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Memory for Temporal Order in Action is Slow Developing, Sensitive to Deviant Input, and Supported by Foundational Cognitive Processes

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Executing actions in a specific order is a critical component of many action sequences that children must acquire, the majority of which are learned through observation and imitation of others. Although a wealth of evidence indicates that children can process and represent temporal order in memory, relatively little is known about the development of this ability and the cognitive mechanisms that support it in the context of imitation. The present research investigated 4- through 8-year-old children's ability to learn the temporal order of novel, arbitrary action sequences via imitation. On Day 1, children observed and imitated four instances each for two different multistep sequences. One sequence was easy and the other was difficult, in terms of categorizing the items used in each instance. For one sequence, the experimenter also performed one instance in a deviant temporal order, which occurred either early or late in learning. Memory generalization for each sequence was assessed on Day 2. Results indicated significant effects of age and sequence difficulty on children's ability to recall the individual actions as well as the standard order. Experiencing the deviant order also uniquely disrupted children's ability to generalize the order. Experiencing the deviant early in learning globally lowered children's memory for both sequences. Thus, children's ability to learn temporal order develops slowly over childhood, is supported by foundational cognitive processes that operate in a hierarchical fashion, and is highly sensitive to variable temporal input. These results have implications for theories of imitation and cultural learning more broadly.

Keywords: memory, imitation, temporal order, cognitive development, cultural learning

To become functional members of their culture, young children must acquire numerous sequences of behavior. Some may serve an instrumental purpose—for example, learning to get dressed or to make a sandwich—and some may serve a conventional purpose—for example, learning a social or religious custom, a game, or a dance (Legare, Wen, Herrmann, & Whitehouse, 2015). Many such sequences will be acquired in the context of observation and imitation of more knowledgeable others (Boyd, Richerson, & Henrich, 2011; Hunnius & Bekkering, 2014; Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Tomasello, 1999). To acquire such sequences, children's memory for the demonstrated events must be accurate, for both the constituent actions involved and the order in which those actions are enacted. Recalling actions in the correct order is critical for many action sequences, both instrumental and

conventional. One will not be properly dressed if pants are put on before underwear, and one risks embarrassment if he or she enacts a religious ritual in the wrong order.

To date, we know relatively little about how children's processing of order information impacts their ability to imitate and recall novel sequences of behavior. Three literatures are relevant to this issue: the literature on scripts and general event representations, the literature on imitation of novel actions, and the literature on children's memory development. As we review these below, it will become clear that much is lacking in our knowledge of children's learning and representation of temporal order. The present experiment serves as the first systematic examination of the cognitive mechanisms that support the acquisition of pure temporal order in action across early and middle childhood.

Scripts and General Event Representations

The literature on scripts provides evidence that children encode information about temporal order for frequently encountered events (Nelson & Gruendel, 1986). For example, even 3-year-olds know the typical sequencing of activities such as going to the supermarket or getting dressed (Hudson, Fivush, & Kuebli, 1992). Scripts are hierarchically organized, general event representations of the typical elements involved in such events (goals, actors, objects, places), which improve the efficiency of information processing. Temporal order in a script is acquired with repeated exposure to the event (e.g., Farrar & Goodman, 1992).

As an abstract representation, the script itself does not specify event details, and individuals must encode such information in

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order to discriminate between different instances of a script. For instance, certain details are variable, in that they change from instance to instance in predictable ways (e.g., food is always ordered at a restaurant but the item may vary on each occasion). Fuzzy trace theory (Brainerd & Reyna, 2002) proposes that for familiar events, individuals encode the overall gist of the event (a general event representation) as well as the verbatim details of the event (the specific instance). These two representations are independent of one another. For example, gist memory decays more slowly, and individuals may recall the gist without recalling verbatim information. This theory also proposes that with increasing age and concomitant improvements in making meaning connections, children's gist memory becomes dominant over their verbatim memory. Evidence supporting this claim comes in the form of developmental reversals, in which older children are more susceptible to suggestions that are consistent with the actual experience than younger children, due to their improved ability to connect meaning (gist) across instances (Brainerd, Reyna, & Ceci, 2008).

While the literature on scripts and repeated events indicates that children can acquire temporal order, it has focused on events that usually occur over a relatively long time frame (typically 15–30 min). The time frame for many cultural action sequences is much shorter, on the scale of a minute or less (e.g., learning to tie one's shoes, bead a necklace, or find information on an iPad). Such sequences are also typically acquired in an imitative context (Boyd et al., 2011; Gergely & Csibra, 2006; Legare & Nielsen, 2015; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009)—an element missing from research on scripts. Young children excel at imitation, which sets humans apart from their closest evolutionary cousins (Subiaul, 2016).

Imitation of Novel Actions

The literature on deferred imitation in infancy and early childhood has examined temporal memory for short action sequences (Barr & Hayne, 1996; Bauer, Wiebe, Carver, Waters, & Nelson, 2003). This ability develops early, as order information for novel sequences is recalled fairly well for short sequences (two to three subactions) late in the first year, especially for those practiced on a previous occasion (Bauer, 2008; Bauer, Wiebe, Waters, & Bangston, 2001). A key finding from this work is that order is recalled with higher fidelity when sequences contain enabling relations—causal connections between subactions, in which enacting one subaction is dependent upon enacting a previous subaction (Bauer & Mandler, 1992; Bauer & Shore, 1987). With such connections, previous subactions can serve as cues for subsequent subactions, allowing for unitization in memory (Bauer, 1992).

Deferred imitation of novel arbitrary sequences, which contain no enabling relations, is a more pure measure of memory for temporal information, as reenactment cannot physically cue memory. Memory for order in arbitrary sequences is present in infancy but is relatively weak (Wenner & Bauer, 1999). Improvements are assumedly gradual into the preschool years, but relatively little is known about memory for temporal information in childhood as it relates to imitation. For example, Riggins and colleagues (Riggins, Miller, Bauer, Georgieff, & Nelson, 2009) demonstrated that 3- and 4-year-old children recalled on average about one to two ordered pairs of actions for arbitrary sequences involving eight possible ordered pairs (nine subactions). Such sequences certainly

taxed children's working memory span (Gathercole, Pickering, Ambridge, & Wearing, 2004), so it is not clear how well they might have done with shorter sequences.

The literature on multiple imitation mechanisms also bears on children's sequencing abilities (Subiaul, Anderson, Brandt, & Elkins, 2012; Subiaul & Schilder, 2014; Subiaul, Zimmermann, Renner, Schilder, & Barr, 2016). For instance, Subiaul et al. (2012) demonstrated that both 3- and 4-year-old children could imitate novel cognitive sequences—touching three different pictures in order according to identity (e.g., animal, toy, vehicle), but only 4-year-olds could successfully imitate novel motor-spatial sequences—touching three identical pictures in order according to a spatial pattern (e.g., top, bottom, right). This work indicates that children can recall the temporal order of relatively arbitrary sequences¹ and that the specific imitative content is a critical factor in the processing of temporal order at young ages.

Memory Development

A core cognitive function in imitative sequence learning is working memory (WM): Children must temporarily maintain subactions in mind in order to enact them and subsequently store them in long-term memory. Baddeley and Hitch's (1974) influential model of WM posits the existence of a central executive and two slave systems: the phonological loop and the visuospatial sketchpad. Considerable evidence indicates that children's WM capacity continuously and gradually develops in early childhood through adolescence (Gathercole et al., 2004). The possibility for children to transform visuospatial content into phonological representations by 7 years of age accounts for some of this increase (Gathercole, 1999), but evidence also indicates that there are real capacity increases even in the visuospatial system (Cowan, AuBuchon, Gilchrist, Ricker, & Saults, 2011; Pickering, 2001).

Research on the development of WM indicates that recall of order information is distinct from recall of item information and that ordered recall is challenging for young children, especially when presentation of items is sequential (Brown & Murphy, 1975; Dempster, 1981). Indeed, it is not uncommon to give young children (4–5 years) smaller lists than older children (7–8 years) when recall of serial order is measured (Huttenlocher & Burke, 1976; Pickering, Gathercole, & Peaker, 1998). Research with adults also indicates that ordered recall is superior for verbal relative to spatial tasks (Gmeindl, Walsh, & Courtney, 2011). This is consonant with research indicating a dissociation in the mechanisms that support encoding of associative, spatial, and temporal properties of events and in the neural systems that underlie these functions (Ekstrom & Bookheimer, 2007; Staresina & Davachi, 2009). Children's ability to encode the temporal properties of an event also develops more slowly than their ability to encode item and spatial properties (Lee, Wendelken, Bunge, & Ghetti, 2016).

Objectives of the Current Research

Thus, to date, surprisingly little is known about young children's ability to acquire temporal information in the context of imitating short action sequences, similar to those learned in ecological

¹ These sequences are not entirely arbitrary since enacting the correct sequence allows the child to view an exciting video on the screen.

cultural contexts. Many imitation studies indicate that children can imitate the order of relatively complex multistep sequences of novel behavior (Clegg & Legare, 2016b; Legare et al., 2015; Loucks, Mutschler, & Meltzoff, 2017; Lyons, Young, & Keil, 2007; McGuigan & Whiten, 2009; Nielsen, 2006; Nielsen & Tomaselli, 2010), but these studies do not often explicitly code for sequencing behavior, or if they do, it is lumped in to an aggregate measure along with their memory for the subactions, as that is not the primary theoretical focus. As such, one focus of the current research was simply to investigate children's ability to acquire temporal information for arbitrary action sequences as a function of age. We examined this question in 4- through 8-year-old children, as this is a period of substantial growth in WM. Based on the literature on children's memory development, we hypothesized that younger children (4–5 years) would have a significantly harder time encoding temporal action information than older children (6–8 years).

We also hypothesize that temporal information is least prioritized in a processing hierarchy, in that the ability to encode temporal information relies upon a foundational ability to encode the subactions involved in the sequence, which relies on a foundational ability to identify the items involved in the subactions. Another way of stating this is that encoding temporal information can only occur if attention is not already devoted to processing the items or the subactions involved. Because children lack a great deal of knowledge and experience regarding item identities and action possibilities, they may devote more processing to items and subactions, at the expense of processing temporal information. We will explain how we explored this hypothesis in the following section.

We also wanted to explore how children's memory for action sequences is affected by deviancy in temporal sequencing during learning. The literature on repeated events has investigated the role of deviancy in the form of deviant instance details, which are not part of the script (e.g., drinking a pop in the tub during bath time). Farrar and Goodman (1992) found that children's memory for such deviant details is poor if they have begun developing a script for a repeated event, in comparison to children's memory for the same deviant activities when they have no script (i.e., they experienced only the deviant). However, Connolly, Gordon, Woiwod, and Price (2016) more recently compared children's memory for an instance of a repeated event involving a deviant activity to the same event without any deviancy. The presence of a deviant activity improved children's recall of the variable details involved in that specific deviant instance and also improved their recall of the variable details experienced across all previous instances of the repeated event.

To our knowledge, there has been only one investigation into children's memory for temporal information when a deviancy in sequencing was experienced in a repeated event. In Farrar and Goodman's (1992) study, one aspect of the deviant event was a reordering of the subevents in the standard event. Children who had more experience with the standard event had substantial difficulty recalling the deviant order compared to those experiencing just the deviant, and the deviant did not alter their recall of the standard event order. However, there was no nondeviant repeated event group to compare this result against; the present study provides this comparison.

In the context of learning a short, arbitrary action sequences via imitation, we hypothesize that experiencing a deviant order during learning will significantly alter children's memory representation of the sequence. Exposure to a deviant order may destabilize the temporal representation or may send a signal to the child that order does not need to be encoded with high fidelity for this action. We further hypothesize that it matters *when* children experience the deviant in the learning process. Specifically, experiencing it in the midst of learning the sequence should have a greater impact on the representation than experiencing it toward the end of the learning process. Finally, given the distinction between item and order recall (Dempster, 1981), we also hypothesize that deviancy in ordering should not impact other aspects of memory (i.e., item and subaction recall).

The Present Experiment

We adopted a 2-day study design with 4- through 8-year-old children. All children visited the lab on Day 1 and learned two labeled sequences of action—"zavving" and "morking"—in a blocked fashion. For each sequence, an experimenter modeled the sequence and encouraged children to imitate across four instantiations (item sets) of the sequence, which varied in the items used. Children returned to the lab on Day 2, were probed for their memory for the items used on the previous day, and were also asked to "zav" and "mork" with new instantiations of these sequences not seen on Day 1 and not modeled on Day 2. In this way, we tested for children's *generalization* of the sequences from long-term memory.

To evaluate our hypothesis that encoding of order information is based upon first encoding items and subactions, we varied how difficult it was to process the items used across the two sequences. For both sequences, each instantiation contained two low variable items (items that only changed in color across sets) and two high variable items (items that could change in form, size, color, or texture across sets). However, the high variable items across instantiations were bound together as members of a category. For the easy sequence, these categories were natural kinds: animals and fruits. For the difficult sequence, these categories were nominal: items that are green and items that are smaller than the green item. Recognizing that each instantiation contains a fruit is presumably easier for children than recognizing that each instantiation contains a relatively small item. We hypothesized that children's ability to recognize (and lexicalize) these categories would influence their ability to learn the temporal order of the sequence, such that poor identification would lead to poor memory for temporal order for the difficult sequence.

To evaluate our hypotheses concerning deviancy in temporal order, each child experienced a deviant order in sequencing the subactions during their learning of either the easy or difficult sequence. This deviant occurred either on the second instantiation (early in learning) or on the fourth instantiation (the last trial of learning). We predicted that children's representation of order in the sequence would be altered by the deviant, such that they would be less able to enact the sequence in the standard order (the order observed on the other three learning trials; 75% of trials) during generalization on Day 2. We predicted that children's representation would be more heavily influenced by an early deviant relative to a late deviant, as by the end of learning, children may have

begun to develop a general event representation that largely ignores deviant information (Farrar & Goodman, 1992). We also predicted that deviancy would interact with sequence difficulty, in that the ease with which children could identify the items in the easy sequence would serve as some protection against the effect of the deviant instance, and conversely that the difficult sequence would be relatively more affected by the deviant instance.

Finally, given evidence that memory for temporal information is a more slowly developing aspect of children's memory (Brown & Murphy, 1975; Lee et al., 2016), we also hypothesized that recall of temporal order would improve with age. We further hypothesized that age would interact with the effects of sequence difficulty in two ways. First, we predicted that younger children would have a much harder time categorizing the items in the difficult sequence, so they would subsequently struggle to encode temporal information and generalize temporal order to a new instance on Day 2. Second, because older children are more likely to rely on gist memory over verbatim memory (Brainerd et al., 2008), and the development of gist memory is promoted by ease of developing meaning connections, we predicted that older children would have a more difficult time recognizing which specific items were used in the easy sequences compared to the difficult sequences. That is, we predicted they would be more likely to recognize based on gist for the easy sequence and make a gist-related error (e.g., selecting the foil animal) than they would for the difficult sequence (e.g., selecting the foil green item). We predicted that younger children would show no such differential pattern between the sequence types but would recall fewer items overall.

Method

Participants

The final sample included 64 children: 32 "young" 4- to 5-year-olds (13 female, $M = 4$ years 7 months, $SD = 5.99$ months) and 32 "old" 6- to 8-year-olds (14 female, $M = 6$ years 9 months, $SD = 8.48$ months). Children were recruited via summer camps and social media advertisements from Regina and the surrounding area. All children were typically developing based on parental report. A power analysis with $\alpha = .05$ and power = .80 indicated that an $N = 64$ would allow us to detect a medium effect size ($f = 0.26$) for our highest level interaction term. An additional 11 children participated but were excluded due to never performing any subactions with the boards on Day 1 ($n = 6$) and experimental error ($n = 5$). Children were compensated with a small toy and parents were compensated with 10 dollars each day. This research was approved by the University of Regina Research Ethics Board under the protocol titled "Children's Action Memory" (#116R1213).

Stimuli

Stimuli included 10 sequence sets. Eight sets were used on Day 1: four for the easy sequence and four for the difficult sequence. The two remaining sets, one for each sequence, were only used for the generalization test on Day 2. Each easy set was presented on a solid color foam board and contained two low variable items—a wooden block with a hole drilled through the sides and a wooden dowel that could fit through the hole—and two high variable natural kind items—an animal and a fruit. The canonical easy

sequence was to (1) stamp the fruit to the top of the block, (2) tap the animal three times with the stick, (3) thread the stick into and back out of the block, and (4) touch the fruit to the bottom of the animal's feet (holding both items). Each difficult set was presented on a striped (black and alternate color) foam board and contained two low variable items—a cardboard tube and a bottlecap—and two high variable nominal category items—a green item and a small item (always smaller than the green item and never green). The canonical difficult sequence was to (1) stamp the green item onto the bottlecap, (2) drop the bottlecap into the tube, (3) circle the small item around the green item, and (4) cover and then uncover the small item with the tube. The subactions were highly similar between the easy and difficult sequence, and there was no causal connection between subactions for either sequence, as the subactions comprising each could be enacted in any order. For both sequences, the items were put back in their respective starting positions on the board once the subaction was completed, such that no spatial transformation had transpired on the board. The only minor deviation from this was for the difficult sequence, in which the cardboard tube was placed near its original position after action (4), so as to not cover the bottlecap again (which was left there from dropping into the tube previously). The bottlecap and tube were then quickly put back to their starting positions before the child's imitation period (see Procedure).

The low variable items (blocks, sticks, cardboard tubes, and bottlecaps) varied only in color and were color-matched within a set. For the high variable natural kind and nominal category items, there were pairs of each of the animals, fruits, green items, and small items for each Day 1 set, which were similar in perceptual appearance to each other. One item of the pair was used during learning and imitation on Day 1, and the other item was used only for the item recognition test on Day 2. Half of the children saw particular members of the pairs serve as targets and the corresponding members of the pairs serve as distractors, and the other half of children saw the reverse pairing of targets and distractors. An example set of easy and difficult boards, with corresponding distractor items, can be found in Figure 1. A complete description of each sequence set can be found in Appendix A.

Design

Participants visited the lab on two consecutive days, spaced by exactly 24 hr. We used a mixed design, in which sequence difficulty (easy vs. difficult) was varied within subjects, and age group (young 4–5 vs. old 6–8), deviant sequence (present in either the easy vs. difficult sequence), and deviant position (occurring on the second vs. fourth board) were varied between subjects. Additional between-subjects counterbalancing variables included sequence presentation order (easy or difficult first), target item set (corresponding pairs used as distractors—see Stimuli), and board presentation order (either ABCD or DCBA).

Procedure

Day 1 procedure. All children learned two sequences of action in a large room, with two separate learning stations, one for each sequence (fixed for easy and difficult sequences). Each station consisted of two chairs arranged opposite each other at a small table. The boards were hidden in a cupboard that was always

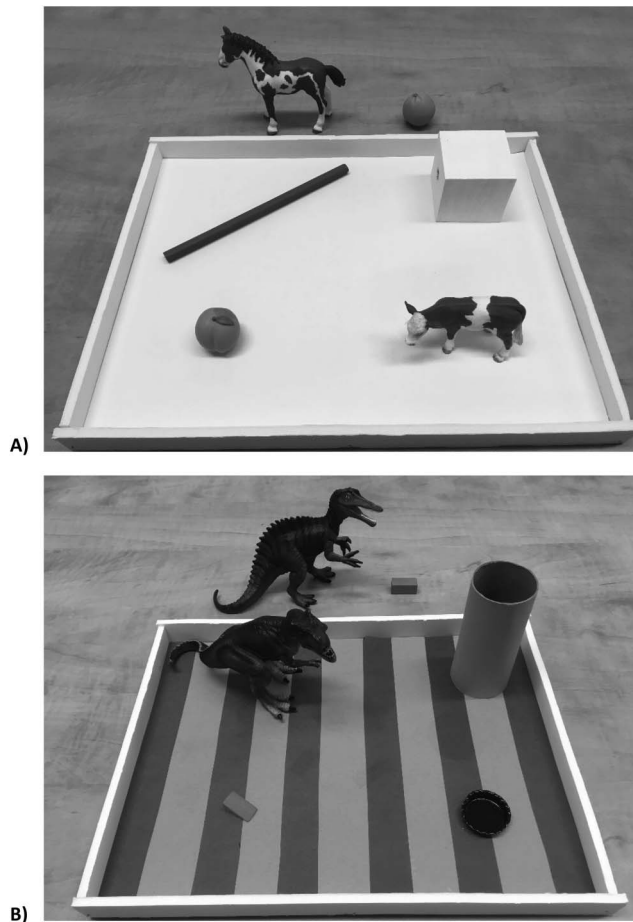


Figure 1. Example boards for the (A) easy and (B) difficult sequences. The items behind the boards are additional variable items that were used for half of the children, and whichever pair was not used on Day 1 served as distractor items on the Day 2 item recognition task.

behind the child at each station. After providing assent, the child and experimenter took their seats at the first station, and the experimenter brought out the first set and explained, “With these things here, I can zav/mork. Watch closely, and I’ll show you how to zav/mork.” The experimenter then performed the sequence, narrating each subaction (“First I do this, then I do this, then I do this, and then I do this”), and after said, “There, I zavved/morked! That’s called zavving/morking.” The experimenter then slid the board to the child and said, “Here, now it’s your turn. Can you zav/mork?” Children’s response period was not timed. If children were slow to respond or asked the experimenter what to do with the items, the experimenter always provided neutral encouragement (e.g., “It’s your turn now”). When the child indicated that he or she was finished, the experimenter took the board away and globally praised the child, regardless of performance. The identical trial structure was used for each subsequent board, and similar language was used (e.g., “I can zav/mork with these too”). After finishing with the first action sequence, the child and experimenter moved to the other station and performed identical trials with the other action sequence.

Each child experienced one deviant sequence during learning on Day 1. The deviant either occurred in the easy sequence or difficult sequence, and either occurred on demonstration of the second board or the fourth board. The deviant was always a transposition of the second and fourth subactions in a sequence (i.e., switching “tapping” and “fruit-feet touch” for the easy sequence or switching “bottlecap drop” and “small item cover/uncover” for the difficult sequence). The experimenter made no special marking of the deviant when it was performed, and the trial was identical in all other respects.

Day 2 procedure. Children were first seated at the same station that they started with on Day 1. The session began with the item recognition test for each board from Day 1. Children were tested in the same board order that they experienced on Day 1. For each board, the trial began with the low variable items already present on the board to cue memory (the stick and the block for the easy sequence; the bottlecap and the tube for the difficult sequence). The experimenter then presented a pair of animals (easy)/green items (difficult), placed them on the board, and asked, “Do you remember if we played with this one (point) or this one (point)?” When the child made a selection, the other item was removed, and then the experimenter presented a pair of fruits (easy)/small items (difficult) and repeated the procedure with these. Following the selection, the board was removed and the child was tested with a new board. Item position on the board (right or left) was random across trials and children.

Following item recognition, the generalization test began. The experimenter brought out a new easy/difficult board (the same new boards for all children) and explained to the child, “I found this one here last night, and I think we could zav/mork with this one too. Can you show me how to zav/mork?” The response period was carried out in an identical manner as the response periods on Day 1. The same procedure (item recognition and generalization) was then carried out at the next station for the other sequence.

Scoring

Scoring from video was carried out by one primary coder who was blind to condition. A second coder, also blind to condition, scored 25% of the videos for reliability purposes. Our primary interest was in Day 2 recall. Day 1 performance was also scored, but only portions of that scoring are reported here (detailed in Results).

Item recognition score. This score reflected how many target items the child correctly selected during the item recognition test for each sequence. Scores could range from 0 to 8. Scorers did not disagree on this measure (100% agreement).

Subaction score. This score reflected how many individual subactions a child imitated for each action sequence, regardless of their enacted order. Minor deviations in imitation were permitted (e.g., a child was credited for tapping if the animal was tapped more or less than three times in succession), but major deviations were not (e.g., stamping the block on the fruit was not credited as stamping the fruit on the block). This score could range from 0 to 4 for each action sequence. Agreement between scorers on this measure was high (92% agreement), and disagreements were resolved by discussion.

Partial order score. This score reflected the strength of children’s memory for the temporal order of subactions in each se-

quence. Preliminary coding revealed that recalling the exact standard order on Day 2 was very challenging, especially for young children, and therefore could not reveal potential differences between groups (see Appendix B for these data). Thus, for this score, children were given a 3 if they recalled the correct order for all four subactions (1234), a 2 if they recalled a triplet of subactions correctly (123 or 234), a 1 if they recalled only a pair of subactions correctly (12, 23, or 34), and a 0 if no subaction was correctly adjacent to any pair. Scores of 2 or 1 could be achieved in various ways, including omitting subactions, performing them in the wrong order, or performing nontarget actions between pairs of target subactions. Three children in the entire sample also recalled all four subactions but recalled them as 1324—these children were given a score of 1, as they correctly enacted 1 as first and 4 as last (similar to pairing). Scores on this measure could range from 0 to 3 for each action sequence. Scorers did not disagree on this measure (100% agreement).

Results

Preliminary analyses of variance (ANOVAs) revealed no significant effects of gender, sequence presentation order, target item set, or board order on any of the variables, so these variables were dropped from further analyses.

Item Recognition Scores

A 2 (age: young 4–5 vs. old 6–8) \times 2 (sequence difficulty: easy vs. difficult) \times 2 (deviant sequence: in easy vs. in difficult) \times 2 (deviant position: second vs. fourth board) mixed ANOVA revealed only a significant main effect of age, $F(1, 56) = 6.03, p = .017, \eta_p^2 = .10$. As hypothesized, older children identified significantly more target items correctly ($M = 7.67, SD = 0.21$) in comparison to younger children ($M = 6.95, SD = 0.21$). No additional main effects or interactions were significant. Thus, contrary to our prediction regarding older children's greater reliance on gist memory, children at both ages had highly accurate memory for the items that did not vary as a function of the difficulty in categorizing items.

Subaction Scores

Figure 2A displays children's average subaction scores by age and across conditions. A 2 (age) \times 2 (sequence difficulty) \times 2 (deviant sequence) \times 2 (deviant position) mixed ANOVA revealed a significant main effect of age, $F(1, 56) = 21.99, p < .001, \eta_p^2 = .28$, with older children recalling more subactions than younger children. There was also a significant main effect of sequence difficulty, $F(1, 56) = 16.08, p < .001, \eta_p^2 = .22$,

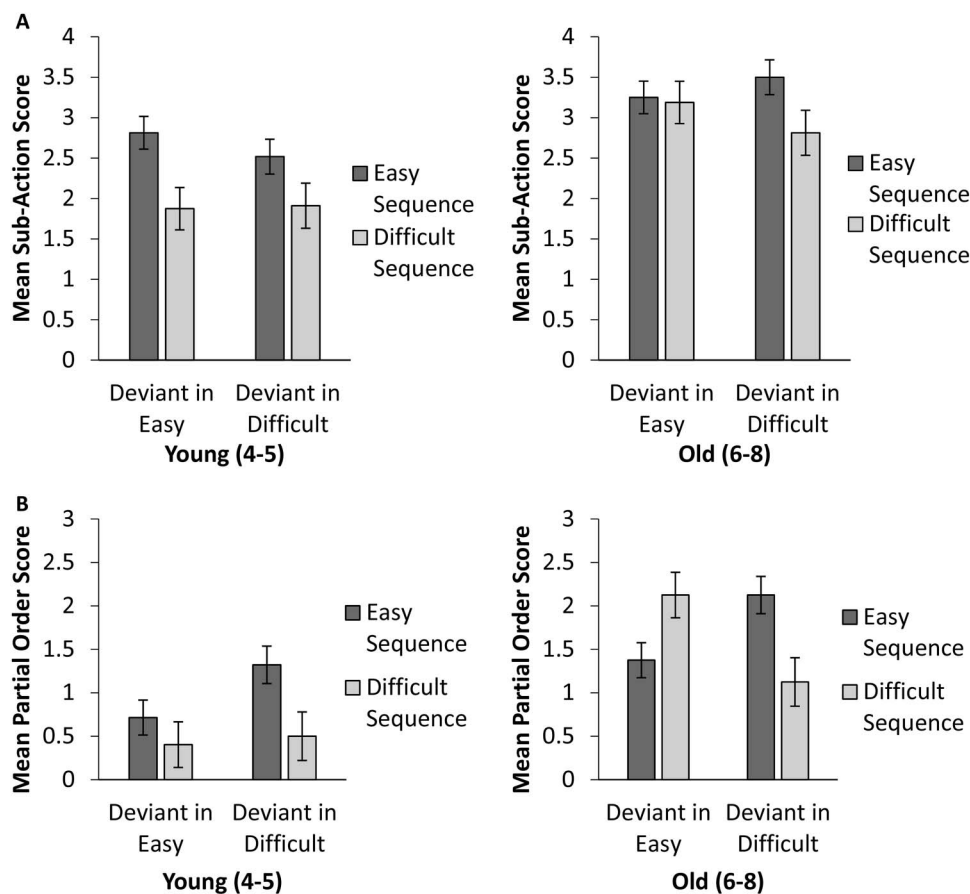


Figure 2. Children's (A) subaction scores and (B) partial order scores as a function of age, sequence difficulty (within subjects), and the presence of a deviant sequence (between subjects). Errors bars represent $\pm SE$.

indicating that children better recalled the subactions from the easy than the difficult sequence. No other main effects or interactions were significant. Thus, as hypothesized, children's memory for the individual subactions was unaffected by the deviancy in sequencing experienced the day before, while age and sequence difficulty played larger roles.

Partial Order Scores

Figure 2B displays children's average partial order scores by age and across conditions. A 2 (age) \times 2 (sequence difficulty) \times 2 (deviant sequence) \times 2 (deviant position) mixed ANOVA revealed significant main effects of age, $F(1, 56) = 28.58, p < .001, \eta_p^2 = .34$; sequence difficulty, $F(1, 56) = 5.00, p = .029, \eta_p^2 = .08$; and deviant position, $F(1, 56) = 4.79, p = .033, \eta_p^2 = .08$. The main effect of deviant position meant that children's recall of order for both sequences was lower when they experienced a deviant (in either sequence) on the second board (easy $M = 1.19, SD = 1.06$; difficult $M = 0.84, SD = 1.08$) relative to the fourth board (easy $M = 1.56, SD = 1.16$; difficult $M = 1.25, SD = 1.08$). Thus, the early deviant globally lowered order recall on Day 2. There was also a significant two-way interaction between sequence difficulty and deviant sequence, $F(1, 56) = 13.32, p = .002, \eta_p^2 = .19$, and a marginally significant three-way interaction between age, sequence difficulty, and deviant sequence, $F(1, 56) = 4.02, p = .050, \eta_p^2 = .07$. No other main effects or interactions were significant.

Independent samples t tests were conducted to explore this three-way interaction further. Recall that a deviant order instance could occur on Day 1 during the learning of the easy or difficult sequence (between subjects). For young children, there was no significant effect of deviancy for the easy sequence, $t(30) = 1.87, p = .07$, or the difficult sequence, $t(30) = 0.47, p = .64$. This pattern for young children is likely a result of a floor effect for order. For older children, the effect of deviancy was significant for the difficult sequence, $t(30) = 2.85, p = .008, d = 1.05$, and for the easy sequence, the effect was in the hypothesized direction but failed to achieve significance, $t(30) = 1.95, p = .06$.

It is important to contextualize the effects of partial order scores as they relate to differences in subaction scores. These scores are not truly independent, as children who forget subactions necessarily can only earn a lower maximum partial order score. From an examination of Figure 2, this does not seem to explain the pattern of partial order scores, as subaction scores were largely unaffected by deviance, yet partial order scores were. However, another way to examine this issue is to look only at children who had good

subaction recall—recalled three or four subactions—and examine the proportion of these children who recalled those three or four actions in order—that is, those with partial order scores of 2 or 3, respectively. These data are displayed in Table 1. As can be seen in the table, subaction scores are not the sole determiner of partial order scores, as substantially fewer older children who recalled a high number of subactions could sequence them properly when a deviant had been presented the day before in comparison to consistent ordering, $\chi^2(1) = 7.49, p = .007$. This pattern is only present for the easy sequence for younger children. Thus, low partial order scores for the difficult sequence for young children reflect, to a much greater extent, an inability to recall subactions from the day before, consistent with our hypothesis that difficult to categorize items influence the recall of subactions involving those items.

General Discussion

Children must acquire a considerable number of behavioral sequences in order to become functional members of their culture, and the lion's share of these will involve learning through observation and imitation. The present study investigated a central cognitive component of this imitative ability: the ability to learn the temporal order of events in a sequence. While much research indicates that children can acquire temporal information for repeated events and causally rich action sequences, no research has systematically examined the cognitive mechanisms that support the acquisition of purely temporal information across a wide age range in childhood. The present findings indicate that this kind of learning is slow developing, sensitive to variable input, and supported by foundational cognitive processes that seem to operate in a hierarchical fashion.

Children's ability to generalize the temporal order for both the easy and difficult sequence improved considerably with age. This is consistent with research on the development of WM (Gathercole et al., 2004), and with research on children's memory binding, which indicates that binding of temporal associations is not adult-like until 11 years of age (Lee et al., 2016). Also consistent with this literature, children's generalization of the individual subactions improved with age. However, the way the task was structured eliminated the possibility that previous subactions could cue memory for order, highlighting the separable development of these components in both age groups.

The 4- and 5-year-olds struggled to order the subactions correctly, similar to their difficulties with order across a broad range of WM tasks (Brown & Murphy, 1975; Dempster, 1981; Gather-

Table 1
Proportion of Children Who Recalled Three or Four Subactions and Sequenced Those Subactions in the Correct Order

Age	Recall of easy sequence		Recall of difficult sequence	
	Deviant in easy	Deviant in difficult	Deviant in easy	Deviant in difficult
Young	.27 <i>n</i> = 11	.88 <i>n</i> = 8	.20 <i>n</i> = 5	.43 <i>n</i> = 7
Old	.38 <i>n</i> = 13	.80 <i>n</i> = 15	.85 <i>n</i> = 13	.25 <i>n</i> = 12

Note. *n* refers to the amount of children who recalled three or four subactions in each cell.

cole et al., 2004; Huttenlocher & Burke, 1976). The novelty of the current study is in demonstrating that they also struggle to process temporal information with more interesting stimuli (for children) and in a more ecologically relevant setting (learning a task from a knowledgeable adult). Action information would likely be maintained using the visuospatial sketchpad (Baddeley & Hitch, 1974), and age-related increases in the capacity of this system can explain the increase we observed in order recall (Cowan et al., 2011). Some evidence indicates that serial order is more difficult to bind to spatial representations in WM compared to verbal representations in WM (Gmeindl et al., 2011; Pickering et al., 1998), which may render action a more difficult stimulus to sequence. It is possible, also, that the increased performance of the 6- to 8-year-olds was due to children recoding the subactions into verbal semantic representations and subvocally rehearsing these (Pickering, 2001). While we cannot rule this out entirely, it seems unlikely given the complexity of the stimuli (two participants and one action per subaction).

Our manipulation of sequence difficulty also impacted children's memory for the subactions and the temporal order of the sequences. To our knowledge, this is the first investigation into the relationship between item and temporal processing in children's learning of novel action sequences, and the present findings support our hypothesis that temporal order is the least prioritized element in this process. Importantly, sequence difficulty was only manifest in children's ability to categorize the highly variable items involved in the sequence. For the easy sequence, children could easily identify the categories that defined these items: animals and fruit. For the difficult sequence, categories similarly defined the items, but they were nominal: green items and relatively small items. Because these items required more processing, memory for order was more difficult to acquire for this sequence (and was more affected by temporal deviation). We predicted that only temporal processing would be affected by the difficulty manipulation, as we were agnostic about the relative prioritization of item and subaction processing. The findings, however, indicated that sequence difficulty also impacted younger children's ability to encode subactions, consistent with the idea that item processing is more highly prioritized over subaction processing, which in turn is more highly prioritized than temporal processing. Young children recalled almost nothing about order for the difficult sequence, and this was largely due to their poor recall of subactions (they had less to sequence). For older children, the effect of sequence difficulty was more subtle, as for nondeviant sequences, there was no effect of sequence difficulty, but the presence of a deviant significantly impacted their order recall for the difficult sequence. Thus, although older children could more efficiently process the difficult sequence, there was still a measurable impact of this difficulty (see also the descriptive results in Appendix B).

For both ages, observing one trial with a deviant order on Day 1 had a profound impact on their representation of order on Day 2. Children were not able to ignore the single deviant and generalize according to what they observed 75% of the time, indicating high sensitivity to this discrepant information. We predicted that observing a deviant early in the learning (second trial) would alter children's representation more than observing a deviant late in learning (fourth trial). However, both types of deviants were equally effective in this regard. This suggests that memory for order is sensitive to discrepant input at any point in the learning

process—at least when learning takes place within a short span on a single day. One way to frame these results is in terms of deviancy *disrupting* children's memory for the standard temporal order that they observed on the majority of trials. Another possibility is to frame these results in terms of children's sensitivity to signals regarding *strictness* in temporal ordering. That is, children may have interpreted the deviant order as a message from the experimenter that strict temporal order is not a feature of this activity. Because there was a protective effect of sequence difficulty on the effect of the deviant (no significant effect for the easy sequence), we lean toward the former interpretation. However, future research with additional measures could more fully explore this possibility. For instance, if children viewed a third party enacting the sequence according in a deviant order, they may protest that a norm has been violated (e.g., Keupp, Behne, & Rakoczy, 2013).

As further support for the separability of item, subaction, and temporal memory, this deviant order only affected memory for order and left the other two components untouched. Research on children's memory for deviant details in repeated events has indicated that deviancy improves children's memory for all variable details (Connolly et al., 2016). In the present experiment, children at both ages were at ceiling in the item memory test, so there was no room for improvement. The relative ease of this task for children is also a likely explanatory factor for the lack of any developmental reversal in item memory (i.e., Brainerd et al., 2008). Perhaps children require exposure to more items across more sequences on Day 1 in order to further tax working memory, or they may have needed more difficult distractors during the test on Day 2. A more challenging item memory test may be required when real objects serve as stimuli, as memory for real objects is superior to memory for pictures (Snow, Skiba, Coleman, & Berryhill, 2014).

One surprising finding that was not predicted was the global effect of deviant position on memory for order. Children who experienced the deviant on the second trial had worse recall for *both* sequences—the one with the deviant and the one without—on Day 2, relative to children who experienced it on the fourth trial, and this occurred regardless of whether the deviant sequence was learned first or second. A deviant in the second position entails that children experience two changes in temporal ordering (standard order, then deviant order, then standard order two more times) while a deviant in the fourth position entails only one switch (standard order three times, then deviant order). Perhaps this additional switching taxes children's ability to encode and represent temporal order generally. Alternatively, this early deviant may globally dampen processing of temporal information in a particular learning setting (the entirety of the Day 1 event). Future research with a purely nondeviant learning group can help elucidate the nature of this global deviancy effect.

From the present findings, a number of broader future directions are possible. One is to explore whether young children's temporal processing can be improved. Highlighting social or linguistic cues may be one route. For instance, Clegg and Legare (2016b) showed that children's imitative fidelity (including ordering) in a necklace-making activity was significantly better when conventional language was used (e.g., "Everyone always does it this way") relative to instrumental language (e.g., "I'll show you how to make a necklace"). With conventional language, sensitivity to temporal order may be heightened. Cross-cultural comparisons may also be

valuable (Nielsen & Haun, 2016). Research has demonstrated that cultural context sometimes does and sometimes does not influence how children utilize imitation for learning (Berl & Hewlett, 2015; Clegg & Legare, 2016a; Nielsen & Tomaselli, 2010). Clegg and Legare (2016a) notably showed that children in Vanuatu are more sensitive to temporal order than U.S. children even without exposure to conventional language during observation. As the present experiment marks the first systematic study into the development of children's memory for temporal order in action, there is much to be learned about the soft and hard limits—sociocultural variation and developing neural systems, respectively—in this ability.

We hope at minimum that these findings bring attention to the critical role that temporal processing plays in children's ability to acquire sequences of behavior from others. A recent analysis suggests that humans, relative to nonhuman animals, have an enhanced ability to learn sequential information (Ghirlanda, Lind, & Enquist, 2017). A large number of sequences that children must acquire do not contain a discoverable causal structure that can assist in sequencing the actions in order, yet children must be sensitive to the order nonetheless. We have shown that this ability evinces continued development over early and middle childhood, is sensitive to variability in input, and has its roots in foundational cognitive processes that operate in a hierarchical fashion. Perhaps the capacity to process sequential temporal information is enhanced in humans relative to our closest cousins, or perhaps we are more strongly motivated to copy others with a high temporal fidelity. In either case, this ability is an integral feature of the imitation that is characteristic of the human species.

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(Appendices follow)

Appendix A

High Variable Items Used in Each Sequence

Sequence	Instance	Variable item 1	Variable item 2
		Animals	Fruits
Easy	1	Lion/tiger	Apple/strawberry
	2	Horse/cow	Orange/peach
	3	Cat/dog	Pear/grapes
	4	Giraffe/zebra	Banana/lemon
Difficult	Generalization	Bear	Watermelon
		Green things	Small things
	1	Tyrannosaurus/suchomimus	Wooden rectangle/triangle
	2	Solid rectangle/dotted triangle pillow	Stegosaurus/dimetrodon
	3	Wooden cube/sphere	Spider/ant
	4	Grasshopper/cricket	Striped square/solid circle pillow
	Generalization	Car	Teacup

Note. Instances 1–4 occurred on Day 1, and generalization occurred on Day 2.

Appendix B

Number of Young and Old Children Who Recalled the Exact Standard Order for the Easy and Difficult Sequence on Day 2, by Deviant Sequence and Deviant Position ($n = 8$ Per Column)

Variable	Deviant in easy		Deviant in difficult	
	Second trial	Fourth trial	Second trial	Fourth trial
Young (4–5)				
Recall of easy	0	0	1	1
Recall of difficult	0	0	0	0
Old (6–8)				
Recall of easy	1	3	3	4
Recall of difficult	4	4	0	1

Note. For nondeviant sequences, the standard order was demonstrated on 100% of Day 1 trials, and for deviant sequences, the standard order was observed on 75% of Day 1 trials.

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