activity scores, $F(2,27) = 1.92$, $p = 0.17$, and were significantly above chance in choosing the correct first activity, $t(29) = 3.53$, $p < .001$. Thus, children in the three conditions recalled something of the temporal nature of the adult's demonstration – they recalled which activity was initiated first and, remarkably, also started off their sequencing with this activity.

Subsidiary analyses

Results from the main analyses show that children in the interleaved and grouped conditions did not differ in terms of goal grouping. However, a child's goal grouping score could be influenced by two aspects of their response: (a) whether they recalled all three target actions; and (b) whether they performed the three target actions in the exact goal sequence. Thus, it was possible that children in the grouped condition may have kept the goals separated, but failed to achieve a full goal grouping score on a set because they forgot one sub-action (e.g., 1-2-3-A-B), while children in the interleaved condition may have had a reduced score if they inserted one whole grouped goal sequence in between another (e.g., 1-2-A-B-C-3). If this was the case, it would indicate that children in the interleaved condition remembered *something* about the interleaved nature of the demonstration. Accordingly, children in the grouped and interleaved conditions could have similar goal grouping scores for reasons other than goal organization in memory per se.

To rule out this possibility and to further explore these facets of children's action memory, data from the interleaved and grouped conditions were re-scored to obtain children's interleaving scores. Children received a 1 for a given test set if they performed any interleaving at all, and thus scores on this measure ranged from 0 to 2. This analysis revealed that children in both conditions interleaved their actions to the same degree, (interleaved $M = 0.7$, $SD = 0.95$, grouped $M = 0.7$, $SD = 0.82$), $t < 1$. Thus, if we take the amount of interleaving observed in the grouped condition as a baseline measure of interleaving, it does not appear that children who observe interleaved action sequences recall the interleaved nature of such demonstrations.

We also conducted an additional subsidiary analysis. Because the two goals were spatially distinct on the board (e.g., *Bed* goal on the left and *Drive* goal on the right, see Figure 2), children in the interleaved condition might have grouped the sub-actions together using a spatial strategy, rather than a goal grouping strategy. If this was the case, then children in the activity control condition could have also used this strategy, and could have grouped the backward sequences they saw together spatially (e.g., 3-2-1-C-B-A).

To address this spatial (rather than goal organization) issue, data from the activity control condition were re-scored in order to obtain children's spatially-relevant grouping scores. This score was identical to the goal grouping score, but the coder identified different sequences: In particular, sequences 3-2-1, C-B-A, 9-8-7, and Z-Y-X. Like the goal grouping score, scores on this measure thus ranged from 0 to 4. Children in the activity control condition did not tend to produce spatially-relevant groupings of the sub-actions: Of the 10 children in the activity control group, 5 children received a score of 0, 4 children received a score of 1, and 1 child received a score of 2. Goal grouping scores were significantly higher in the interleaved condition ($M = 2.3$, $SD = 1.34$) than spatially-relevant grouping scores in the activity control condition ($M = 0.6$, SD = 0.70), $t(18) = 3.56$, $p = .002$, Cohen's $d = 1.60$. Thus, goal grouping, and not spatially-relevant grouping according to where the adult had acted (left or right side of the stimulus-presentation board), is salient in children's memory and driving children's tendency to group sub-actions together in the interleaved condition.

DISCUSSION

Efficient processing of human action is central in young children's developing social cognition. In everyday life, action sequences that involve multiple hierarchical goals are often carried out in an interleaved fashion. This happens every time we multi-task. For a child to be able to make sense of the complex stream of human action in the real-world, they must be able to disentangle the interwoven series of actions actually performed into meaningful sets of goal-directed actions. This is one way of inferring "what the actor has in mind" when they switch from one activity to another (working on the computer, folding the laundry, then back to the computer). Without some such mechanism for grouping actions, the child might easily be overwhelmed by the *surface* chaos of the dynamic action stream in everyday life.

Restated more formally, the sequential order of actions and the goal structure are often *discordant* – children are exposed to an interleaved, tangled event. In such cases there are two plausible ways of organizing the observed action stream in memory: According to the veridical sequential structure of the action, or according to the hierarchical goal structure of the action (Figure 1). The current data indicate that children's memory privileges goal structure over veridical sequential structure.

It is striking that children responded in nearly identical ways whether they saw the interleaved or grouped demonstrations. Children in both conditions grouped goal actions together at the same rate, recalled the same number of sub-actions, and when they did interleave the two goals, they did so to the same degree. Children's memory representations for these two different action displays did not differ, despite *seeing* something different. It appears that as long as children are able to infer two sensible higher-level goals, memory organization is structured according to those goals.

Children's reactions in the interleaved condition were also significantly different than their reactions in the activity control condition. Because children in the interleaved condition observed familiar goals and sub-actions, it might have been that seeing one or more of these sub-actions triggered a pre-existing script for that activity (e.g., Schank & Abelson, 1977). In this case, children's goal grouping during the test would not be due to their inferred goal organization of the observed sequence, but rather due to a "read out" of a habitual action script which was simply triggered by seeing parts of it (familiar sub-actions). However, if this was the case, then children in the activity control condition should also have grouped the goals together, because the experimenter demonstrated all of the same target sub-actions in this condition (just in a different order). Not a single child in the activity control condition grouped the target actions according to the higher-level goal. This strongly suggests that children's re-enactment in the interleaved condition was the result of recalling a newly formed memory for the demonstrated actions.

These findings are consonant with broader theoretical perspectives on social cognition (Baldwin, 2005; Meltzoff, 2007; Meltzoff, Williamson & Marshall, 2013; Tomasello, 1999). When observing others performing actions, adults, children, and even infants readily infer the deeper goal or intention underlying those actions. By three years of age if not before, inferences about higher-level goals also play a key role in the way action information is organized in memory. Such memory organization is likely undertaken because a meaningful analysis of the action stream based upon goals is privileged in children's interpretation of human activity, and goal organization (Figure 1) retains this information with higher fidelity.

Relation to previous work

Cognitive science studies indicate that adults segment the ongoing action stream according to a partonomic hierarchy (Zacks *et al.*, 2001b), and that action memory is also organized according to such a hierarchy (Brewer & Dupree, 1983; Lichtenstein & Brewer, 1980; Zacks, Speer, Swallow, Braver & Reynolds, 2007; Zacks *et al.*, 2001b). The current results add to this literature in two ways.

First, much of this previous research utilized verbal measures of recall, which only indirectly measure the organization of memory (though see Brewer & Dupree, 1983). Because our imitation task was non-verbal in nature, it provides stronger evidence on this point. Second, to our knowledge this is the first research with children to directly compare whether goal information is *prioritized* over veridical sequential information when the two are in conflict. This is an important finding, given that these two types of information are often discordant in the observation of everyday actions that children see, and they may lack the linguistic savvy to rely on adult narration to disentangle them.

This work also relates to research on children's memory for mechanical enabling relations (e.g., Bauer, 1992). However, there is a critical distinction to be made between this literature and the current findings: In the case of enabling relations the link is *physical* in nature, and in the present study the link is *psychological* in nature. An enabling relation requires that certain actions follow one another in sequence – for instance, it is impossible to hammer a nail into a hole if one does not place the nail in the hole first. Bauer's stimuli used enabling relations of this type. The goal relations between sub-actions used in the current study could have been executed out of order: For instance, the experimenter could have placed the bib on the doll before putting the doll in the chair, or vice versa. Relatedly, a necessary connection used in the typical studies of enabling condition may make execution of the enabled action difficult to inhibit. This was also not a property of the current stimuli – in our research scrubbing the doll with Lego-block soap does not alter the state of the doll such that wiping the doll with a towel becomes an irresistible next step. Thus, the current results add to this body of developmental research, and suggest that by 3 years of age, children identify abstract relations among actions, and use such relations to organize memory for human action. Interestingly, because grouping according to mechanical enabling relations only requires an analysis of the physical parameters of an event, it may be present prior to the ability to group actions of a more arbitrary and conventional type such as those used here. This is an interesting question for future research and informs debates about the role of action imitation as a mechanism of cultural learning (e.g., Meltzoff *et al*., 2009).

Representational flexibility

We should emphasize that the current findings do not indicate that veridical sequential information is entirely left out of children's memory representations of action. The results only indicate that children's memory for action *emphasizes* goal relations relative to sequential relations – at least under the nonverbal conditions tested here. Interestingly, recent research on statistical learning of action sequences suggests that sequential information can be used to discover higher-level units within continuous novel action (e.g., Baldwin *et al*., 2008; Swallow & Zacks, 2008). In some cases, sequential ordering among actions might even be a cue to goal inference. Information about the veridical sequential structure of action could still be stored in memory but simply not as prominently as goal information, especially when the two are in conflict. Indeed, children in all of the experimental conditions recalled something about the broader temporal order of events, inasmuch as they all began their imitation with the same set of goal objects that the experimenter did (the 'first-activity' measure).

One could argue that children in the interleaved condition actually did remember the veridical sequential ordering of the events, but failed to demonstrate this aspect of their memory due to social pressure. Because the experimenter was present during the response periods, children's imitation may have reflected what they believed the adult experimenter wanted them to do, rather than reflecting their veridical memory representation. Without denying the power of such social effects, previous research on deferred imitation suggests they are unlikely to provide a full explanation for the current findings. Klein and Meltzoff (1999) examined 12-month-old infants' deferred imitation across changes in context which included a change in the identity of the experimenter, and found that infants' recall was unaffected by this change. Of course, social expectations could have exerted a larger influence over 3-year-olds, and a direct test of this possibility would involve changing the experimenter between demonstration and test, as was done in the infant study. Such experiments are currently underway in our laboratory.

Veridical sequential information might also be more readily available at recall under different circumstances. We introduced a 5-minute delay in between demonstration and test. However, if we were to shorten the length of the delay, we might observe stronger effects of veridical sequential organization. In the language processing literature, for example, memory for the surface features of language decays over time while memory for meaning does not show this same decay rate (Fillenbaum, 1966; Sachs, 1967). Future research should explore the connection between time, meaningfulness, and action memory in children.

It is also important to note that sequential information may play an enhanced organizational role under certain circumstances. In the present research, children's inferences regarding the higher-level goal may have been facilitated by the fact that the actions were familiar. However, when inferring higher-level goals is difficult, as may be the case when action is entirely novel, sequential information may recruit more attention in online processing and gain ascendance in memory organization. Sequential information may also rise in prominence when the over-arching goal is novel, despite familiarity with the component actions – as in the case of learning to prepare a new recipe.

This in turn raises a special point relevant to the developmental literature. The term "overimitation" has been introduced to refer to young children's tendency, in certain contexts, to imitate exactly the actions that an experimenter demonstrates, regardless of the causal relevance of these actions to achieving an end goal (Horner & Whiten, 2005; Lyons, Young & Keil, 2007). Importantly, overimitation appears to be driven in part by the relative novelty (or lack of comprehension) of the actions or objects used. For instance, Williamson and Markman (2006) demonstrated that in the absence of a specified goal, children will imitate all of the actions that an experimenter demonstrates, but when informed about the specific goal, children will preferentially imitate the causally relevant actions. Thus the emerging literature suggests that rather than being slavish copiers, children are "flexible imitators," able to vary their imitation of different aspects of the demonstration based on their interpretation of the event or social interaction (see also Meltzoff & Williamson, 2010; Williamson, Meltzoff & Markman, 2008). The relevance to the current work is that it underscores that there is not only one way to process and encode the complexities of the human action stream. Factors such as context and relative novelty can influence which aspects of the action stream are represented and retained in memory. Future research should explore the flexibility of children or infants to toggle between the sequential and hierarchical organization of human action, the factors that govern this, and their potential relation in the development of social understanding.

Individual differences may also play a role. For instance, individuals with autism spectrum disorders (Baron-Cohen, 1995; Gernsbacher, Stevensen, Khandaka & Goldsmith, 2008; Toth, Munson, Meltzoff & Dawson, 2006) may have particular difficulty extracting higher-level goals from action and organizing their memory with respect to such goals. We would predict that in the paradigm introduced here, their memory may emphasize veridical sequential order (relative to the hierarchical organization in terms of goals) to a greater degree than typically developing individuals.

CONCLUSIONS

The current results are the first to demonstrate that memory for complex interleaved streams of human action are hierarchically organized according to inferred higher-level goals in the minds of young children. This organizational strategy takes priority over veridical sequential organization, to such an extent that sequential relations can even be distorted in memory. Future work in our laboratory will be directed toward exploring the causal and contextual parameters that might affect memory organization for actions, and the developmental underpinnings of this social-cognitive ability. Because goals and intentions are so crucial in children's making sense of adult everyday actions, these future studies will help flesh out crucial, early building blocks for social cognition.

This research was supported by an NRSA postdoctoral fellowship (F32HD058445-01A2) to JL, and by grants from NSF (SMA-0835854), NIH (HD-22514), and ONR (N000140910097) to ANM. We thank Craig Harris and Calle Fisher for their assistance, and are grateful to all of the families who volunteered to participate in the research.

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Received 4 September 2012, accepted 5 September 2012