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Multiple Imitation Mechanisms in Children

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Four studies using a computerized paradigm investigated whether children's imitation performance is content-specific and to what extent dependent on other cognitive processes such as trial-and-error learning, recall, and observational learning. Experiment 1 showed that 3-year-olds could successfully imitate what we call novel cognitive rules (e.g., first → second → third), which involved responding to 3 different pictures whose spatial configuration varied randomly from trial to trial. However, these same children failed to imitate what we call novel motor–spatial rules (e.g., up → down → right), which involved responding to 3 identical pictures that remained in a fixed spatial configuration from trial to trial. Experiment 2 showed that this dissociation was not due to a general difficulty in encoding motor–spatial content, as children successfully recalled, following a 30-s delay, a new motor–spatial sequence that had been learned by trial and error. Experiment 3 replicated these results and further demonstrated that 3-year-olds can infer a novel motor–spatial sequence following observation of a partially correct and partially incorrect response—a dissociation between imitation and observational learning (or emulation learning). Finally, Experiment 4 presented 3-year-olds with "familiar" motor–spatial sequences that involved making a linear response (e.g., left → middle → right) as well as "novel" motor–spatial sequences (e.g., right → up → down) used in Experiments 1–3 that were nonlinear and always involved a change in direction. Children had no difficulty imitating familiar motor–spatial sequences but again failed to imitate novel motor–spatial sequences. These results suggest that there may be multiple, dissociable imitation learning mechanisms that are content-specific. More importantly, the development of these imitation systems appears to be independent of the operations of other cognitive systems, including trial and error learning, recall, and observational learning.

Keywords: social learning, emulation, imitation, cognitive architecture, preschool children

How do children imitate? Do they rely on one general-purpose imitation mechanism that develops continuously? Or do they possess multiple content-specific imitation mechanisms that develop discontinuously and independently of other cognitive systems?[1] Certainly, children from an early age appear to imitate everything, from words used to describe novel objects (Jaswal & Hansen, 2006) to abstract rules (Subiaul, Lurie, Klein, Holmes, & Terrace, 2007; Subiaul, Romansky, Cantlon, Klein, & Terrace, 2007; Williamson, Jaswal, & Meltzoff, 2010) to actions with novel tools (Horner & Whiten, 2005; Lyons, Damrosch, Lin, Macris, & Keil, 2011; Lyons, Young, & Keil, 2007; Meltzoff, 2007; Nielsen & Tomaselli, 2010) and everyday artifacts such as telephones, brooms, and remote controls. As adults, humans from all cultures imitate everything from posture to styles of dress to conventions of affection. In fact, imitation comes so naturally to our species that we do it automatically, a phenomenon that has been referred to as *the chameleon effect* (Chartrand & Bargh, 1999) and *automatic imitation* (Cook, Bird, Lunser, Huck, & Heyes, 2011; Heyes, 2011; Press, Bird, Walsh, & Heyes, 2008). A long-standing assumption in the social sciences has been that all these skills, which together represent human imitative virtuosity, are derived from a single, broad imitation faculty that is content-general, its power stemming, in part, from the universal learning mechanisms of associative and operant learning (Bandura, 1977; Buller, 2005; Heyes, 2004, 2011; Skinner, 1953).

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[1] Borrowing from Leslie (1994, 2000), *mechanism* is used throughout this article to refer to a neural-cognitive information processor that performs computations on particular types of stimuli or input. The result of these computations is sent as output to other mechanisms that may perform additional computations, execute specific motor response(s), or both.

Developmental psychologists, however, have long recognized that imitation performance changes throughout development (Meltzoff, Kuhl, Movellan, & Sejnowski, 2009; Piaget, 1951; Uzgiris, 1973, 1981) and have argued that "all imitative acts are not of the same kind" (Meltzoff & Moore, 1997, p. 179). However, what mediates these changes in imitation performance remains poorly understood. The most thorough perspective on imitation development was proposed by Piaget (1951). Piaget, for instance, distinguished between simple and complex imitation, where the former preceded and served as a scaffold for the development of the latter. Similarly, he noted that the imitation of transparent imitative acts, such as manual actions on objects, necessarily preceded the development of opaque imitative acts, such as oral–facial imitation. For Piaget, such changes in imitation performance were contingent upon broader changes in cognitive and sensorimotor development, with one developmental milestone serving as a necessary building block to the next, thereby making more sophisticated types of imitation possible.

Though some important qualifications have been made to Piaget's (1951) view of imitation development (Carpenter, Nagell, Tomasello, Butterworth, & Moore, 1998; Mandler, 2004; McCall, Parke, & Kavanaugh, 1977; Meltzoff et al., 2009; Uzgiris, 1981; Want & Harris, 2001), his larger theoretical framework on the development of imitation has not been superseded (Jones, 2009). For example, scientists have revised Piaget's developmental timing of various imitation milestones such as oral–facial imitation (Meltzoff & Moore, 1977) and delayed imitation (Meltzoff, 1988b). Investigators have also debated the relationship between imitation and other cognitive skills such as theory of mind (Meltzoff & Decety, 2003; Tomasello, 1999), language development (Bloom, 2000; Kuhl, 2000; Pinker, 1994; Tomasello, 2008), and causal understanding (Gergely, Bekkering, & Kiraly, 2002; Want & Harris, 2001). Though providing important insights into children's social-cognitive development, they have provided little, if any, information about whether imitation learning is achieved independently of these other cognitive operations or whether imitation is dependent upon them.

Nadel (2006) has argued that "the construct of imitation is better understood if not considered as describing a unitary phenomenon, but, rather, as resulting from a hierarchy of mechanisms involved in different types of reproductions" (p. 126). Yet, characterizing such a "hierarchy of mechanisms" has proven to be difficult. Subiaul and colleagues (Subiaul, Cantlon, Holloway, & Terrace, 2004; Subiaul, Lurie, et al., 2007) addressed some of these methodological problems using a novel imitation paradigm, where a naïve individual was given the opportunity to imitate a model's use of a novel and abstract ordinal rule, as opposed to a novel motor response. Because participants had to copy an abstract (cognitive) rule rather than a specific motor response, this class of imitative responses was referred to as *cognitive imitation*. Using this paradigm, Subiaul and colleagues showed that monkeys (Subiaul et al., 2004) and children with autism (Subiaul, Lurie, et al., 2007), two populations that typically evidence motor imitation difficulties, succeeded in imitating novel cognitive rules. These results suggested that the problem might not be with imitation in general but with the imitation of novel motor responses specifically. Williamson et al. (2010), in an innovative set of studies, extended Subiaul et al.'s (2004; Subiaul, Lurie, et al., 2007) paradigm to test a different kind of cognitive or "abstract" imitation, *sorting strategies*. Results demonstrated that 3-year-olds successfully inferred and imitated various categorization rules used by a model who intentionally sorted objects into categories along a particular dimension (e.g., observable [color] vs. unobservable [sound]). Williamson et al. argued that this form of cognitive imitation may be "a powerful, nonverbal mechanism by which generalizable rules or strategies can be learned" (p. 58).

The distinction between cognitive and motor imitation domains is based on the same logic that is used to differentiate cognitive and motor learning in asocial settings (Terrace, 2005). In the case of cognitive learning, information is inferred rather than directly perceived, whereas in the case of motor learning, specific actions, responses, and interactions with stimuli serve as direct observable cues for future responses. Imagine observers watching someone enter their personal identification number (PIN) on an automated teller machine. In this example, observers can imitate two different responses. They may imitate the observed motor–spatial response (e.g., up, down, left, right), ignoring the sequence of numbers being pressed, or they may imitate the actual sequence of numbers touched (e.g., 2, 8, 4, 6), disregarding the specific motor responses corresponding with each number's location on the touch pad. In both instances, observers are intentionally imitating a specific response, the principal difference here being the representational content of each response.

To test the learning and imitation of these two types of responses, the present study adopted the paradigm used by Subiaul et al. (2004) to create two tasks: cognitive and motor–spatial (see Figure 1). In the

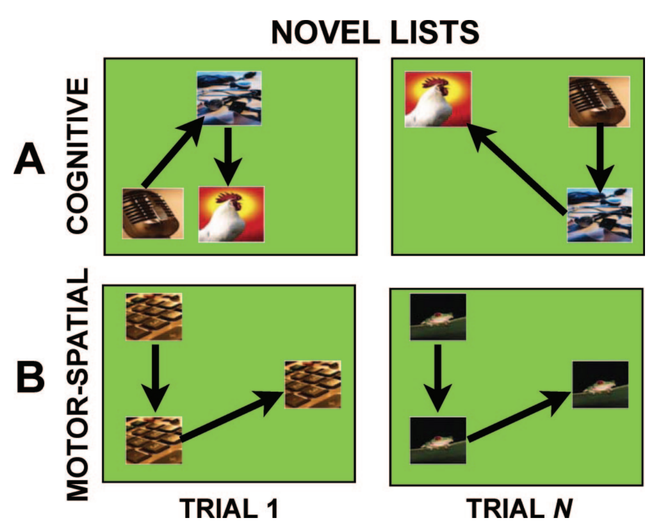

Figure 1. Cognitive and motor–spatial tasks. A: In the cognitive task, different items appear simultaneously in different spatial positions on a touch-sensitive screen. Items' positions change from trial to trial, but the order in which they must be touched (i.e., ordinal position) remains constant. The objective is to touch each item (irrespective of position) in a specific order. B: In the motor–spatial task, identical items appear simultaneously in different spatial positions on a touch-sensitive screen. Items' positions remain fixed from trial to trial but their identity changes as shown. The objective is to respond to each item (irrespective of identity) in a specific motor–spatial sequence as shown. Both tasks used novel lists of pictures that were arbitrarily related to each other (e.g., cognitive task) or arranged in a random pattern on the screen that always involved a change in direction (e.g., motor–spatial task).

motor–spatial task the ordinal content is perceptually bound to the motor–spatial response. That is, one can see the serial actions. When imitating a model, participants can directly imitate the serial actions they have witnessed. In the cognitive task, however, the ordinal content is independent of specific motor responses because the pictures' positions change randomly from trial to trial. As a result, one cannot imitate the motor–spatial actions of the model in the cognitive task. So, while both tasks are "cognitive" tasks because they both require the representation of ordinal knowledge, the distinction made here between cognitive and motor–spatial refers to the primary form of information being learned: a serial motor–spatial response that can be directly imitated (hence, "motor–spatial") versus one that cannot be directly imitated but must be inferred from the model's responses (hence, "cognitive"). This is not unlike the more common distinction between motor and vocal imitation, where the latter presumes the former.

In order to identify whether distinct cognitive mechanisms are mediating the imitation of distinct content types, differences in imitation performance must be independent of differences in task demands. To that end, Experiment 1 used a within-subject imitation learning paradigm that narrowly defined testing parameters in order to contrast each participant's ability to differentially imitate cognitive-specific and motor-specific rules and responses (Subiaul, 2010). If general learning mechanisms mediate imitation, then, all things being equal in task demands, children who excel in cognitive imitation should similarly excel in motor–spatial imitation. However, if there are different imitation mechanisms, then imitation performance in one imitation domain should be independent of imitation performance in other imitation domains.

Experiment 1

Method

Participants. A total of 64 children—thirty-two 3-year-olds (M = 42.50 months, SD = 3.07, range = 37–47 months; boys = 15, girls = 17) and thirty-two 4-year olds (M = 52.79 months, SD = 3.31, range = 48–59 months; boys = 14, girls = 18)—participated in the present study. Five children were excluded because of experimenter error (3-year-olds = 2, 4-year-olds = 3). The racial/ethnic breakdown of participants was as follows: White/Caucasian = 71%, Black/African American = 6%, Asian = 2%, Native American = 0%, Hispanic = 3%, Mixed/Other = 0%, No Response = 18%. All participants were recruited from various childcare centers. Informed consent was collected from participants' parents or legal guardians, and informed assent from the child was obtained immediately prior to testing.

Tasks. Children were presented with two different tasks: a cognitive task and a motor–spatial task. In both tasks, picture items are displayed simultaneously throughout each trial on a touch-sensitive video monitor (see Figure 1). In the cognitive task, the identity of the items on the screen is different and their position on the screen is varied randomly from trial to trial (cf. Figure 1A). For example, three different pictures constituting a list—A, B, C—appear simultaneously on the touch screen. Each picture must be touched in a specific serial order A → B → C. From trial to trial the pictures appear in different spatial positions. In the motor–spatial task, the identity of the items on the screen is identical and their position on the screen remains constant throughout the testing period. However, from trial to trial the identity of the pictures changes (cf. Figure 1B). For example, three identical pictures—A, A, A—appear simultaneously on the screen. Each picture must be touched in a specific motor–spatial pattern $A_{up} \rightarrow A_{down} \rightarrow A_{right}$. From trial to trial a different set of pictures—B, B, B—appears in the same spatial position and must be touched in the same motor–spatial pattern as in the previous trial ($B_{up} \rightarrow B_{down} \rightarrow B_{right}$).[2]

Both tasks used a 4 × 4 template where pictures could appear in any of 16 nonoverlapping positions on the screen. During testing, only novel lists were used. Novel lists of pictures appear in a random configuration on the touch screen and always involve a change in direction (e.g., up, down, right). Unless otherwise stated, none of the lists are ever repeated between conditions.

This paradigm is unique because it allowed us to hold constant a number of variables that would be difficult, if not impossible, to hold constant using a standard motor imitation paradigm (with objects or tools), including familiarity and novelty associated with task demands (i.e., the task is the same—order pictures—but new pictures present a novel rule that must be executed in a familiar context), motor planning and execution (i.e., children are given experience executing both tasks and the motor demands are well within the capability of the youngest participants), visual attention and load (three pictures/locations in each task), serial memory (both tasks involved responding to three items in a specific sequence), and inhibitory and executive functioning demands (cognitive task: inhibit responding to rewarded location; motor–spatial task: inhibit attending to identity of items). The only difference between tasks was the content that had to be represented and imitated (i.e., cognitive or motor–spatial). A summary description of each task is presented in Table 1.

Materials. Picture items were presented on a Macintosh desktop computer with a 54.61-cm screen with a Magic Touch (Keytech; Garland, TX) detachable screen. List items used throughout testing were composed of color photographs (3.81 cm × 5.08 cm). Each task used a different library of pictures to avoid any overlap in picture content.

Prior to training and testing and in between testing conditions, children were distracted and rewarded with a variety of stickers and stamps that varied in size, shape, color, and content. These were affixed to white printing paper (8.5 in. × 11 in.) with the help of a second experimenter.

Procedure. Prior to testing, children were trained on the cognitive and the motor–spatial tasks (see Figure 1). During training, experimenters helped participants produce the correct sequence of pictures through trial-and-error learning (i.e., operant learning). Experimenters provided the same instructions during training, regardless of task. The experimenter would say to the child, "Let's find Jumping Man," and encouraged the child to touch one of the pictures on the screen. If the child made an error, the computer emitted a low, dull tone; picture items disappeared; and the screen turned black for a 2-s time-out. The experimenter would say, "Oops! That's not right. Let's try a different picture." After the time-out, the screen would turn on and pictures would reappear (cognitive task: same pictures in a different

[2] Identical, rather than different, pictures were use in the motor-spatial task in order to visually differentiate it from the cognitive task and minimize task interference.

Table 1
Description of Tasks (Cognitive, Motor–Spatial) and Conditions Used in Experiments 1–4

Variable	Description	Underlying ability
Task		
Cognitive	Task is to respond to three *different* pictures presented simultaneously on a touch screen in a specific order. From trial to trial, the *same* three pictures appear in a *unique* spatial configuration (cf. Figure 1A).	(a) Visual attention to *identity* of items, (b) inhibit attention to *location*, (c) working memory, (d) serial memory, (e) representation of *novel ordinal* knowledge
Motor–spatial	Task is to respond to three *identical* pictures presented simultaneously on a touch screen in a serial spatial pattern. From trial to trial, three *different* but identical pictures appear in a *fixed* spatial configuration (cf. Figure 1B).	(a) Visual attention to *location* of items, (b) inhibit attention to *identity*, (c) working memory, (d) serial memory, (e) representation of *novel motor–spatial* knowledge
Condition		
Novel imitation	Experiments 1–4: Observe, learn, and copy a novel rule executed by the model on the first trial, without making any errors	(a) Create a new representation from observation and (b) translate it into a matching response
Trial and error/Baseline	Experiments 2–4: Discover a new rule entirely by trial and error, without any assistance from the experimenter	(a) Monitor correct/incorrect responses and (b) update the representation of the target sequence in working memory
Recall	Experiments 2–3: Following a delay, accurately recall a rule/response that was previously learned by trial and error	(a) Encode and (b) recall information within a given content domain
Observational learning/ emulation	Experiment 3: Child sees model repeatedly touch the first item then the last item, ignoring the second item in the sequence. Child never sees correct sequence.	(a) Inhibit copying the model's error, (b) vicariously learn the first item, and (c) infer from the model's error the second item in the sequence and touch the remaining item by default.
Familiar imitation	Experiment 4: Same as in Experiment 1 but the rule has a meaningful or familiar linear pattern (left, middle, right; or top, middle, bottom).	(a) Match observed responses with those stored in semantic memory and (b) recall matching (target) response correctly

Note. Italicized text highlights differences between tasks.

spatial location; motor–spatial task: different pictures in the same spatial location). Though rare, some 3-year-olds perseverated and repeated the same error several times. In such cases, the model blocked the children from repeating this error by holding their hand, placing it on their lap, and saying, "Try another picture." If the children continued to make the same perseverative response, the children's hand was again placed on their lap and the model pointed to the correct picture in the sequence, saying, "Try this one." This latter type of prompting corresponded to a "hint." This procedure was repeated until the child touched the correct picture. Once the child made a correct response, the computer would generate a 1,000-Hz tone and the experimenter would say, "That's right! Remember, that's picture number 1." At this point the experimenter would say to the child, "OK, what's next?" and would encourage the child to touch another picture on the screen. If the child made an error, the experimenter said, "Oops! That's not right. But you found picture number 1. Let's try again. Remember, start with picture number 1." The same procedures were used to find the second picture in the sequence. Once the child touched the second picture in the list, the experimenter said, "That's right! What's last?" Having touched all pictures in the correct order, a 5-s video clip of a man doing a backward summersault played on the touch screen. On half of the (correct) trials, Jumping Man is accompanied by cheers and clapping or by the sounds of trumpets in addition to praise from the experimenter, "Yay! You found Jumping Man!" To advance to testing, children had to touch all pictures on the screen correctly without any assistance from the experimenter.

Testing consisted of one session with two counterbalanced conditions of novel imitation using the cognitive and the motor–spatial tasks. Children were tested twice in each task (i.e., two testing periods per condition). The measure of learning was children's accuracy on the very first trial. At the start of each testing condition, the experimenter said, "Watch me," and proceeded to touch each item on the screen in the correct sequence. Following each correct trial, the experimenter clapped, smiled, and said, "Yay! I found Jumping Man!" This procedure was repeated three consecutive times. Following this demonstration, the experimenter said, "It's your turn. Remember, start with number 1." At this point, the child was allowed to respond. Trials continued until the child responded to all of the items in the correct serial order on a single trial. This was done to assess the different types of errors made by children who did not respond correctly on the first trial. After the participant correctly completed a trial, the experimenter reconfigured the computer for the next condition while the child was distracted with stickers and stamps by a second experimenter.

We used a within- rather than a between-subjects design because it was critical to assess whether dissociations in imitation performance were evident in the same child. Although a between-subjects design minimizes confounds that might result from the cumulative effects of the various types of training each participant was given, it does not allow for the direct comparison of individuals in different imitation tasks. Confounds associated with testing order, expertise, and task type are all addressed later. Four different lists of picture sequences were used in the present study: two novel cognitive lists and two novel motor–spatial lists. Each condition consisted of a maximum of 20 trials. However, testing was terminated once the participant responded correctly to all items on the screen, without making an error. Cognitive and motor–spatial lists were counterbalanced across testing, guaranteeing that each list type (i.e., cognitive vs. motor–spatial) appeared first an equal number of times.

Measures. Our dependent measure was first trial accuracy rather than the more common (but relative) measures of imitation performance such as a mean number of trials or average number of responses or "response approximations." First trial accuracy is the most sensitive measure of imitation because after the first trial a participant's performance may be influenced by imitation, by trial and error, or by both factors. Because learning was compared with a conservative measure of chance (see earlier), no subjective measure(s) of imitation was required, as the computer recorded all responses whether correct or incorrect.

Calculation of chance probabilities. Participants could select any of three items for their first response ($1/3 = .33$), any of two items for their second response ($1/2 = .5$), and one item for their third response ($1/1 = 1$). It follows that the probability of completing the first trial on a new list correctly by chance is $1/3 \times 1/2 \times 1/1$ or $1/3! = .165$. That probability is based on the conservative assumption that participants did not make backward errors of the type $A \rightarrow B \rightarrow A$ (Swartz, Chen, & Terrace, 1991, 2000; Subiaul et al., 2004; Terrace, Son, & Brannon, 2003), given that picture items did not disappear after a correct response. Successive responses to the same item (e.g., $A \rightarrow B \rightarrow B \rightarrow B$) were not considered errors, as we did not want to punish accidental double touches of a particular item.

Results

Testing order, gender, and age effects. Preliminary analysis of the data revealed no significant effect for testing order and no significant differences between the performance of boys and girls. This was true for all the studies. Consequently these variables were not analyzed further. Given that there were no significant order or gender effects, we evaluated group (age) differences followed by first trial accuracy for each group and then within-group (task) differences.

A Kruskall-Wallis test was used to assess whether there were any age- or task-specific main effects. As can be seen in Figure 2A, there were significant differences between the performances of 3- and 4-year-olds, $\chi^2(7, 64) = 22.55$, $p = .002$, $\eta^2 = .357$. Mann-Whitney U tests, using a Bonferroni corrected alpha of .013 (.05/4) revealed that this significant effect was driven by differences in the motor–spatial imitation task (Testing Period 1: $Z = -2.46$, $p = .010$, $r = 31$; Testing Period 2: $Z = -1.68$, $p = .09$, $r = .21$) not the cognitive imitation task (Testing Period 1: $Z = -0.19$, $p = .85$, $r = .02$; Testing Period 2: $Z = -0.45$, $p = .65$, $r = .06$).

First trial accuracy. Underlying these differences were group differences in first trial accuracy. For example, when tested on the cognitive task, 67% of 3-year-olds (20/30) and 69% of 4-year-olds (20/29) correctly imitated the model on the first trial. This result was significantly greater than the 17% (5/30) of children expected to discover the sequence by chance alone (Testing Periods 1 and 2: $ps < .001$, $g > .5$, binomial test). When tested on the motor–spatial task, however, only 27% of 3-year-olds correctly imitated the model. This result did not significantly differ from what would be expected from chance alone (Testing Periods 1 and 2: $ps > .10$, $g = .11$). In contrast, when tested on the motor–spatial task, 59% of 4-year-olds correctly imitated the model's response, a result that significantly differed from chance (Testing Periods 1 and 2: $ps < .001$, $g = .43$).

Performance across tasks and testing periods. A Friedman test was used to compare children's performance across tasks and testing periods. The performance of 3-year-olds significantly differed across tasks and testing periods, $\chi^2(3, 30) = 19.61$, $p < .001$, $W = .22$. Wilcoxon signed ranked tests, using a Bonferroni adjusted alpha of .013 (.05/4) for multiple comparisons revealed significant differences between the motor–spatial and the cognitive imitation task during the first ($Z = -3.0$, $p = .003$, $r = .55$) and second ($Z = -2.71$, $p = .007$, $r = .49$) testing periods. However, 3-year-olds' performance within tasks did not significantly improve from the first to second testing period in either the cognitive ($Z = -0.30$, $p = .76$, $r = .05$) or the motor–spatial ($Z = -0.82$, $p = .41$, $r = .15$) imitation task. In contrast to the performance of 3-year-olds, 4-year-olds' performance did not statistically differ across tasks or testing periods, $\chi^2(3, 29) = 2.28$, $p = .52$, $W = .03$, Friedman test. That is, 4-year-olds performed equally well in both the cognitive and the motor–spatial tasks during both testing periods.

Given the broad spectrum of 3- and 4-year-olds, we assessed how the skills measured here changed in the course of development. A Spearman correlation showed that age (in months) significantly contributed to performance, but only for 3-year-olds. This correlation was restricted to performance in motor–spatial imitation, not cognitive imitation. Specifically, the older the 3-year-old, the more likely they were to evidence imitation learning in the motor–spatial imitation task ($r = .467$, $p = .007$).

Role of training in imitation performance. Children's difficulty imitating novel motor–spatial sequences may have been due to a *general* difficulty learning novel motor–spatial content, as opposed to a *specific* problem imitating novel motor–spatial sequences. If this is the case, when children are first introduced to each task during training, they should require many more trials to reach criterion in the motor–spatial task than in the cognitive task. To test this hypothesis, we analyzed children's performance in training, their first encounter with each task. Specifically, we assessed the total number of trials it took children to satisfy the performance criterion necessary to advance to testing. A mixed between–within repeated-measures analysis of variance that included task (cognitive vs. motor–spatial) as a within-subject variable and training order (cognitive task first vs. motor–spatial task first) and age (3- vs. 4-year-olds) as between-subjects variables was used to evaluate differences during training for the cognitive and motor–spatial tasks. Results revealed a main effect for task, $F(1, 45) = 11.60$, $p = .001$, $\eta^2 = .21$, but no significant interaction between task and training order, $F(1, 45) = 1.65$, $p = .21$, $\eta^2 = .04$, or between task and age, $F(1, 45) = 0.03$, $p = .87$, $\eta^2 < .01$. The three-way interaction between task, order, and age was also

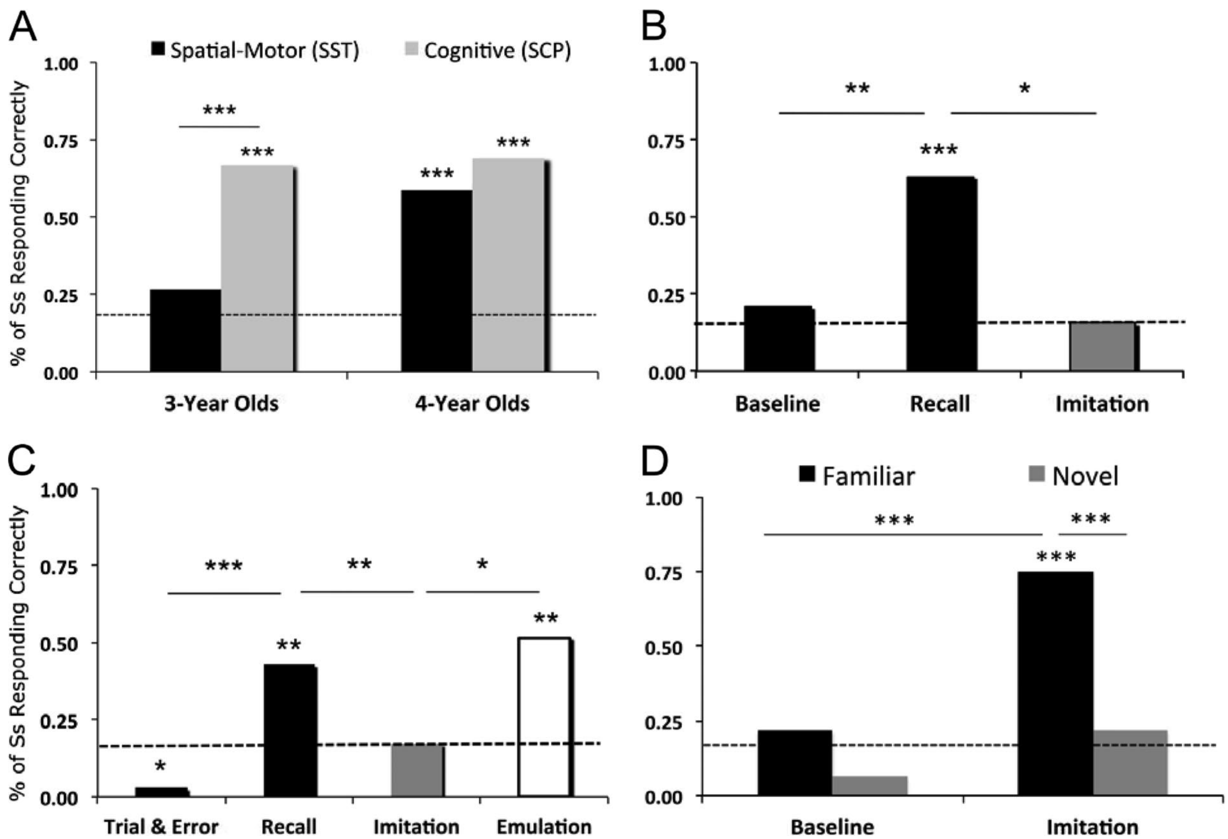

Figure 2. First trial accuracy: Percentage of children responding correctly on Trial 1. A: Three- and 4-year-olds' performance in the motor–spatial and cognitive imitation task in Experiment 1. B: Three-year-olds' within-subject performance in three conditions (baseline, recall, imitation) in Experiment 2. C: Three-year-olds' within-subject performance in four conditions (baseline, recall, observational learning [emulation], and novel imitation) in Experiment 3. D: Three-year-olds' within-subject performance in four conditions (baseline [familiar], baseline [novel], novel imitation, familiar imitation) in Experiment 4. Dashed lines correspond with chance performance (p = .165). $^{*}p < .05$. $^{**}p < .01$. $^{***}p < .001$.

not significant, $F(1, 45) = 0.20$, $p = .65$, $\eta^2 = .01$. None of the between-subjects variables (age, training order) were statistically significant, order: $F(1, 45) = 1.30$, $p = .26$, $\eta^2 = .03$; age: $F(1, 45) = 2.40$, $p = .13$, $\eta^2 = .05$; Order × Age: $F(1, 45) = 0.17$, $p = .68$, $\eta^2 < .01$.

A pairwise comparison revealed that both 3- and 4-year-olds required more trials to meet the training criterion for the cognitive task than for the motor–spatial task ($p = .002$). On average, 3- and 4-year-olds required more trials (1.45 and 1.79 trials, respectively) to satisfy the performance criterion for the cognitive task than the motor–spatial task. A Spearman correlation was used to assess whether these extra trials positively contributed to imitation performance. Results showed no significant correlations between training and imitation performance. Statistical results are summarized in Table 2. These results refute the hypothesis (a) that the task that is harder to learn by trial and error is also harder to imitate and (b) that increasing expertise or experience with a given task leads to better imitation performance.

Table 2
Correlations Between Mean Number of Training Trials and First Trial Accuracy in the Cognitive and the Motor–Spatial Tasks for Experiment 1

	Cognitive task				Motor–spatial task			
			Correlation				Correlation	
Group	Training	Testing	ρ	p	Training	Testing	ρ	p
3-year-olds	6.21	0.67	–.168	.403	4.48	0.27	–.208	.287
4-year-olds	5.33	0.69	.279	.186	3.69	0.59	–.042	.837

Discussion

The results of Experiment 1 revealed a suite of surprising dissociations. Among 3-year-olds, there was a robust dissociation between the imitation of motor–spatial sequences as measured by the motor–spatial task and the imitation of pure ordinal content represented independently of motor–spatial content as measured by the cognitive task. This result indicates that distinct cognitive computations mediate the imitation of novel ordinal content as opposed to novel motor–spatial content. Data from training (cf. Table 1), contradicts the prediction that 3-year-olds' failure to imitate novel motor–spatial sequences can be explained by an initial difficulty learning novel motor–spatial sequences. Rather, judging from children's first exposure to these two novel tasks in the course of training, one would have reasonably expected children to have problems imitating novel cognitive rules. But such was not the case. Rather, within the motor–spatial domain there appears to be a further dissociation between the cognitive mechanisms mediating trial-and-error learning and those mediating imitation learning. Such a pattern of results is consistent with the hypothesis that distinct computations, mediated by specific cognitive mechanisms, support individual (operant) learning within a given content domain and imitation learning in the same domain.

Nonetheless, there is the possibility that motor–spatial sequences are generally more difficult to learn, because while they might be easy to encode initially, they might not be recalled following a brief delay, as was the case when learning from the model. In this view, the 3-year-olds' motor–spatial imitation failure is, essentially, a memory failure. Why would such a failure happen only when executing novel motor–spatial sequences but not novel ordinal rules? One possibility is that 3-year-olds have some experience individuating items (e.g., apple, boy, cat) belonging to an open class but significantly little to no experience naming motor–spatial relationships (e.g., up, down, right) that belong to a more closed class of words (Gentner & Boroditsky, 2001). Failure in the motor–spatial task may have been due to the difficulty of conceptually or linguistically encoding such motor–spatial relationships.

Experiment 2

Experiment 2 sought to test the hypothesis that children's failure to imitate motor–spatial sequences is because of a failure to recall novel motor–spatial sequences. If 3-year-olds have a problem recalling novel motor–spatial representation, then children's imitation performance following a model's demonstration and recall following trial-and-error learning should both be impaired relative to chance (and baseline). That is, a general memory problem in the motor–spatial domain should lead to recall-related problems independently of the learning mechanism (i.e., trial-and-error, observational, and imitation learning).

To test this hypothesis, a new group of 3-year-olds was tested in three conditions where they had an opportunity to learn a new motor–spatial sequence by trial-and-error learning (baseline). Following a 30-s delay, they were tested in a recall condition where they had to reproduce the motor–spatial sequence that they had just learned by trial-and-error learning in baseline, a measure of children's ability to encode and recall newly learned motor–spatial content. Following this experience, we tested the same children in a novel imitation condition (as in Experiment 1).

Method

Participants. Twenty 3-year-olds (M = 39.22 months, SD = 2.44, range = 36–45 months; boys = 10, girls = 10) were trained and tested in the motor–spatial task. One child was excluded because of experimenter error. The racial/ethnic breakdown of participants was as follows: White/Caucasian = 79%, Asian = 11%, Hispanic = 11%. Children were recruited and tested in daycare centers and in a public setting, the Think Tank of the National Zoological Park, Smithsonian Institution.

Procedure. The materials, design, and procedures used in Experiment 2 were identical to those used for Experiment 1 with the following exceptions: Children were tested in only the motor–spatial task, and immediately following training on the motor–spatial task, each participant was tested in one session that included the following three conditions (cf. Table 1): trial-and-error learning, recall, and novel imitation, which are described in the next sections.

Trial-and-error learning (baseline). Children had to touch a new three-item motor–spatial sequence entirely by trial and error.

Recall. Immediately upon generating the correct motor–spatial sequence in baseline, participants were distracted with stickers and stamps by another experimenter. After 30 s the children were asked to reproduce the motor–spatial sequence that they had just learned by trial-and-error learning in baseline.

Novel imitation. As in Experiment 1, the model demonstrated the response for three trials and then allowed the children to respond after saying, "Now it's your turn. Remember, start with picture number 1."

Baseline and recall used the same list because in recall the aim was to assess whether children were capable of successfully representing motor–spatial content as evidenced by their ability to reproduce a recently learned motor–spatial sequence following a delay. Children were presented with a different list in the novel imitation condition. Given the structure of the task, it was impossible to counterbalance the baseline and recall conditions (as the latter was yoked to the former). We chose not to counterbalance baseline–recall and imitation to provide 3-year-olds with greater first-hand experience executing novel motor–spatial sequences prior to testing on the imitation condition, where 3-year-olds failed. Counterbalancing would have reduced the amount of experience children had executing motor–spatial sequences, a concern in Experiment 1.

Results

First trial accuracy. As can be seen in Figure 2B, 20% (4/20) of children produced the target motor–spatial sequence on the first trial of baseline, a result that did not differ from what is expected by chance alone (p = .79, g = .03, binomial test). However, 63% (12/20) of children responded correctly in recall, accurately recalling the motor–spatial sequence they had learned by trial and error following a 30-s delay. This result significantly differed from chance ($p < .001$, g = .46, binomial test). Yet, given this experience in baseline and recall, only 15% (3/20) of these same children evidenced imitation learning in the novel imitation condition (p = 1.0, g = .03, binomial test), replicating the results of Experiment 1.

Performance across conditions. Children's performance between conditions (baseline, recall, novel imitation) was statistically significant, $\chi^2(2, 19) = 9.73$, $p = .007$, $W = .26$, Friedman test. Wilcoxon signed-ranks tests using a Bonferroni corrected alpha of .017 (.05/3) for multiple comparisons showed significant differences between baseline and recall ($Z = -2.53$, $p = .011$, $r = .59$) and between recall and novel imitation ($Z = -2.50$, $p = .013$, $r = .59$) but not between baseline and novel imitation ($Z = -0.378$, $p = .705$, $r = .09$). Because the baseline condition was first, it is possible that performance in either the recall or the novel imitation condition benefited from expertise acquired when learning novel motor–spatial content by individual trial-and-error learning (i.e., baseline). Specifically, there may be a linear relationship between the total number of trials it took children to produce the correct motor–spatial sequence and their performance in subsequent conditions. That is, the more trials in baseline, the greater the expertise in learning novel motor–spatial sequences, the better the performance in recall and/or novel imitation. However, when the number of trials in baseline was correlated with first trial accuracy in recall and novel imitation, the correlations were not statistically significant (baseline–recall: $r = .168$, $p = .479$; baseline–novel imitation: $r = .211$, $p = .371$, Pearson correlation).

Discussion

Coupled with the results of Experiment 1, the results of Experiment 2 refute the possibility that 3-year-olds' difficulty imitating novel motor–spatial sequences is due to a general difficulty encoding and recalling motor–spatial content. This conclusion is supported by data (cf. Figure 2B) showing 3-year-olds can accurately execute new motor–spatial sequences learned by trial and error after a single correct trial (in baseline) and following a 30-s delay (in recall). Additionally, expertise in learning novel motor–spatial rules during baseline failed to significantly improve performance in either the recall or novel imitation condition. Thus, knowing how to encode and execute novel motor–spatial content did not improve 3-year-olds' imitation performance in this domain, a functional dissociation between trial-and-error learning and imitation learning within the motor–spatial domain. This pattern of results casts doubt on the possibility that a lack of familiarity with motor–spatial content or some general difficulty in encoding and recalling this content in a rule-governed fashion explains 3-year-olds' failure in the novel imitation condition. If such were the case, why would 3-year-olds evidence relative ease recalling this rule type following trial-and-error learning but have difficulty imitating the same type of rule?

This unique pattern of dissociations raises the possibility that in Experiments 1 and 2, three-year-olds learned the new motor–spatial sequence in the novel imitation condition but could not translate this knowledge into a matching (imitative) response, an observational learning problem. Experiment 3 sought to address this question.

Experiment 3

Experiment 3 sought to test the possibility that 3-year-olds' failure to imitate novel motor–spatial sequences was due to a difficulty in learning motor–spatial sequences vicariously by observing a model. This is a concern because all novel imitation conditions, where participants have to learn a new rule or response, confounds observational (vicarious) learning and imitation learning (i.e., copying). As such, one may predict that children who cannot learn motor–spatial relationships vicariously by observation will subsequently fail to imitate novel motor–spatial sequences. There are several ways to decouple observational learning and imitation. One way is to use a goal emulation paradigm (e.g., Want & Harris, 2001), where participants see a model make an incorrect response and have to infer from the model's error what the correct response should be. In this case, observational learning interacts with causal and inferential reasoning mechanisms to generate a nonmatching (but a target) response that is impossible to achieve without observational learning.

Method

Participants. Thirty-five 3-year-olds ($M = 40.10$ months, $SD = 3.02$, range = 36–47 months; boys = 19, girls = 16) were trained in the motor–spatial task using the same procedures described in Experiment 2. Two children were excluded from the final analysis because of experimenter error. The racial/ethnic breakdown of participants was as follows: White/Caucasian = 77%, Black/African American = 6%, Asian = 6%, Native American = 3%, Mixed/Other = 9%. Children were recruited and tested in the National Museum of Natural History, Smithsonian Institution.

Tasks and materials. Tasks and materials were the same as those used in Experiments 1–3.

Procedure. Procedures were the same as those used in Experiments 1 and 2. The only difference was that children were tested once in an observational learning or goal emulation (henceforth, "emulation") condition in addition to baseline–recall and novel imitation (as in Experiment 2). During the emulation condition, a model demonstrated an incorrect motor–spatial sequence before allowing the child to respond (cf. Table 1). Specifically, the model responded correctly to the first item in the sequence and then incorrectly to the last item in the sequence, skipping the second (middle) item, making an error (i.e., screen turned black, picture items disappeared for 2 s). To highlight that this error was an "unintentional" response, the model said after each error, "Oops! That's not right! Let me try again." This procedure was repeated for three trials, during which the child was allowed only to watch and not to respond. Following the second incorrect demonstration, the experimenter repeated the same rejoinder, "Oops! That's not right," but then added, "Let me try one more time. Then it will be your turn." After failing to discover Jumping Man, the experimenter said, "I can't find Jumping Man. Can you find Jumping Man? Remember, start with picture number 1." As in Experiments 1 and 2, new lists of pictures were used in each condition except baseline–recall, where the same list of pictures was used in both conditions. All lists were novel (i.e., involving a change in direction) and counterbalanced between conditions, except for baseline–recall, which, as noted earlier, are yoked and so were counterbalanced as one condition.

Results

First trial accuracy. As can be seen in Figure 2C, only 3% (1/36) of children produced the motor–spatial sequence on the first trial of baseline, a result that was significantly below chance ($p = .03$, $g = .14$, binomial test). However, 43% (15/36) of children responded correctly in recall, accurately recalling the individually learned motor–spatial sequences following a 30-s delay. This result significantly differed from chance ($p < .001$, $r = 26$, binomial test). And, as in Experiments 1 and 2, only 17% (6/36) of 3-year-olds evidenced learning in the novel imitation condition. This result did not differ from chance ($p = 1.0$, $r < .01$, binomial test). However, despite this failure, 51% (18/36) of 3-year-olds evidenced learning in the emulation condition, a result that was statistically significant ($p < .001$, $r = 34$). In contrast to Experiment 1, we did not find any significant correlation between months of age and performance for any of the conditions, including imitation ($r_{\text{range}} = -.20$ to .16, $p_{\text{range}} = .24$ to .84).

One possibility is that children's success in the emulation condition was because they avoided making the model's error. This knowledge may have narrowed children's range of responses, increasing the likelihood of producing the motor–spatial sequence entirely by chance. To test this possibility, we increased chance probability on the first trial for the emulation condition from 16% [P(1) = .33 × P(2) = .5 × P(3) = 1 = .25] to 33% [P(1) = .33 × P(2) = 1 × P(3) = 1 = .33]. This change in probability reflects the fact that children have just three possible responses they can make after excluding the model's error as a possible response option. An analysis of 3-year-olds' performance in the emulation condition using the most conservative estimate of chance showed that children's learning was, nonetheless, greater than what was expected by chance alone ($p = .036$, $g = .18$, binomial test).

Another possibility is that children's learning in the emulation condition was driven by the performance of children who successfully imitated novel motor–spatial sequences. To test that hypothesis, we analyzed performance in the emulation condition, excluding children who had successfully imitated novel motor–spatial sequences (i.e., "imitators"). Results showed that 48% (14/29) of nonimitators learned in the emulation condition, a result that was statistically significant ($p < .001$, g = .31, binomial test).

Performance across conditions. Children's performance between conditions excluding imitators (baseline, recall, and emulation) was also statistically significant, $\chi^2(2, 33) = 18.105$, $p < .001$, W = .31, Friedman test. Wilcoxon signed ranks tests using a Bonferroni corrected alpha of .017 (.05/3) for multiple comparisons showed that baseline significantly differed from the recall ($Z = -3.74$, $p < .001$, $r = .69$) and emulation ($Z = -4.12$, $p < .001$, $r = .76$) conditions. The recall condition did not differ from the emulation condition ($Z = -0.83$, $p = .41$, $r = .15$).

Discussion

Experiment 3 replicates the results of Experiments 1 and 2 and further demonstrates that 3-year-olds who fail to imitate novel motor–spatial sequences can successfully learn from a model's errors, evidence of observational or goal emulation (Carpenter & Call, 2002; Whiten & Ham, 1992) learning in the motor–spatial domain. Because Experiment 3 used a within-subject design, we were able to show a significant and robust dissociation between observational learning, recall, and imitation learning in the motor–spatial domain. That is, a child who was not able to learn in the novel imitation condition successfully learned in the emulation and recall conditions. To our knowledge, this within-subject dissociation between imitation, recall following individual trial-and-error learning, and observational learning is unique in the developmental literature.

Three-year olds' success in the emulation condition is striking given that they never saw a correct trial. Rather, they saw a correct response (to the first list item) followed by an incorrect response (to the last list item). From this error, 3-year-olds inferred that if the correct sequence was not 1 → 3, then it must be 1 → [2] → 3. Learning in the emulation condition should be harder than learning in the novel imitation condition (cf. Experiments 1 and 2), because children have to (a) inhibit imitating the model's incorrect response; (b) identify (and distinguish between) the correct and the incorrect responses; (c) identify the "missing" item, Item 2, and (d) inhibit touching this item first; (e) combine this information to construct a novel representation of an unobserved motor–spatial sequence; and (f) execute the inferred (rather than the observed) motor–spatial sequence. Even if children learn from exclusion in this condition, that is, they learn that 1 → 3 is an incorrect sequence, children must hold this response in working memory and deduce from this incorrect information the correct sequence. This is no easy feat (cf. Horner & Whiten, 2007).

These and other studies make it clear that preschool-age children have at their disposal sophisticated inferential reasoning mechanisms that allow them to predict likely (unobserved) outcomes (Gopnik & Schulz, 2004; Kushnir & Gopnik, 2005; Schulz, Gopnik, & Glymour, 2007; Sobel & Munro, 2009). These causal and inferential (i.e., abductive) reasoning mechanisms may have played a role in the emulation condition, where the model demonstrated a correct followed by an incorrect response, perhaps mediating emulation learning. However, these mechanisms are inadequate for learning in the novel imitation condition, where the model responded correctly to all items on the screen (without making an error). Want and Harris (2001) argued that this is because young children need more causal information to learn and subsequently imitate novel motor responses. Instead, we propose that the reason for the observed dissociation between learning a novel motor–spatial sequence from a model's error (i.e., emulation) and imitating a model's execution of a novel motor–spatial sequence (i.e., imitation) is because imitation requires a different (or an additional) mechanism, one specifically dedicated to copying motor–spatial sequences in a rule-governed fashion.

Experiment 4

Thus far, the results reported here demonstrate that 3-year-olds, as a group, fail to imitate novel motor–spatial sequences. This outcome is surprising because various studies have reported that children as young as 14 months imitate actions on objects. However, these tasks involve imitating familiar motor responses that exist in children's cognitive and behavioral repertoire such as touching and rattling objects (Abravanel & Sigafoos, 1984; Barr, Dowden, & Hayne, 1996; Bauer & Mandler, 1989; Collie & Hayne, 1999; Learmonth, Lamberth, & Rovee-Collier, 2004), as well as more uncommon or arbitrary responses such as turning on a light using one's head, rather than one's hand (Buttelmann, Carpenter, Call, & Tomasello, 2008; Gergely et al., 2002; Meltzoff, 1988a), or hopping versus sliding to reach one of two goals (Wagner, Yocom, & Greene-Havas, 2008). In the former case, familiar motor schemas involving the use of a specific body part (e.g., head) are executed in novel contexts (e.g., turning on a light).

In the latter case, familiar actions are paired with ambiguous goals. In the present study, children also used a familiar motor response (i.e., touching items on the screen). However, the motor–spatial task required children to direct this basic (familiar) action to three specific points on a screen and do so in a specific pattern that was nonlinear and entirely arbitrary. The result is a novel motor–spatial action unlikely to exist in the child's behavioral or cognitive repertoire.

But what if 3-year-olds were presented with a motor–spatial sequence that consisted of a familiar motor–spatial pattern such as a straight line? Given results from other laboratories reviewed earlier, one might expect that children who fail to imitate a novel motor–spatial sequence may successfully imitate a familiar motor–spatial sequence despite the fact that the task and the context are novel.

Experiment 4 sought to test the hypothesis that 3-year-olds who fail to imitate novel motor–spatial sequences can successfully imitate familiar motor–spatial sequences. This result would be consistent with research using standard motor tasks (e.g., employing toys or problem boxes) where task affordances and actions are familiar to the children and scaffold imitation performance among preschool-age children.

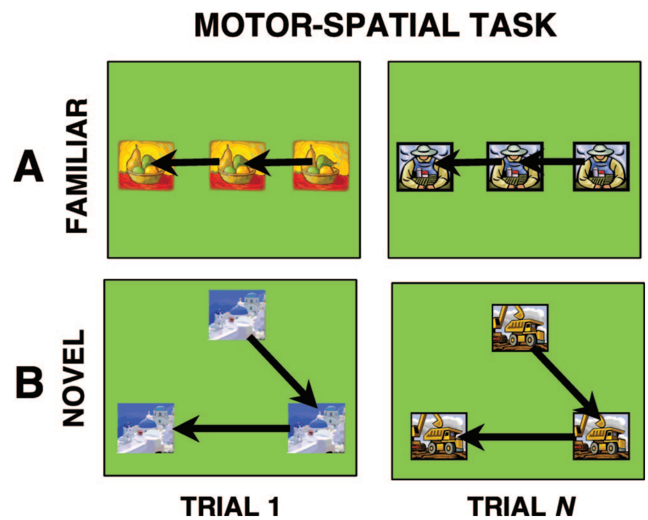

Figure 3. Motor–spatial task in Experiment 4. A: In the condition using familiar lists, pictures appear in a straight line. Participants must respond to the items from left to right, right to left, top to bottom, or bottom to top. B: In conditions with novel lists, pictures appear in a random (arbitrary) pattern on the screen and always involve a change in direction.

Method

Participants. Thirty-two 3-year-olds (M = 42.69 months, SD = 3.52, range = 36–47 months; boys = 16, girls = 16) were trained in the motor–spatial task. The racial/ethnic breakdown of participants was as follows: White/Caucasian = 72%, Black/African American = 6%, Asian = 3%, Hispanic = 6%, Mixed/Other = 3%, No Response = 9%. Children were recruited and tested in a public setting, the Think Tank of the National Zoological Park, Smithsonian Institution.

Tasks and materials. Tasks and materials were the same as those used in Experiments 1–3.

Procedures. Children were trained prior to testing on the motor–spatial task using novel lists that involved a change in direction (e.g., up → down → right). Testing consisted of a single session with four conditions: baseline–familiar (familiar list), baseline–novel (novel list), novel imitation (novel list), familiar imitation (familiar list). The different list types and conditions are described in Table 1 and depicted in Figure 3. Familiar conditions, such as familiar imitation or baseline (familiar list), use lists of pictures that always appear in a linear pattern on the screen either vertically (e.g., left → middle → right; right → middle → left) or horizontally (e.g., top → middle → bottom; bottom → middle → top) and never involve a change in direction. Novel conditions use lists of pictures that never appear in a linear pattern and always involve a change in direction (as in Experiments 1–3). Importantly, all the lists (familiar and novel) were new to the children, and none of the lists were repeated between conditions. Conditions were counterbalanced, guaranteeing that all children were tested first in each of the four conditions. Procedures used during baseline and imitation conditions (regardless of list type) were identical to those of Experiment 3.

Results

First trial accuracy. As can be seen in Figure 2D, 22% (7/32) of children produced the correct sequence on the first trial in baseline–familiar, and 6% (2/32) discovered the correct sequence on the first trial in the baseline–novel condition; neither result significantly differed from what was expected by chance (baseline–familiar: p = .54, g = .05; baseline–novel: p = .17, g = .11, binomial test). As in Experiments 1–3, three-year-olds failed to evidence imitation learning in the novel imitation condition (M = .22, p = .54, g = .05, binomial test). However, 75% (24/32) of these same children learned in the familiar imitation condition, a result that was significantly greater than what is expected by chance ($p < .001$, g = 58, binomial test). This result remained statistically significant after excluding novel imitators (M = .72, $p < .001$, g = .55, binomial test).

Given that the second item in the familiar imitation condition was always the middle item, it is possible that children only had to learn the order of the first item, touching the rest by default [P(1) = .5 × P(2) = 1 × P(3) = 1 = .5]. Using this more conservative assessment of chance (.5) for the familiar imitation condition, the performance of 3-year-olds was, nonetheless, significantly above chance (including novel imitators: p = .007, g = .25; excluding novel imitators: p = .043, g = .22, binomial test). As in Experiment 3, there was no significant relationship between months of age and performance in any of the conditions of Experiment 4 (r_{range} = –.22 to +.26, p_{range} = .15 to .82).

Performance across conditions. Performance in these different conditions significantly differed within-subject, $\chi^2(3, 32)$ = 36.26, $p < .001$, W = .38, Friedman test. A Wilcoxon signed ranks test using a Bonferroni corrected alpha of .013 (.05/4) for multiple comparisons revealed significant differences between baseline–familiar and familiar imitation and between the novel and familiar imitation conditions (Z = –3.90, p = .010, r = .69). The differences between baseline–familiar and baseline–novel and between baseline–novel and novel imitation were not statistically significant (Z = –1.68, p = .10, r = .30).

Developmental trends across studies. Despite the fact that age did not correlate with imitation performance in Experiments 2

– 4, there was an age effect in Experiment 1 showing that the older the 3-year-old, the better the imitation performance in the motor–spatial task. To clarify this issue further, we evaluated the performance of all 3-year-olds from Experiments 1–4. When we compared the performance of young 3-year-olds (36–41 months) with that of older 3-year-olds (42–47 months) from Experiments 1–4 (N = 114), there was a significant difference between these age groups (Z = –2.0, p = .04, r = .19, Mann-Whitney test). Specifically, older 3-year-olds evidenced more imitation learning in the motor–spatial task than did younger 3-year-olds. However, when we compared the older 3-year-olds from Experiments 1–4 (n = 54) with all 4-year-olds from Experiment 1 (n = 29), results were also significant (Z = –1.98, p = .04, r = .22, Mann-Whitney test): 4-year-olds evidenced significantly more imitation learning in the motor–spatial task than did older 3-year-olds.

These results confirm that there are significant developmental differences between 3- and 4-year-olds' ability to imitate novel motor–spatial sequences. While differences between younger and older 3-year-olds are not entirely surprising, they are developmentally important. Such differences suggest that toward the end of the 3rd year, children begin to imitate entirely abstract and novel motor–spatial sequences. However, it is not until after the fourth birthday that this performance pattern comes to characterize the majority of children.

Discussion

These results are consistent with other studies showing that are consistent with other studies showing younger can imitate in the motor–spatial domain (Abravanel & Sigafoos, 1984; Barr et al., 1996; Bauer & Mandler, 1989; Buttelmann et al., 2008; Collie & Hayne, 1999; Gergely et al., 2002; Learmonth et al., 2004; Meltzoff, 1988a; Nielsen, 2006; Wagner et al., 2008).[3] But these results go further than any previous study by demonstrating that imitation performance in this domain is constrained by whether the content is familiar (i.e., present in the child's behavioral or cognitive repertoire) or novel (i.e., unlikely to be present in the child's behavioral or cognitive repertoire).

Bauer (1992; Bauer & Hertsgaard, 1993) reported similar results showing that enabling relations (i.e., causal relationships between actions in a sequence) enhance imitation performance throughout development. But note that this effect did not extend to baseline in the present study, where, regardless of list type (novel/familiar), children's performance did not differ from chance. Additionally, differences between familiar and novel imitation, as well as between these imitation conditions and short-term memory (recall) and trial-and-error learning, were within- rather than between-subjects, highlighting dissociations in performance in the same individual.

General Discussion

The results of Experiments 1–4 demonstrate that young children have at their disposal a whole suite of cognitive skills that bear upon their imitation-learning performance, as several researchers have noted (Csibra & Gergely, 2009; Meltzoff, 2008; Rogers, 2006; Tomasello, 1999; Want & Harris, 2002). These different skills make young children flexible and adaptive social learners. Such cognitive abilities are particularly evident when children are provided with problems that involve learning rules and responses that are entirely new and arbitrary and are not present in their behavioral or cognitive repertoire. Given children's exceptional imitative abilities, it's surprising that in Experiment 1, four-year-olds excelled in both cognitive and motor–spatial imitation but children as old as 3.5 years of age excelled only in cognitive imitation, failing to evidence novel motor–spatial imitation. These results were replicated in Experiments 2–4 with different groups of children. In every case, 3-year–olds' ability to imitate novel motor–spatial sequences was poor when compared with chance and baseline rates of learning.

As noted earlier, we are not the first to report that 3-year-olds have difficulties imitating novel motor rules (e.g., Horner & Whiten, 2007; Want & Harris, 2002). However, unlike these previous studies, we have demonstrated that 3-year-olds' imitation failure in the motor–spatial domain is content-dependent and dissociable from other cognitive skills, including individual learning within the motor–spatial domain. Generally, a failure to imitate in a given task or a given content domain is attributed to various task-specific variables that include the type of response, the complexity of the motor demands, the availability of visual feedback, and the degree of novelty (Hepburn & Stone, 2006; Rogers, 1999; Smith & Bryson, 1994). These different tasks present participants with unique challenges, including attention and memory, executive or inhibitory control, and action planning and execution. However, the computerized paradigm used here challenges many of these traditional competence–performance explanations because the two tasks (cognitive and motor–spatial) require the same basic motor and cognitive skills. If there's a central (i.e., domain-general) mechanism mediating imitation learning, then success in one task should transfer to success in the other task. Conversely, failure in one task should predict failure in the other task. Next we address these and other concerns.

In both the cognitive and motor–spatial tasks, attention and memory demands were constant. In both the cognitive and motor–spatial tasks, children had to attend to and remember three items. In both tasks, these three items had to be remembered in a precise serial order. As such, both tasks possessed a serial memory component. Three-year-olds' success imitating an abstract and novel ordinal response in the cognitive task and a familiar motor–spatial response in the motor–spatial task rejects the possibility that deficits in visual attention or serial memory explain this population's performance in novel motor–spatial imitation. The results of Experiment 4 reject the possibility that there is something inherently harder about touching three identical pictures (i.e., motor–spatial task) versus touching three different pictures (i.e., cognitive task), because 3-year olds successfully imitated a familiar motor–spatial sequence.

Three-year-olds' pattern of performance may be attributed in part to a general (rather than a specific) learning problem within the motor–spatial domain. Such problems are associated with a

[3] Note that many of these studies used relative measures of learning such as the target number of responses when compared with a no demonstration baseline and counted instances of emulation (or partial responses) as equivalent to imitation. Moreover, many of these studies did not report first trial accuracy or the frequency of responding to all demonstrated actions correctly on the first trial, as was done in the present study.

whole suite of skills that include visual–motor control and the ability to sequentially point to targets. These skills are believed to develop late in childhood (Badan, Hauert, & Mounoud, 2000; Pellizzer & Hauert, 1996). Another potential problem may have to do with the encodability of the stimuli in the cognitive and the motor–spatial tasks. For example, whereas the content in the cognitive task may be easily encoded linguistically, the content in the motor–spatial task may have been more difficult to encode linguistically (Gentner & Boroditsky, 2001). These factors may have limited 3-year-olds' ability to encode and recall novel motor–spatial content, generally. Three facts challenge these hypotheses. First, if the motor–spatial task was in general more difficult to learn, then it should have taken 3-year-olds longer to learn the motor–spatial task than the cognitive task. Based on performance during training, the opposite was true: Children required more trials to master the cognitive than the motor–spatial task. Second, 3-year-olds showed no difficulty learning, and subsequently recalling, novel motor–spatial sequences after a delay, evidence that this population can encode novel motor–spatial sequences. Finally, if 3-year-olds had a general difficulty learning motor–spatial content, they should have been as impaired in the familiar imitation condition as they were in the novel imitation condition. Instead, 3-year-olds successfully imitated familiar motor–spatial sequences (cf. Figure 3A).

An adult's pedagogical or social-referencing intent has been shown to have a significant effect on word learning in infants and children (Baldwin et al., 1996; Campbell & Namy, 2003). In the current paradigm, when adults nonverbally pointed to a series of items on a touch screen, children might have expected adults to be referencing individual kinds rather than spatial locations. This social-communicative bias may have led to imitation learning in the cognitive task, where the model touched three *different* pictures (i.e., sequencing by kind, while ignoring location), but not in the motor–spatial task, where the model touched three *identical* pictures (i.e., sequencing by location, while ignoring kind). However, the results reported here argue against such an interpretation. First, given the within-subject design of Experiments 1–4, for such an explanation to be correct children's expectations about what they were being taught would have to change from condition to condition and task to task despite receiving the same instructions by the same experimenter. Second, recall that in Experiment 4 three-year olds excelled when imitating familiar but not when imitating novel motor–spatial rules. If 3-year-olds have different social-referential expectations biasing them to imitate sequences of different kinds (i.e., cognitive task) over sequences of different locations (i.e., motor–spatial task), the results of Experiment 4 would indicate that 3-year-olds also have different social-referential expectations when imitating familiar versus novel motor–spatial patterns. Given that the task and the social-referential context were the same, why would children's expectations change? Nonetheless, it is entirely possible that manipulating children's expectations or the social-referential context may affect children's imitation performance, as it affects word learning (Campbell & Namy, 2003). While the current study held these variables constant, other studies that manipulated some of these variables have shown that both prior experience with a task and children's expectations about the goals of the task affect children's imitation fidelity (Subiaul, Vonk, & Rutherford, 2011; Williamson & Markman, 2006; Williamson, Meltzoff, & Markman, 2008).

There is one other difficulty with the conclusion that 3-year-olds lack a content-specific mechanism for novel motor–spatial imitation: Successful performance in any of the imitation conditions included in this article is dependent upon observational learning. As such, children may have failed to imitate novel motor–spatial sequences because they failed to vicariously learn from the model. Two sets of facts reject this hypothesis. First, Experiment 3 effectively demonstrates that 3-year-olds learn novel motor–spatial relationships from a model's incorrect responses and use this information to infer the correct motor–spatial sequence. Second, Experiment 4 similarly demonstrates that 3-year-olds who fail to imitate novel motor–spatial sequences have no problems imitating familiar motor–spatial sequences. The results of Experiments 3 and 4 are impossible if children are incapable of observational learning or goal emulation in the case of Experiment 3.

Having excluded the possibility that differences in task demands (rather than content demands) explains 3-year-olds' imitation performance in the cognitive and the motor–spatial imitation tasks, it is incumbent upon us to explain why novel motor–spatial content appears to be more difficult to imitate than novel cognitive content or familiar motor–spatial content. The copying of novel motor–spatial sequences likely requires the engagement of a dedicated imitation mechanism, one that resolves a particular form of the (motor) correspondence problem (Nehaniv & Dautenhahn, 2002; Subiaul, 2010). Note that there is no motor correspondence problem in the cognitive task, as there's no motor response to match or imitate per se. What is imitated is a pure cognitive or ordinal rule. Children's success in the familiar motor–spatial imitation task may be explained by the dual processing route hypothesis (Rumiati & Tessari, 2002), where familiar responses bypass the motor correspondence problem by relying on either causal or inferential reasoning and/or semantic memory systems that prime linear action sequences.

Nonetheless, it remains an open question exactly how these dedicated motor–spatial imitation mechanisms operate and resolve the correspondence problem in novel and familiar motor–spatial imitation. We are not the first to grapple with this question, of course. Meltzoff and Moore (1977, 1997) proposed a supramodal mechanism that represents sensory and motor information in one common code. Mirror neurons are frequently cited as serving this very function (Cattaneo & Rizzolatti, 2009; Rizzolatti, 2005) and may ultimately explain different forms of imitation across content domains. However, Lingnau, Gesierich, and Caramazza (2009) have demonstrated that mirror neurons play an active role in familiar but not novel imitation. Consequently, while a supramodal mechanism like mirror neurons may be necessary to resolve some types of the correspondence problem, such a mechanism is unlikely to resolve all forms of the correspondence problem, as Subiaul (2010) and Nehaniv and Dautenhahn (2002) have reasoned.

The present work builds on this literature by highlighting significant dissociations between different forms of learning and different forms of imitation. But in contrast to the developmental and cognitive neuroscience literature, the present study goes beyond a global dissociation between novel and familiar imitation and argues that there are likely to be many other specialized imitation mechanisms each mediating the imitation of different content types, including novel motor and novel cognitive imitation. But we imagine that there are multiple novel motor and novel cognitive imitation mechanisms that specialize in the copying of different motor–spatial and cognitive contents. If this hypothesis is correct, one should expect instances where children do imitate novel motor rules. For instance, the novel motor–spatial mechanism described here is unlikely to mediate the imitation of novel manual gestures. But within the domain of artifacts, the results reported here closely match those from other laboratories who have consistently demonstrated various developmental discontinuities in the imitation performance of 3- and 4-year-olds (McGuigan & Whiten, 2009; McGuigan, Whiten, Flynn, & Horner, 2007; Want & Harris, 2001).

The present work sheds new light on the development of imitation by providing researchers with both a conceptual framework and a methodological tool to explore the independence of specific imitation mechanisms and the relationship of these to the operations of other cognitive and learning processes. However, any final judgment on the domain-specificity of imitation must be tempered by the fact that all studies have limitations, including the ones reported here. While the pattern of dissociations reported is consistent with the hypothesis of multiple specialized (domain-specific) mechanisms mediating the learning and imitation of motor–spatial content (Subiaul, 2010), the present study cannot say anything else about the nature of these mechanisms. As a result, we cannot fully explain why 3-year-olds, despite their competence in the motor–spatial domain (cf. Figure 2), fail to imitate novel motor–spatial sequences. Moreover, the present studies cannot answer whether performance in the motor–spatial or the cognitive task predicts performance in object-based tasks. But we hypothesize that performance in these tasks, particularly the novel motor–spatial task, may predict performance in tasks that involve novel actions on objects with tools (e.g., Bauer, 1992; Lyons, 2009; McGuigan et al., 2007) rather than tasks that involve a (single) manual action on an object (e.g., Gergely et al., 2002; Meltzoff, 1988a). A related question that the present study does not fully address is the role of specific experiences on imitation performance. For instance, do experiences tracing, drawing, or writing improve novel motor–spatial imitation?

Addressing these questions will not be easy. But doing so has the promise of transforming core assumptions in the cognitive and developmental sciences as well as in clinical and educational practices. Specifically, the systematic study of imitation employed here may further the understanding of the cognitive architecture of the imitation faculty and its development. Such knowledge may provide clinicians and educators alike with a powerful tool to predict the conditions and tasks under which children optimally learn on their own and from others.

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