JOURNAL OF COGNITION AND DEVELOPMENT, 00(00):1–23

ISSN: 1524-8372 print/1532-7647 online
DOI: 10.1080/15248372.2015.1053483

Defining Elemental Imitation Mechanisms: A Comparison of Cognitive and Motor-Spatial Imitation Learning Across Object- and Computer-Based Tasks

Francys Subiaul
The George Washington University, Center for the Advanced Study of Hominid Paleobiology, GW Institute for Neuroscience, National Museum of Natural History

Laura Zimmermann
Georgetown University

Elizabeth Renner and Brian Schilder
Center for the Advanced Study of Hominid Paleobiology

Rachel Barr
Georgetown University

Abstract

During the first 5 years of life, the versatility, breadth, and fidelity with which children imitate change dramatically. Currently, there is no model to explain what underlies such significant changes. To that end, the present study examined whether task-independent but domain-specific—elemental—imitation mechanism explains performance across imitation tasks or domains. Preschool-age children (n = 156) were tested on 4 imitation tasks, 2 object-based (animal, puzzle box) and 2 computer-based (cognitive, motor-spatial). All tasks involved 3 serial actions. The animal task involved making an animal face, and the puzzle box task involved manipulating a box to retrieve a reward. The cognitive task involved responding to 3 different pictures in a specific picture order, and the motor-spatial task involved responding to 3 identical pictures in a specific spatial order. A principal component analysis including performance on all 4 tasks produced 2 components: "cognitive imitation" (cognitive and animal tasks) and "motor-spatial imitation" (motor-spatial and puzzle box tasks). Regression analyses replicated these results. These findings provide preliminary support for the hypothesis that underlying performance across these different tasks involves multiple—elemental—imitation mechanisms for learning and copying domain-specific information across tasks.

Correspondence should be sent to Francys Subiaul, 2115 G Street, NW # 204, Washington, DC 20052, USA. E-mail: Subiaul@gwu.edu

Color versions of one or more of the figures in the article can be found online at http://www.tandfonline.com/hjcd.

INTRODUCTION

Imitation, the ability to learn and replicate others' responses and knowledge, is essential to cognition and development. Its importance is evidenced by the fact that imitation has been used to assess everything from learning and memory (Barr & Hayne, 2000; Bauer & Mandler, 1989) to causal (Bauer, 1992) and statistical (Schulz, Hooppell, & Jenkins, 2008) reasoning to social development and behavior (Bandura, 1977; Chartrand & Bargh, 1999). Imitation has also been instrumental in treating cognitive and linguistic deficits in special populations with developmental disorders such as individuals with autism (Ingersoll, 2011; McDuffie et al., 2007). The use of imitation tasks to assess and treat cognitive and developmental disorders demands a better understanding of the nature of imitation itself. Yet it is unclear whether imitation performance can be predicted across different tasks with any reliability. Some studies have shown that early in development (12–24 months of age), imitation performance correlates across relatively simple tasks that include clapping, banging blocks, and making simple sounds (Rogers, Hepburn, Stackhouse, & Wehner, 2003; Young et al., 2011). Others studies have demonstrated that later in development (older than 24 months of age), there are both age-related and task- or content-related differences in imitation performance (McDuffie et al., 2007; Rumiati & Tessari, 2002; Subiaul, Anderson, Brandt, & Elkins, 2012; Subiaul, Patterson, Renner, Schilder, & Barr, 2014; Tessari, Canessa, Ukmar, & Rumiati, 2007; Vanvuchelen, Roeyers, & De Weerdt, 2011). For instance, Vanvuchelen et al. (2011) tested more than 400 preschool-age children on a variety of object-based tasks and reported four distinct imitation components corresponding with imitating single actions, goal-directed actions, sequential action gestures, and non-goal-directed actions. Subiaul et al. (2010, 2012, 2014) have also suggested that there might be distinct imitation mechanisms underlying imitation performance across tasks. In one study, they demonstrated that preschoolers' imitation performance on a computer-based motor-spatial task and their performance on a computer-based cognitive task were not associated with one another. In another study, they showed that children who excelled in cognitive imitation failed to imitate in motor-spatial imitation.

Such seemingly contradictory results—a single imitation component versus multiple imitation components—is partly due to the fact that we do not have a clear understanding of the elemental components or essential cognitive processes underlying imitation performance and how these components map onto tasks. Even less is known about how such processes interact during the course of development. Resolving this impasse is made difficult by the fact that there is no standard imitation task or procedure used across studies, which is unusual. Most areas within the cognitive sciences have "gold standard" tests: the Flanker (Eriksen & Eriksen, 1974) and Stroop (Stroop, 1935) Task in attention and executive control research, the Digit Span Task in working-memory research (Humstone, 1919), the Sally-Anne Task in theory-of-mind research (Wimmer & Perner, 1983), and the Heider and Simmel Task and the Michotte Tasks (Heider & Simmel, 1944; Michotte, 1946) in agency and causality perception research, to name a few. Importantly, there is general agreement in most of these areas about the underlying constructs that such tasks measure. For example, executive-functioning tasks measure a range of skills from inhibitory control to working memory to set shifting; researchers have found significant associations between different tasks clustering around the content domains they are supposed to assess (Bauer & Zelazo, 2013; Best & Miller, 2010; Garon, Bryson, & Smith, 2008). The same cannot be said about imitation or social-learning research. The neuropsychological literature represents an exception. See Goldenberg (2009) for a review.

The fact that traditional imitation research in the developmental sciences has used a variety of toy-like tasks (henceforth, object-based tasks) to answer research questions across a number of cognitive domains and a wide age range speaks to its many advantages. One of the major advantages is that tasks for preverbal infants are ecologically valid, designed to be contextually similar to everyday experiences for very young children. Consequently, participation and engagement with these tasks are high and attrition is low, thereby allowing for a wide range of children to be tested. Other tasks used to measure infant cognition, such as habituation and Q3 conditioning measures, have much higher attrition rates (see Rovee-Collier & Barr, 2010). Unfortunately, object-based tasks have several significant limitations. Besides not being scalable from younger to older children and adults, object-based tasks can rarely be used to discern different types of learning (social and asocial/individual) within subjects. And, it is difficult if not impossible, to control for differences in affordances, familiarity, or top-down knowledge Q4 between objects. For example, Lyons et al. (2007) used three different object-based tasks ("puzzle box," "cage," and "dome") to assess "overimitation" or high-fidelity imitation that includes the imitation of causally irrelevant actions. These tasks were modeled after tasks used by various researchers (e.g., McGuigan, Whiten, Flynn, & Horner, 2007). Although children overimitated in all three tasks, the number of imitators in the cage task was nearly half that reported for the puzzle box. Such discrepancies may stem from the fact that coders can more easily discern some responses than others or that some actions are less complex than others to learn and replicate. Whatever the case may be, such results raise important questions about task generalization, but more importantly, about the content validity of commonly used imitation tasks.

An alternative to object-based tasks is to use computerized, touch-screen paradigms. Although relatively rare in developmental psychology, touch screens have been used to investigate learning in 11-month-olds (Ayoun, 1998), visual search in 1- to 3-year-olds (Gerhardstein & Rovee-Collier, 2002), and spatial search in 2- to 4-year-olds (Sutton, 2006). Touch screens have also been used to study imitation in typically developing 1-year-olds (Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009; Zack, Barr, Gerhardstein, & Meltzoff, 2013), 2- to 4-year-olds (Subiaul et al., 2012; Subiaul, Romansky, Cantlon, Klein, & Terrace, 2007), and individuals with autism (Subiaul, Lurie, et al., 2007). Computerized imitation paradigms overcome many of the limitations associated with object-based tasks. First, they do not require human coders, as the program records all responses, correct and incorrect. Second, they precisely and objectively isolate the imitation of specific types of information (i.e., specific items touched, number of responses, errors, reaction time, etc.). Third, these computerized imitation paradigms allow for the experimental control of task complexity by manipulating cognitive load (e.g., sequence length) without altering the task itself, something that is difficult to do with traditional object-based tasks (Subiaul & Schilder, 2014). These features allow researchers to use the same task to assess different forms of learning within subjects (e.g., Subiaul et al., 2012, 2014). Although children typically learn less from video and touch screens than from object-based interactions with real experimenters—termed the transfer deficit (Barr, 2013; Roseberry, Hirsch-Pasek, Parish-Morris, & Golinkoff, 2009; Zack et al., 2009, 2013)—they can learn very well when the social and perceptual contingencies are matched, such as when the demonstration and imitation phase occur within the same dimension and both involve a

Q17 touch screen (Moser, Gerhardstein, Zimmermann, Grenell, & Barr, in press; Roseberry, Hirsch-Pasek, & Golinkoff, 2014; Zack et al., 2009, 2013). The wide applicability of this technology (infants and adults, clinical and nonclinical, humans and nonhuman animals) gives this approach broad interest and usefulness (Terrace, 2005).

Computerized paradigms are often criticized for lacking ecological validity, and some question whether computer-based task performance mirrors performance with three-dimensional (3D) objects. Although it is certainly true that computer-based tasks are not as ecologically valid as object-based tasks, children are very much motivated to interact with both. The ubiquity of iPhones and iPads among other touch-enabled devices across the globe has made the use of this technology common in the lives of children (Radesky, Schumacher, & Zuckerman, 2015). In fact, research has shown that use of touch-screen technology starts at a young age and is rapidly increasing. As of 2013, a nationally representative sample of 2- to 4-year-olds showed that 80% used a touch-screen device compared with 39% in 2011; smartphones are the most frequently used touch-screen device (51% have used them at least once), although tablets are close behind at 44% (Rideout, 2013). This trend is only likely to increase as schools have begun to incorporate smartphones and tablets in preschool classrooms to promote learning (Malone, 2011). The lack of ecological validity should not prevent researchers from adopting a tool, particularly if performance is more stable across participants, generalizes to other tasks, and more accurately measures underlying constructs.

The main aim of the present study was to test whether imitation performance on object-based tasks and computer-based tasks can be supported by two “elemental” imitation mechanisms. These elemental mechanisms are predicted to mediate fundamental or essential computations involving the copying of item-specific rules, or “cognitive imitation,” and action/spatial-specific rules, or “motor-spatial imitation” (Subiaul, 2010; Subiaul et al., 2012).

The study is designed to examine whether motor-spatial and cognitive elements emerge across tasks. To test this hypothesis, we compared performance on two computerized touch-screen imitation tasks, cognitive and motor-spatial (Figure 1), to performance on two object-based tasks, puzzle box and animal (Figure 2). The computer- and object-based tasks all involve three arbitrary responses to achieve a goal. We chose tasks that involved multiple responses because simple imitation tasks that require a single (or familiar) response may be explained by other social-learning processes such as stimulus/local or social enhancement (for a review, see Want & Harris, 2002). More complex, multistep, object-based sequences and tool-based tasks provide a more robust index of imitation learning in preschoolers (Subiaul et al., 2012; Want & Harris, 2002).

We chose 2.5- to 4.5-year-olds because there is mounting evidence of a developmental change in the fidelity of imitation in this age range (Dickerson, Gerhardstein, Zack, & Barr, 2013; McGuigan, Makinson, & Whiten, 2011; McGuigan et al., 2007; Moser et al., in press; Nielsen, 2006; Nielsen, Moore, & Mohamedally, 2012; Sherwood, Subiaul, & Zawidzki, 2008; Subiaul et al., 2012). In addition, age-related imitation changes have been independently documented with variations of these tasks (Herbert & Hayne, 2000; McGuigan et al., 2007; Nielsen, 2006; Subiaul et al., 2012, 2014). Because tool-based tasks involve complex motor-spatial responses that are developmentally constrained, failure to imitate in such tasks may be explained by limitations in motor performance rather than imitation competence. To reduce potential problems of poor motor performance, we tested children older than 2 years of age. To avoid ceiling effects, we tested children younger than 5 years of age.

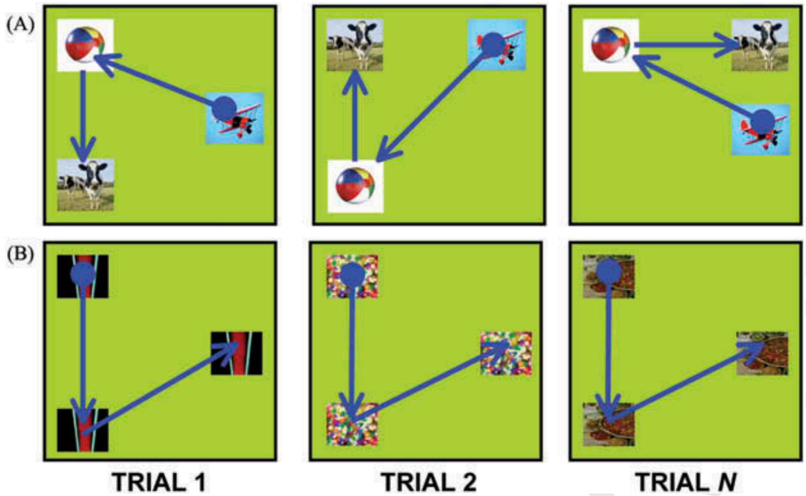


FIGURE 1 Computer-based tasks. A) Cognitive task. Three different pictures appear simultaneously on the screen. On each trial, their spatial configuration varies, while their identity remains the same. Children must respond to each picture in a target order while ignoring their spatial location. B) Motor-spatial task. Three identical pictures appear simultaneously on the screen. On each trial, their spatial configuration remains the same, while the identity varies. Children respond to target locations on the screen (as demonstrated) while ignoring the identity of pictures.

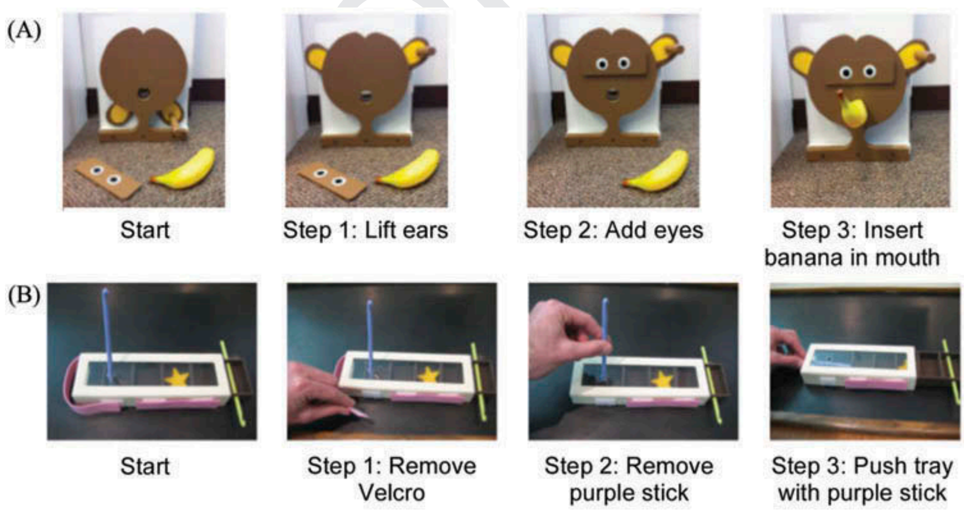


FIGURE 2 Object-based tasks. A) Animal task. The task is to create an animal shape in three steps (monkey shown, rabbit not shown). B) Puzzle box task. The task is to retrieve a star from inside the box. There are two sticks (purple relevant, green distractor) and a distractor piece of Velcro attached to the side of the box.

The “elemental” hypothesis predicts strong associations among tasks requiring the imitation of item-specific content rules (e.g., animal task and cognitive task) and associations among tasks requiring the imitation of action/spatial-specific content rules (e.g., puzzle box and motor-spatial task) but predicts no association between the two “elemental” content types. The predicted associations between the computer- and the object-based tasks are based on task features. The object-based animal and computerized cognitive imitation tasks include semantically meaningful —item-specific—information that can be easily labeled. For example, children could identify and name the eyes and ears necessary to make a face in the animal task, or they could identify and name individual photographs of familiar items in the computerized cognitive task (e.g., airplane, balloon). The motor-spatial and puzzle box tasks involve motor-spatial transformations that cannot be as easily labeled during early childhood (Huttenlocher, Newcombe, & Sandberg, 1994; Lakusta & Landau, 2005). Given that previous studies have shown that cognitive and motor-spatial imitation in the computer tasks were not significantly associated (Subiaul et al., in press), we also predicted that the puzzle box and animal tasks would not be significantly associated with one another.

We contrasted this elemental hypothesis with two alternative hypotheses: the unitary model and the task-specific model. The unitary model of imitation assumes that domain-general—universal—learning processes underlie all imitation performance (e.g., Heyes, 2012). As such, this hypothesis predicts significant correlations across tasks, regardless of task type (i.e., object- or computer-based) or representational content (i.e., item- or action/spatial-specific). The task-specific model assumes that each task has unique representational and response/action requirements. It may be the case that actions with 3D “real-world” objects are represented differently than actions on two-dimensional (2D) picture items presented on a touch screen (e.g., Subiaul, 2010). For instance, while 3D “real-world” objects can be held and manipulated and are associated with unique (or distinguishing) haptic experiences and affordances, 2D picture items cannot be manipulated and lack unique haptic experiences. That is, in contrast to 3D objects, different 2D items provide the same haptic experience. As such, the task-specific model predicts strong associations between object-based tasks (animal and puzzle box) and between computer-based tasks (cognitive and motor-spatial), but it predicts no association among task types in contrast to the elemental hypothesis. The three competing models and the predicted associations for each task in each model are summarized in Table 1.

TABLE 1
Three different models of associations between tasks: The different predictions made by each model about the possible associations between tasks and domains

	Models		
	Unitary model	*Task-specific model*	*Elemental model*
Component 1	Cognitive task, motor-spatial task, animal task, puzzle box task	Cognitive task, motor-spatial task	Cognitive task, animal task
Component 2	N/A	Animal task, puzzle box task	Motor-spatial task, puzzle box task

METHODS

Participants

This study included 156 typically developing children (77 boys). Children were recruited at the Smithsonian Institute's National Zoological Park. Independent groups of children were tested at each of the following ages: 2 years (N = 34, M_{age} = 2;8, SD = 2.03 months), 3 years (N = 72, M_{age} = 3;5, SD = 3.5 months), and 4 years (N = 50, M_{age} = 4;5, SD = 3.4 months). Participants were primarily Caucasian (64.7%).

Additional children (N = 39) were excluded from the analysis for failure to complete at least three tasks (n = 36), 1 was excluded because of experimenter error on one task, and 2 were excluded due to parental interference.

Apparatus

There were four different imitation tasks, two computer-based and two object-based.

Computer Tasks (Figure 1)

Children were presented with two different computerized imitation tasks: a cognitive task and a motor-spatial task (Figure 1). In each, picture items were displayed simultaneously throughout each trial on a MagicTouch detachable touch-sensitive screen that was placed in front of an Apple iMac monitor. In the cognitive task,[1] the identities of the items on the screen were different from one another, and their positions on the screen were varied randomly from trial to trial (cf. Figure 1A). For example, three *different* pictures, including a list—A, B, C—appeared simultaneously on the touch-screen. Each picture had to be touched in a specific serial order A → B → C. From trial to trial, the pictures appeared in different spatial positions. In contrast, in the motor-spatial task,[2] the identities of the items on the screen were identical and their positions on the screen remained constant throughout the testing period. However, from trial to trial, the identities of the pictures changed (cf. Figure 1B). For example, three identical pictures—A, A, A—appeared simultaneously on the touch screen. Each picture had to be touched in a specific motor-spatial pattern: $A^{top} \rightarrow A^{bottom} \rightarrow A^{right}$. From trial to trial, a *different* set of identical pictures—B, B, B—appeared in the same spatial position and had to be touched in the same motor-spatial pattern as in the previous trial: $B^{top} \rightarrow B^{bottom} \rightarrow B^{right}$.

Both computer tasks used a 4 × 4 template in which pictures could appear in any of 16 nonoverlapping positions on the screen. During testing, only "novel" lists were used. Novel lists of pictures for the cognitive task appeared in random configurations on the touch screen that varied from trial to trial; novel lists of pictures for the motor-spatial task consisted of three identical pictures that changed randomly from trial to trial but always appeared in the same positions. Lists used in the motor-spatial task always involved a change in direction (e.g., up, down, right). None of the lists were ever repeated between conditions.

[1] Video of cognitive task: https://www.youtube.com/watch?v=XzwOMF8W5Wc
[2] Video of motor-spatial task: https://www.youtube.com/watch?v=W8pjTME_ugY

On both computer tasks, whenever children touched a picture item, they received feedback from the computer and the experimenter as to whether they were correct or incorrect. Picture items were presented on a 54.61-cm screen Macintosh desktop computer with a Magic-Touch detachable screen. List items used throughout testing were composed of colored images (3.81 cm × 5.08 cm). Each task employed a different list of pictures to avoid any confusion.

Object-Based Tasks (Figure 2)

There were two object-based tasks, animal and puzzle box. Two forms of the animal task (Figure 2A) were used: rabbit and monkey. The stimuli for the rabbit consisted of two plastic eyes (3 cm × 2 cm) attached to a 9-cm × 6-cm magnet, a 12-cm orange and green plastic carrot, and a gray circle of wood (the head, 15 cm in diameter) mounted horizontally on a gray rectangular wooden base (30 cm × 20 cm). A 3-cm-diameter hole was drilled at the bottom of the head. Two gray "ears" (20 cm × 5 cm) decorated with stripes of white paint were hidden behind the head. A button on the top of the rabbit when pressed raised the ears above the head. The stimuli for the monkey consisted of two plastic eyes (2.5 cm in diameter) that were attached to a brown rectangular magnet (9 cm in width, 6 cm in height), a 20.5-cm yellow plastic banana, and a brown circle of wood (the head) mounted horizontally on a brown wooden base (22 cm × 38 cm). A 4-cm hole was drilled at the bottom of the head. Two brown ears (3.5 cm × 7 cm) decorated with a piece of yellow wood were hidden behind the head. A 3-cm lever on the top, attached to the right ear, allowed the ears to be pulled up from behind the head in a circular motion to the side of the head. Separate video demonstrations of the target actions for the rabbit and monkey were recorded. During the video demonstration, an adult (with only the hands shown) model assembled an animal face three times. The order of these items was arbitrarily related, and they were not causally yoked to one another.

Puzzle Box Task (Figure 2B). The puzzle box task was adapted from previous tasks (Horner & Whiten, 2005; McGuigan et al., 2007). There were two different versions of the box (dimensions: 21.59 cm × 6.99 cm × 3.33 cm)—white and brown—which were counterbalanced across participants (Figure 2B). Three target actions were required to retrieve a felt star from either the brown box or the white box. For the white-box version, the target actions were to: a) remove the Velcro loop (23 cm), b) remove the purple stick (15 cm), and c) push the inner chamber from left to right to remove the yellow star sticker. The green stick and other Velcro pieces (c) were distractor items that were irrelevant to completing the task of retrieving the star. In the brown-box version, the target actions were: a) remove the green stick (15 cm), b) remove the purple stick (15 cm), and c) push the inner chamber from right to left to remove the red star. The three Velcro pieces were distractor items. Video demonstrations of the target actions for each box were recorded separately. During the video demonstration, an adult (with only the hands shown) retrieved the star three times.

Design

We used a mixed design that included two different age groups derived by median split (younger than 3;7, older than 3;7) randomly assigned to two conditions (social learning, trial-and-error) as between-subject factors and four different tasks (cognitive, motor-spatial, animal, puzzle box) as

TABLE 2
Experimental design

Between-subjects	*Within-subjects task*			
Groups	Computer-based tasks		Object-based tasks	
Social learning	Cognitive	Motor-spatial	Animal	Puzzle box
Trial & error	Cognitive	Motor-spatial	Animal	Puzzle box

a within-subjects repeated measure (Table 2). We compared the baseline rate of performance on each task (trial-and-error condition) to performance in the social-learning condition, where a model demonstrated the target responses for each task prior to testing.

Procedure

Participants were recruited and tested in the Think Tank at the Smithsonian Institute's National Zoological Park. The battery of tasks was completed in a single session lasting 10 min to 15 min per child. In the social-learning condition, children saw three demonstrations of the target actions for each task, which took a maximum of 60 s to demonstrate. Children were then given a test period on each task. The trial-and-error group was not provided with a demonstration but did participate in the test phase of the four tasks. Each child received either the rabbit or the monkey (but not both) for the animal task and either the white or the brown version (but not both) of the puzzle box task. The order of all four imitation tasks was fully counterbalanced across participants. Counterbalancing ensures that any statistical significance in our results is not a product of the order in which children participated in each imitation task, because all possible orders are equally represented in the final data set. The protocols for the touch screen and the object-based tasks are described in the following paragraphs.

Training and Testing for Computer-Based Tasks

Following the protocol developed by Subiaul et al. (2012), participants in both the social-learning and trial-and-error groups were trained on each task (cognitive, motor-spatial) prior to the demonstration and test phases of the experiment. Training ensured that group performance did not reflect any lack of familiarity with the touch screen, experimenter, or procedure. During training, children were exposed to each task and were encouraged to "find 'Jumping Man'" by touching the pictures in a target order (cf. Figure 1A, 1B). Children received social feedback from the model and asocial (audio, visual) feedback from the computer following each response, whether correct or incorrect. An incorrect response terminated the trial. Incorrect trials generated a brief (~500 ms) "whoosh" sound, all pictures disappeared, the screen turned black for 2 s, and the experimenter said, "Whoops! That's not right!" Following a correct response, the computer generated a brief (~500 ms) "bing" sound, all pictures remained on the screen, and the experimenter said, "That's right!" When all three pictures were touched in the correct order, a 5-s video clip of a man doing a backward somersault—"Jumping Man"—played in the middle of the screen accompanied by music or clapping, and the model smiled and said, "Yay! You found Jumping Man!" To advance to testing, children had to independently respond to all three pictures on the screen in the target order without making any errors. In each condition, children were allowed up to 10 trials to touch all three pictures in the target order. However, once the child responded correctly to all three pictures (i.e., first correct trial) on two separate trials, they moved on to the next imitation task.[3]

Social-Learning Group. The experimenter faced the child and said, "Watch me!" and then proceeded to touch pictures in the target sequence (e.g., A → B → C) three consecutive times. After having touched all three pictures in the correct order after the first demonstration, the computer played "Jumping Man" accompanied by music. While "Jumping Man" was playing, the experimenter turned back to the child, smiled, clapped, and said, "Yay, I found Jumping Man!" The model repeated this procedure for two more trials (total of three demonstration trials). Immediately after the third and final demonstration, the experimenter faced the child and exclaimed, "Yay! I found Jumping Man! OK, now it's your turn. Can you find Jumping Man? Remember, start with Picture Number 1." If the child did not discover the correct sequence, the total number of recorded trials was capped at 10 trials.

Trial-and-Error Group. Children were tested on novel lists using the cognitive and motor-spatial tasks. Following the training phase, at the start of testing, children were encouraged to touch the pictures to find "Jumping Man" to discover the correct sequence entirely by trial-and-error learning.[4] If children touched the wrong picture, the pictures disappeared, the screen turned black (2 s), and the experimenter said, "Whoops, that's not right." Once pictures reappeared on the screen, the experimenter said, "Try another picture." This procedure was repeated until the child made a correct response (to the correct picture in the cognitive task or the correct location in the motor-spatial task). Then the experimenter said, "That's right! You found Picture Number 1! What comes next?" If the child responded incorrectly, the procedures described earlier were repeated, but at the beginning of the trial, the experimenter added, "Remember, start with Picture Number 1." These procedures were repeated until the child touched all three pictures correctly and the Jumping Man video played, or until they completed 10 trials. If the child failed to discover the correct sequence within 10 trials, they were automatically moved to the next task. Performance on this condition was used to establish the spontaneous rate of sequence learning and was directly compared to the social-learning group performance.

Training and Testing for Object-Based Tasks

Children did not receive any prior training or familiarization with the objects prior to testing.

Social-Learning Group. Procedures for the object tasks also included three demonstrations. At the beginning of the session, the experimenter played a video demonstration on the same computer screen that was used for the touch-screen tasks. The video was of an adult modeling the three target actions on either the animal task or puzzle box task. The target actions

[3] A subset of 30 children did not complete the training phase for the cognitive and motor-spatial touch-screen tasks. Their scores were compared to the scores of those who completed the training phase and did not differ on any measure (*p*s > .80). Data were collapsed across children for all analyses.

[4] Both the model and the computer provided feedback following each response to equate other factors that might influence performance across tasks and conditions. Specifically, social feedback consisted for eye contact, smiles, etc., and verbal reinforcement (e.g., "That's right!" or "Oops! That's not right!").

were demonstrated three times. The verbal cues (also on video) were, “Look at this!” before the first demonstration (to capture participants’ attention); “Wasn’t that fun?” after the first demonstration; and “One more time!” after the second demonstration. At no point in the video did the video model label any parts of the animal or puzzle box stimuli. At the end of the video, the model said, “Your turn.” If the child appeared distracted while viewing the video, the experimenter redirected their attention to the video with a gesture. The experimenter turned off the video and handed the objects (either the assembled puzzle box or the unassembled animal with corresponding parts) to the child and said, “Your turn.” The child then had 30 s to interact with the animal stimuli and 60 s to interact with the puzzle stimuli from the time that he/she first touched any of the objects. A manipulation check was conducted after testing with both the animal and puzzle box tasks to ensure that the tasks were within the motor abilities of each child. During the manipulation check, the experimenter demonstrated the correct gestures and then gave the participant one more turn to complete the task.

Trial-and-Error Group. For these tasks, there was no demonstration of the target actions on the video. Experimenters handed children the objects for the animal or puzzle box task (either the assembled puzzle box or the unassembled animal with corresponding parts) and said, “Your turn.” Children were given the same amount of time as children in the other groups to spontaneously produce the target actions. During testing, the experimenter did not provide any additional instructions or prompting. If the child asked what to do, the experimenter simply repeated the instruction, “It’s your turn.” Parents were also instructed to allow the child to figure out the problem by themselves. A manipulation check was conducted after testing with both the animal and puzzle box tasks to assess motor abilities. The experimenter demonstrated the correct actions and then gave the participant one more turn to complete the task.

Coding

Imitation was operationally defined as performance significantly greater than trial-and-error performance (Barr & Hayne, 2000).

Measures of Learning on Computer-Based Tasks

The computer automatically recorded the sequence of behaviors for each trial on each touchscreen task. First-trial accuracy was measured as 0 or 1, meaning that the child completed the sequence accurately on the first trial or not, respectively. This protocol corresponds with those used in previous publications using this paradigm (Subiaul et al., 2012; Subiaul, Lurie, et al., 2007; Subiaul, Romansky, et al., 2007).

Measure of Learning on Object-Based Tasks

One coder scored each videotaped test session for the presence of the three target actions during the 30-s test period for the animal task and the 60-s test period for the puzzle box task. Q7 Using a protocol developed by Bauer et al. (2007), the order in which the target actions were reproduced was recorded for a maximum order score of 2 for the animal task and 3 for the puzzle box task. Participants were awarded 1 point for reproducing Behavior 1 followed by

Behavior 2, and they were awarded 1 point for reproducing Behavior 2 followed by Behavior 3. For the puzzle box task, they were awarded an additional point for reproducing Behavior 3 and then Behavior 4. Like first-trial accuracy for the computer tasks, the order score accounted for reproduction of actions in the accurate order but also allowed for the fact that there were more affordances to the object-based tasks. First-trial accuracy was calculated for object-based tasks as well. The first three behaviors reproduced by children during the test phase were coded. For the puzzle sequence, which was constrained by the target order, children received a score of 1 if they reproduced the target actions in the correct order to retrieve the star. For the animal task, however, unlike the other three tasks, there were no constraints on target order to achieving the goal; the sequence order was arbitrary as it was possible to complete the target actions in any order and still complete the animal face. Therefore, children were given a score of 1 if the first three behaviors reproduced were the target behaviors and were given a score of 0 if they did not reproduce the target behaviors. A second independent coder scored the videos to determine reliability of the ratings; based on 15% of the data, interrater reliability for the animal task was high (kappa = .95), and based on 23% of the data, interrater reliability for the puzzle box task was also high (kappa = .88).

These measures were chosen for a number of reasons. First, after the first trial, learning may be achieved by imitation, individual learning, or both (e.g., (Boutin, Fries, Panzer, Shea, & Blandin, 2010; Boutin, Panzer, Salesse, & Blandin, 2012). As such, commonly used measures that sum up target responses or average the "best" performance across multiple trials are not ideal measures because they inherently confound individual (operant) learning with imitation (observational) learning. Second, while first-trial accuracy has been used to assess imitation learning in computer tasks, first-trial accuracy is rarely used for object-based tasks. We reasoned that although not ideal, comparing performance using measures that are both rigorous and commonly used would make the results reported here more generalizable to the existing developmental and comparative social-learning literatures. Moreover, order scores and first-trial accuracy were highly correlated in object-based tasks (box, $r = .55$, $p < .001$; animal, $r = .93$, $p < .001$, Pearson correlation). Nonetheless, we report first-trial accuracy for both object- and computer-based tasks in addition to the more common measure, order scores, for the object-based tasks.

RESULTS

The order scores for the animal and puzzle box tasks were first transformed into proportions (score/max order score) to allow for direct visual comparison to the first-trial accuracy scores for the computer-based cognitive and motor-spatial tasks. The results of the social-learning and trial-and-error groups as a function of age group (younger than 3;7 vs. older than 3;7), derived on the basis of a median split, are presented in Figure 3.

The order scores for the animal task and puzzle box task and the first-trial accuracy for the cognitive and motor-spatial tasks were compared to one another as a function of age group and conditions (social-learning and trial-and-error) using nonparametric tests because task performance was not normally distributed. Using Mann Whitney U tests for independent samples ($p < .05$), for the younger age group, there was a significant difference between the social-learning and trial-and-error groups for the animal task and the puzzle box task ($ps < .001$), but not the

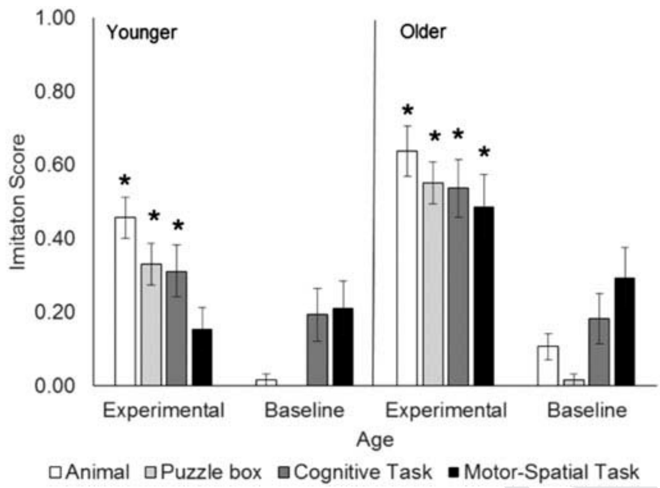
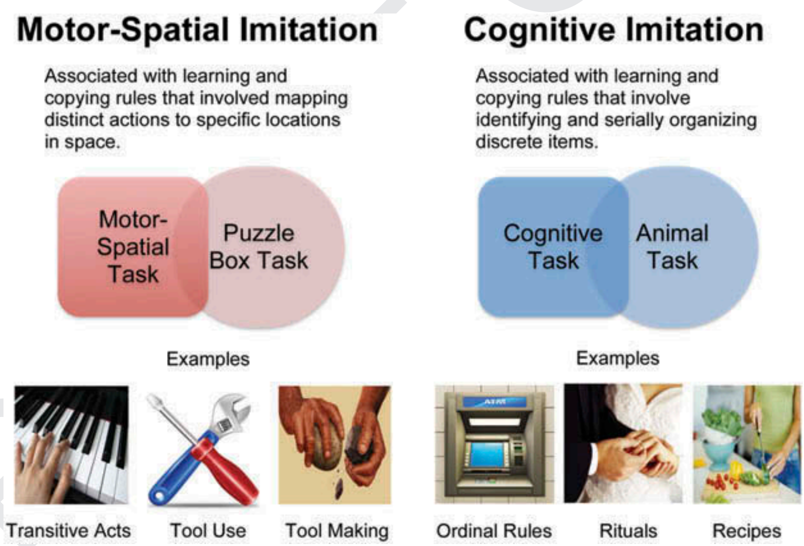


FIGURE 3 Mean imitation (± 1 SE) order scores of the object-based tasks (proportions) and first-trial accuracy of the touch-screen-based tasks as a function of group and age. An asterisk indicates that the experimental group performed significantly better on the task than the baseline control group.



Q15 FIGURE 4 Summary of associations between computer- and object-based tasks. Possible everyday problems that might differentially engage cognitive and motor-spatial imitation mechanisms.

cognitive and motor-spatial tasks (*ps* > .3). For the older age group, there was a significant difference between groups on all tasks (*ps* < .001) except the motor-spatial task (*p* = .11). Results did not differ when using first-trial accuracy for the object-based tasks.

Correlational Analysis

Are Tasks Related to One Another in the Experimental Groups?

Preliminary results showed that sex of the child did not correlate with performance. As such, sex was excluded from further analyses. Age was significantly correlated with imitation performance on all tasks (all *r*s > .23, all *p*s < .02). A partial correlation that included correlations between the order scores for the two object-based tasks and first-trial accuracy for the computer-based tasks, while controlling for the age of the child in months, showed that the object-based tasks were negatively associated with one another. The computer-based tasks were not associated with one another, but there was a trend for the cognitive task to correlate with the animal task and a significant correlation between the motor-spatial task and the puzzle box task performance (see Table 3). A similar pattern of results emerged when using first-trial accuracy for the object-based tasks, except that the first-trial accuracy of the animal task was significantly related to cognitive task first-trial accuracy and marginally related to motor-spatial and cognitive task first-trial accuracy. Once again object-based tasks were not related on this measure.

Principal Component Analysis

To more thoroughly assess associations between tasks, we performed a principal component analysis (PCA) with Promax rotation to allow for associations between variables (n = 50) on animal task order, puzzle box task order, cognitive task first-trial accuracy, and motor-spatial task first-trial accuracy (KMO = .50, $\chi^2(6) = 16.86$, p = .01, Barlett's Test of Sphericity). The analysis yielded two factors with an eigenvalue greater than 1.00, which together explained 70.14% of the cumulative variance. The cognitive task and animal task variables loaded onto the first factor (with rotated factor loadings > .78), and the motor-spatial and puzzle box task variables loaded onto the second factor (loadings > .80). One component corresponded with "cognitive imitation" that included imitation performance in the cognitive and animal tasks (eigenvalue = 1.34). The second component corresponded with "motor-spatial imitation" that included imitation performance in the motor-spatial and puzzle box tasks (eigenvalue = 1.46). Results were the same when using first-trial accuracy for the object-based tasks. Again, there were two factors—cognitive and motor-spatial—with an eigenvalue greater than 1.00, which together explained 71% of the cumulative variance. The cognitive imitation component (eigenvalue = 1.61) included the cognitive and animal tasks (with rotated factor loadings > .75), while

TABLE 3
Partial correlation table (correcting for age, *df* = 47)

	Animal order	*Animal first*	*Puzzle box order*	*Puzzle box 1st*	*Cognitive task*	*Motor-spatial task*
Animal order	—	.52**	–.30*	–.29*	.26†	–.056
Animal first	—	—	.09	–.01	.35*	.24†
Puzzle box order	—	—	—	.69**	–.06	.30*
Puzzle box first	—	—	—	—	–.20	.27†
Cognitive task	—	—	—	—	—	.16

*p < .05. †p < .10.

Q27 *Note.* Significant correlations (p < .05) and trends (p < .10) are bolded.

TABLE 4
Pattern matrix: Principal component analysis using the Promax rotation methods with Kaiser normalization.

	First-trial accuracy			*Order score*	
Imitation task	*Component 1*	*Component 2*	*Imitation task*	*Component 1*	*Component 2*
Cognitive	.820		Cognitive	.792	
Animal	.781		Animal order	.781	
Motor-spatial		.866	Motor-spatial		.814
Puzzle box		.719	Puzzle box order		.805

Note. Left: first-trial accuracy. Right: order score.

the motor-spatial imitation component (eigenvalue = 1.23) included the motor-spatial and puzzle box tasks (loadings > .65). Table 4 shows both models side by side.

Logistic Regression

To assess whether performance on one task predicted performance on other tasks, we conducted two logistic regressions, one with first-trial accuracy of the motor-spatial computer-based task as the outcome variable (motor-spatial model) and the other with first-trial accuracy of the cognitive computer-based task as the outcome variable (cognitive model). The age, in months, of the child and order scores for the object-based tasks were entered into both regressions. For the motor-spatial model (cf. Table 5), first-trial accuracy for the cognitive task was entered as a predictor variable, and for the cognitive model (cf. Table 6), first-trial accuracy in the motor-spatial task was entered as a predictor variable. Models were also run entering the first-trial accuracy measures instead of the order scores.

The motor-spatial model was significant, $\chi^2(4) = 12.36$, $p = .02$. In this model, the order score for the puzzle box task (OR = 2.17, $p = .03$) was a significant predictor of first-trial accuracy in the motor-spatial Task (see Table 5). That is, for every unit increase in the order score used for the puzzle box task, children were 2.17 times more likely to respond correctly on the first trial when tested on the motor-spatial task. No other variables were significant predictors of first-trial

TABLE 5
Motor-spatial imitation model: Results from logistic regression analysis of first-trial accuracy in the motor-spatial task

	First-trial accuracy				*Order score*			
	B	*SE*	*p value*	*Exp (B)*	*B*	*SE*	*p value*	*Exp (B)*
Age (months)	0.077	0.05	.10	1.08	0.06	0.05	.18	1.06
Cognitive	–1.02	0.81	.20	0.36	–1.02	0.726	.16	0.36
Puzzle box	1.97	0.91	.03	7.50	0.77	0.37	.03	2.17
Animal	1.61	1.02	.12	4.98	0.04	0.45	.93	1.04

Note. B = unstandardized estimates; SE = standard error; Exp (B) = odds ratio.

TABLE 6
Cognitive imitation model: Results from logistic regression analysis of first-trial accuracy in the cognitive task

	First-trial accuracy				*Order score*			
	B	*SE*	*p value*	*Exp (B)*	*B*	*SE*	*p value*	*Exp (B)*
Age (months)	0.05	0.04	.22	1.05	0.04	0.04	.27	1.05
Cognitive	–0.8	0.81	.34	0.47	–1.00	0.74	.20	0.39
Puzzle box	–0.09	0.32	.78	0.91	–0.09	0.32	.78	0.91
Animal	1.58	0.78	.04	4.85	0.69	0.40	.08	2.00

accuracy in the motor-spatial task. The overall accuracy of prediction by the model was 74%. The same pattern emerged when first-trial accuracy measures were used, $\chi^2(4) = 9.17$, $p < .03$.

There was a trend for the overall cognitive model to be statistically significant, $\chi^2(4) = 8.21$, $p < .08$ (Table 6). And although none of the variables in the model were significant, there was a trend for order scores in the animal task to be associated with first-trial accuracy in the cognitive task, such that with every unit increase in animal task order score, children were 2.00 times more likely to respond correctly on the first trial when tested on the cognitive task. The pattern of results did not change when using first-trial accuracy, but the model became significant, $\chi^2(4) = 9.40$, $p < .03$.

DISCUSSION

The present study sought to examine whether different elemental imitation mechanisms are associated with learning and copying content-based rules across tasks. Based on degree of ecological validity and measurement precision, respectively, researchers have been critical of computer- and object-based measurement of imitation. Moreover, it was assumed that both types of tasks would provide similar estimates of imitation, but until the present study, this assumption had not been directly tested. Consequently, the present study makes at least three unique contributions to the imitation literature. First, results show that performance on ecologically invalid computer-based tasks can predict performance on more ecologically valid object-based tasks. Second, and more importantly, imitation performance can be predicted by elemental mechanisms that are domain-specific but task-general. Specifically, the reported associations were not uniform or task-specific but, rather, domain-specific: Performance on object-based tasks and performance on computer-based tasks with cognitive content (i.e., semantically meaningful, nameable) were significantly associated, while performance on object-based tasks and performance computer-based tasks with motor-spatial content (i.e., location-based and non-nameable) were significantly associated. Finally, results show that although age was significantly associated with performance across tasks, the cognitive structure and pattern of associations between tasks did not differ in younger and older children. As such, developmental changes during the preschool years do not appear to affect the association between computer- and object-based tasks reported here.

These results across multiple analyses provided converging support for the hypothesis that there are multiple imitation mechanisms, some of which might be elemental, underlying performance across different tasks. For example, a PCA failed to show a single imitation component as might be predicted by a unitary model of imitation (Heyes, 2012; Young et al., 2011). Instead, PCA results produced two significant components. These components were not task-specific. Rather, one component corresponded with the imitation of item-specific content rules or "cognitive imitation" and included imitation performance on the cognitive and animal tasks. The second component corresponded with the imitation of action/spatial-specific rules or "motor-spatial imitation" and included imitation performance on the motor-spatial task and the puzzle box task. Partial correlations controlling for age revealed the same pattern of results. In the final set of analyses, logistic regression including age showed that in the motor-spatial imitation model, performance on the motor-spatial task—the most difficult of the imitation tasks as evidenced by children's relatively poor performance (cf. Figure 3)—was associated with performance on the puzzle box task. In a separate analysis, there was a trend in the cognitive imitation model for cognitive imitation to be associated with the animal task. These results show that performance on object-based tasks corresponds in predictable ways to performance on these two computerized tasks, which arguably assess the learning and copying of content-specific rules and responses. This pattern of results is consistent with the hypothesis that these two imitation mechanisms are, in fact, "elemental." That is, these mechanisms—cognitive and motor-spatial—appear to significantly contribute to fundamental or essential operations of imitation performance across different tasks, including 3D, complex objects. Finally, it is important to note that the pattern of results comparing first-trial accuracy measures typically used in computer-based tasks and the pattern of results comparing both first-trial accuracy and object-based task order score measures were highly consistent with one another. The only difference observed was likely due to the fact that the animal task is object-based and involved some motor-spatial manipulation and therefore showed a marginally significant partial correlation with the motor-spatial task as well as the cognitive task. Results for the logistic regression and the PCA did not differ across measures. Given the rapid adoption of touch-screen technology in home and educational settings (Malone, 2011; Radesky et al., 2015), the present findings are methodologically promising. In particular, such computer-based measures may be very conducive to the assessment of neural correlates of social learning due to the fact that they reduce motion artifacts and allow for multiple trials on the same apparatus.

Of course, we assessed performance on only two object-based tasks and not on every object-based task that has been used by social-learning researchers. Moreover, the present study does not contribute to our understanding about imitation in other domains such as communicative domains that include vocal and gestural imitation, which are nontransitive or do not involve direct actions on objects. So not only do these results need to be replicated and extended to at least a subset of other commonly used object-based tasks, but it is also necessary to assess what the relationship is between object- and computer-based and vocal- and gesture-based tasks, particularly because there is evidence suggesting that object-based, gestural and vocal imitation are associated with language development measures (e.g., Bates, Thal, Whitesell, Fenson, & Oakes, 1989). Other overlapping processes not measured in the present study, such as differences in language ability, exploratory behavior, inhibitory control, and working memory, may also contribute to task performance as they do with other specialized skills such as theory of mind (Wellman & Cross, 2001; Wellman, Lopez-Duran, LaBounty, & Hamilton, 2008) and language (Kousaie, Sheppard, Lemieux, Monetta, & Taler, 2014; Zelazo & Bauer, in press, 2013).

Finally, a potential limitation of the present study is that we did not collect information on the frequency with which participants used different types of media (television, video games, iPad and iPhone use). Consequently, we do not know whether there are individual differences between children exposed to media and those who are not. Although not a central question in the present study, it is certainly a question that deserves further study. Regardless, existing evidence is clear: Computer-based tasks are now regularly marketed to and used by preschool-age children (Lee, 2012).

Nonetheless, the current study suggests that while some tasks that involve learning novel responses engaged "cognitive" versus "motor-spatial" imitation mechanisms, other tasks might assess both of these mechanisms. Still others might engage neither mechanism. In particular, we expect that complex tasks that involve the serial identification of individual items and the manipulation of objects in space are likely to involve both elemental imitation mechanisms simultaneously, which can account for the partial correlations between the animal task and puzzle box task on the first-trial accuracy measures. Conversely, simple tasks, such as those commonly used to test children 2 years of age and younger might not engage either of these imitation mechanisms. We do not expect these imitation-learning mechanisms to be involved in tasks that require copying familiar or over-rehearsed actions, regardless of complexity. These tasks, while requiring individuals to imitate, confound novel imitation with familiar imitation. Such tasks are more likely to involve other learning processes such as goal emulation (Bekkering, Wohlschlager, & Gattis, 2000; Wohlschlager, Gattis, & Bekkering, 2003) or associative learning (Heyes, 2012; Ray & Heyes, 2011).

In very simple tasks, young children might use their prior knowledge of operating related objects and reproduce the demonstrated response via goal emulation or affordance learning, rather than imitation. Instances of "automatic imitation," where individuals cannot inhibit reproducing the actions of others, as in the rock, paper, scissors game (Cook, Johnston, & Heyes, 2013), are also unlikely to engage cognitive and motor-spatial imitation mechanisms because individuals are not learning novel responses; rather, they are recalling previously executed actions. In such instances, individuals are more likely using "familiar imitation" mechanisms (Subiaul, 2010) or truly associative—domain-general—learning processes (Heyes, 2011).

There is also evidence that the imitation of simple, familiar, or over-rehearsed actions engages different underlying neural mechanisms than the imitation of novel responses that are not already present in the behavioral repertoire of the individual. Whereas the imitation of familiar responses has been associated with mirror neurons—a neural population in the ventral-lateral prefrontal cortex and inferior parietal lobes (Rizzolatti & Craighero, 2004)—novel imitation has been shown to involve a larger suite of neural structures and does not always include mirror neurons (Grezes & Decety, 2001; Lingnau & Caramazza, 2014; Lingnau, Gesierich, & Caramazza, 2009). Electroencephalographic studies of mu rhythm in very young children have begun to address this question (see Cuevas, Cannon, & Fox, 2014; Marshall & Meltzoff, 2014, for review). These studies have reported mu attenuation—an index of mirror neuron activity—when young children observe and execute behaviors that are within their behavioral repertoire such as grasping an object.

Another important consideration is which measures are used to assess imitation. Various measures have been used in the literature for various reasons. The most common measures assess the number of "target" responses made by children. The problem with this type of measure is that it does not control for affordance learning or "orienting" social attentional processes such as stimulus and local enhancement that are activated in social-learning conditions but are absent in baseline or trial-and-error conditions (Want & Harris, 2002; Zentall, 2012). Measures that average performance across multiple trials have similar limitations and confound individual learning with social and imitation learning. For this reason, we used first-trial accuracy for the computer-based tasks and an analogous first-trial and ordinal (order) score for the object-based tasks. Future studies should examine these more tightly controlled measures further.

CONCLUSION

The present study makes at least three significant contributions to the imitation literature. First, before this study, it was unclear whether there was any significant association between imitation performance using computer-based tasks and object-based tasks. Here, we show that less ecologically invalid computer-based tasks such as the cognitive and motor-spatial tasks are associated with performance with more ecologically valid object-based tasks. Second, despite the significant differences between computer- and object-based tasks, the two resulting components were not task-dependent and domain-general (i.e., object-based vs. computer-based); rather, they were task-independent and domain-specific (cognitive vs. motor-spatial). This result builds on previous studies and provides unique support for the multiple-imitation-mechanisms hypothesis (Subiaul, 2010). According to this hypothesis, underlying imitation performance are multiple domain-specific "elemental" imitation mechanisms dedicated to copying information in specific content domains, regardless of task type. Third, although age was significantly associated with performance across tasks, the cognitive structure and pattern of associations between tasks did not differ in younger and older children.

The picture that emerges from these studies is complex. Ongoing research points to two potential architectures for imitation: one that is content-general and another that is content-specific. The content-general architecture—possibly mediated by associative learning—in certain cases may support or interact with content-specific architectures—mediated by multiple imitation mechanisms. So, whereas the initial learning of any given skill might be mediated by content-specific imitation mechanisms, the execution of that same behavior, once it has been learned and extensively practiced, will almost certainly involve content-general—associative—learning processes and will no longer activate content-specific imitation mechanisms. In addition, there are likely to be age-related changes that affect the relationship between domain-general and domain-specific cognitive processing. For example, early in development (e.g., younger than 12 months of age) when there is rapid brain development and brain plasticity is high, systems are more likely to overlap (D'Souza & Karmiloff-Smith, 2011; Karmiloff-Smith, 1992). However, with time, we expect greater differentiation of neural networks, resulting in more specialized and coordinated subsystems. The question of what leads to the refinement of different learning processes is the subject of ongoing research. Of particular interest is whether changes in imitation performance are supported by concurrent changes in executive functions or if they are independent of other developmental changes (e.g., Subiaul et al., 2014). Future research will, ultimately, have to address such questions. Here, we can say that, although preliminary, results from the present study support the hypothesis that there are multiple, content-specific elemental mechanisms mediating the imitation of new skills and responses across different tasks.

ACKNOWLEDGEMENTS

We would like to thank the many student volunteers in the Social Cognition Lab of the George Washington University for assisting with recruitment and data collection, and we extend our gratitude to the staff of the Smithsonian Institute, National Zoological Park, and visiting children whose participation made this study possible.

FUNDING

This study was supported by University Facilitating Funds (George Washington University) and two National Science Foundation grants: one to F. Subiaul (BCS-0748717) and another to R. Q28 Barr and P Gerhardstein (BCS-1023772).

REFERENCES

Ayoun, C. (1998). Maternal responsiveness and search for hidden objects and contingency learning by infants. *Early Development and Parenting*, *7*, 61–72. doi:10.1002/(sici)1099-0917(199806)7:2<61::aid-edp165>3.3.co;2-i

Bandura, A. (1977). *Social learning theory.* Upper Saddle River, NJ: Prentice Hall.

Barr, R. (2013). Memory constraints on infant learning from picture books, television, and touchscreens. *Child Development Perspectives*, *7*, 205–210. doi:10.1111/cdep.12041

Barr, R., & Hayne, H. (2000). *Age-related changes in imitation: Implications for memory development* (Vol. 1). Mahwah, NJ: Erlbaum.

Bates, E., Thal, D., Whitesell, K., Fenson, L., & Oakes, L. (1989). Integrating language and gesture in infancy. *Developmental Psychology*, *25*, 1004–1019. doi:10.1037//0012-1649.25.6.1004

Bauer, P. J. (1992). Holding it all together: How enabling relations facilitate young children's event recall. *Cognitive Development*, *7*, 1–28. doi:10.1016/0885-2014(92)90002-9

Bauer, P. J. (2007). *Remembering the times of our lives: Memory in infancy and beyond*. Mahwah, NJ: Lawrence Q10 Erlbaum.

Bauer, P. J., & Mandler, J. M. (1989). One thing follows another: Effects of temporal structure on 1- to 2-year olds' recall Q11 of events. *Developmental Psychology*, *25*, 197–203. doi:10.1037//0012-1649.25.2.197

Bauer, P. J., & Zelazo, P. D. (2013). IX. NIH Toolbox Cognition Battery (CB): Summary, conclusions, and implications for cognitive development. *Monographs of the Society for Research in Child Development*, *78*, 133–146. doi:10.1111/mono.12039

Bekkering, H., Wohlschlager, A., & Gattis, M. (2000). Imitation of gestures in children is goal-directed. *Quarterly Journal of Experimental Psychology Section A*, *53*, 153–164. doi:10.1080/713755872

Best, J. R., & Miller, P. H. (2010). A developmental perspective on executive function. *Child Development*, *81*, 1641–1660. doi:10.1111/j.1467-8624.2010.01499.x

Boutin, A., Fries, U., Panzer, S., Shea, C. H., & Blandin, Y. (2010). Role of action observation and action in sequence learning and coding. *Acta Psychologica*, *135*, 240–251. doi:10.1016/j.actpsy.2010.07.005

Boutin, A., Panzer, S., Salesse, R. N., & Blandin, Y. (2012). Testing promotes effector transfer. *Acta Psychologica*, *141*, 400–407. doi:10.1016/j.actpsy.2012.09.014

Chartrand, T. L., & Bargh, J. A. (1999). The chameleon effect: The perception–behavior link and social interaction. *Journal of Personality and Social Psychology*, *76*, 893–910. doi:10.1037/0022-3514.76.6.893

Cook, R., Johnston, A., & Heyes, C. (2013). Facial self-imitation: Objective measurement reveals no improvement without visual feedback. *Psychological Science*, *24*, 93–98. doi:10.1177/0956797612452568

Dickerson, K., Gerhardstein, P., Zack, E., & Barr, R. (2013). Age-related changes in learning across early childhood: A new imitation task. *Developmental Psychobiology*, *55*, 719–732. doi:10.1002/dev.21068

D'Souza, D., & Karmiloff-Smith, A. (2011). When modularization fails to occur: A developmental perspective. *Cognitive Neuropsychology*, *28*, 276–287. doi:10.1080/02643294.2011.614939

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon identification of a target letter in a non-search task. *Perception and Psychophysics*, *16*, 143–149. doi:10.3758/bf03203267

Garon, N., Bryson, S. E., & Smith, I. M. (2008). Executive function in preschoolers: A review using an integrative framework. *Psychological Bulletin*, *134*, 31–60. doi:10.1037/0033-2909.134.1.31

Gerhardstein, P., & Rovee-Collier, C. (2002). The development of visual search in infants and very young children. *Journal of Experimental Child Psychology*, *81*, 194–215. doi:10.1006/jecp.2001.2649

Goldenberg, G. (2009). Apraxia and the parietal lobes. *Neuropsychologia*, *47*, 1449–1459. doi:10.1016/j.neuropsychologia.2008.07.014

Grezes, J., & Decety, J. (2001). Functional anatomy of execution, mental simulation, observation, and verb generation of actions: A meta-analysis. *Human Brain Mapping*, *12*, 1–19. doi:10.1002/1097-0193(200101)12:1<1::aid-hbm10>3.0.co;2-v

Heider, F., & Simmel, M. (1944). An experimental study of apparent behavior. *American Journal of Psychology*, *57*, 243–259. doi:10.2307/1416950

Herbert, J., & Hayne, H. (2000). The ontogeny of long-term retention during the second year of life. *Developmental Science*, *3*, 50–56. doi:10.1111/1467-7687.00099

Heyes, C. (2011). Automatic imitation. *Psychological Bulletin*, *137*, 463–483. doi:10.1037/a0022288

Heyes, C. (2012). What's social about social learning? *Journal of Comparative Psychology*, *126*, 193–202. doi:10.1037/a0025180

Q12 Humstone, H. J. (1919). Memory span tests. *Psychol. Clin.*, *12*, 196–200.

Huttenlocher, J., Newcombe, N., & Sandberg, E. H. (1994). The coding of spatial location in young children. *Cognitive Psychology*, *27*, 115–147. doi:10.1006/cogp.1994.1014

Ingersoll, B. (2011). Brief report: Effect of a focused imitation intervention on social functioning in children with autism. *Journal of Autism and Developmental Disorders*, *42*, 1768–1773. doi:10.1007/s10803-011-1423-6

Karmiloff-Smith, A. (1992). *Beyond modularity.* Cambridge, MA: MIT.

Kousaie, S., Sheppard, C., Lemieux, M., Monetta, L., & Taler, V. (2014). Executive function and bilingualism in young and older adults. *Frontiers in Behavioral Neuroscience*, *8*, 250. doi:10.3389/fnbeh.2014.00250

Lakusta, L., & Landau, B. (2005). Starting at the end: The importance of goals in spatial language. *Cognition*, *96*, 1–33. doi:10.1016/j.cognition.2004.03.009

Lee, E. (2012). iPad app targets preschool learning market. *San Francisco Chronicle*. Retrieved from http://www.sfgate.com/technology/article/iPad-app-targets-preschool-learning-market-4082439.php

Lingnau, A., & Caramazza, A. (2014). The origin and function of mirror neurons: The missing link. *Behavioral and Brain Sciences*, *37*, 209–210. doi:10.1017/S0140525X13002380

Lingnau, A., Gesierich, B., & Caramazza, A. (2009). Asymmetric fMRI adaptation reveals no evidence for mirror neurons in humans. *Proceedings of the National Academy of Sciences*, *106*, 9925–9930. doi:10.1073/pnas.0902262106

Lyons, D. E., Young, A. G., & Keil, F. C. (2007). The hidden structure of overimitation. *Proceedings of the National*
Q13 *Academy of Sciences*, *104*, 19751–19756. doi:10.1073/pnas.0704452104

Malone, T. (2011). Finger paints, picture books and iPads—the newest classroom tools for some preschools, kindergartens. *Chicago Tribune*. Retrieved from http://articles.chicagotribune.com/2011-05-10/news/ct-met-ipad-for-prek-0511-20110510_1_ipads-preschool-classroom-kindergartens

McDuffie, A., Turner, L., Stone, W., Yoder, P., Wolery, M., & Ulman, T. (2007). Developmental correlates of different types of motor imitation in young children with autism spectrum disorders. *Journal of Autism and Developmental Disorders*, *37*, 401–412. doi:10.1007/s10803-006-0175-1

McGuigan, N., Makinson, J., & Whiten, A. (2011). From over-imitation to super-copying: Adults imitate causally irrelevant aspects of tool use with higher fidelity than young children. *British Journal of Psychology*, *102*, 1–18. doi:10.1348/000712610X493115

McGuigan, N., Whiten, A., Flynn, E., & Horner, V. (2007). Imitation of causally opaque versus causally transparent tool use by 3- and 5-year-old children. *Cognitive Development*, *22*, 353–364. doi:10.1016/J.Cogdev.2007.01.001

Michotte, A. (1946). *The perception of causality.* New York, NY: Basic Books.

Moser, A., Gerhardstein, P., Zimmermann, L., Grenell, A., & Barr, R. (in press). Transfer learning from touchscreens in
Q22 toddlers.

Nielsen, M. (2006). Copying actions and copying outcomes: Social learning through the second year. *Developmental Psychology*, *42*, 555–565. doi:10.1037/0012-1649.42.3.555

Nielsen, M., Moore, C., & Mohamedally, J. (2012). Young children overimitate in third-party contexts. *Journal of Experimental Child Psychology*, *112*, 73–83. doi:10.1016/j.jecp.2012.01.001

Radesky, J. S., Schumacher, J., & Zuckerman, B. (2015). Mobile and interactive media use by young children: The good, the bad, and the unknown. *Pediatrics*, *135*, 1–3. doi:10.1542/peds.2014-2251

Ray, E., & Heyes, C. (2011). Imitation in infancy: The wealth of the stimulus. *Developmental Science*, *14*, 92–105. doi:10.1111/j.1467-7687.2010.00961.x

Q23 Rideout, V. (2011). *Zero to eight: Children's media use of America*. Retrieved from http://www.commonsensemedia.org/about-us/news/press-releases/new-research-from-common-sense-media-reveals-mobile-media-use-among

Q24 Rideout, V. (2013). *Zero to eight: Children's media use in America*. San Francisco, CA.

Q14 Rizzolatti, G., & Craighero, L. (2004). The mirror-neuron system. *Annual Review of Neuroscience*, *27*, 169–192. doi:10.1146/annurev.neuro.27.070203.144230

Rogers, S. J., Hepburn, S. L., Stackhouse, T., & Wehner, E. (2003). Imitation performance in toddlers with autism and those with other developmental disorders. *Journal of Child Psychology and Psychiatry*, *44*, 763–781. doi:10.1111/1469-7610.00162

Roseberry, S., Hirsch-Pasek, K., & Golinkoff, R. M. (2014). Skype me! Socially contingent interactions help toddlers learn language. *Child Development*, *85*, 956–970. doi:10.1111/cdev.12166

Roseberry, S., Hirsch-Pasek, K., Parish-Morris, J., & Golinkoff, R. M. (2009). Live action: Can young children learn verbs from video? *Child Development*, *80*, 1360–1375. doi:10.1111/j.1467-8624.2009.01338.x

Rumiati, R. I., & Tessari, A. (2002). Imitation of novel and well-known actions: The role of short-term memory. *Experimental Brain Research*, *142*, 425–433. doi:10.1007/s00221-001-0956-x

Schulz, L. E., Hooppell, C., & Jenkins, A. C. (2008). Judicious imitation: Children differentially imitate deterministically and probabilistically effective actions. *Child Development*, *79*, 395–410. doi:10.1111/j.1467-8624.2007.01132.x

Sherwood, C. C., Subiaul, F., & Zawidzki, T. W. (2008). A natural history of the human mind: Tracing evolutionary changes in brain and cognition. *Journal of Anatomy*, *212*, 426–454. doi:10.1111/j.1469-7580.2008.00868.x

Stroop, J. D. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662. doi:10.1037/h0054651

Subiaul, F. (2010). Dissecting the imitation faculty: The multiple imitation mechanisms (MIM) hypothesis. *Behavioural Processes*, *83*, 222–234. doi:10.1016/j.beproc.2009.12.002

Subiaul, F., Anderson, S., Brandt, J., & Elkins, J. (2012). Multiple imitation mechanisms in children. *Developmental Psychology*, *48*, 1165–1179. doi:10.1037/a0026646

Subiaul, F., Lurie, H., Kathryn, R., Klein, T., Holmes, D., & Terrace, H. S. (2007). Cognitive imitation in typically-developing 3- and 4-year olds and individuals with autism. *Cognitive Development*, *22*, 230–243. doi:10.1016/j.cogdev.2006.10.003

Subiaul, F., Patterson, E., Renner, E., Schilder, B., & Barr, R. (2014). Becoming a high-fidelity - super - imitator: What are the contributions of social and individual learning? *Developmental Science*. Advance online publication. Q25 doi:10.1111/desc.12276

Subiaul, F., Romansky, K., Cantlon, J. F., Klein, T., & Terrace, H. S. (2007). Cognitive imitation in 2-year-old children (Homo sapiens): A comparison with rhesus monkeys (*Macaca mulatta*). *Animal Cognition*, *10*, 369–375. doi:10.1007/s10071-006-0070-3

Subiaul, F., & Schilder, B. (2014). Working memory constraints on imitation and emulation. *Journal of Experimental Child Psychology*, *128*, 190–200. doi:10.1016/j.jecp.2014.07.005

Sutton, J. (2006). The development of landmark and beacon use in young children: Evidence from a touchscreen search task. *Developmental Science*, *9*, 108–123. doi:10.1111/j.1467-7687.2005.00467.x

Terrace, H. S. (2005). The simultaneous chain: A new approach to serial learning. *Trends in Cognitive Sciences*, *9*, 202–210. doi:10.1016/j.tics.2005.02.003

Tessari, A., Canessa, N., Ukmar, M., & Rumiati, R. I. (2007). Neuropsychological evidence for a strategic control of multiple routes in imitation. *Brain*, *130*, 1111–1126. doi:10.1093/brain/awm003

Vanvuchelen, M., Roeyers, H., & De Weerdt, W. (2011a). Development and initial validation of the Preschool Imitation and Praxis Scale (PIPS). *Research in Autism Spectrum Disorders*, *5*, 463–473. doi:10.1016/j.rasd.2010.06.010

Vanvuchelen, M., Roeyers, H., & De Weerdt, W. (2011b). Measuring procedural imitation aptitude in children: Further validation of the Preschool Imitation and Praxis Scale (PIPS). *Perceptual and Motor Skills*, *113*, 773–792. doi:10.2466/10.11.22.PMS.113.6.773-792

Want, S. C., & Harris, P. L. (2002). How do children ape? Applying concepts from the study of non-human primates to the developmental study of 'imitation' in children. *Developmental Science*, *5*, 1–14. doi:10.1111/1467-7687.00194

Wellman, H. M., & Cross, D. (2001). Theory of mind and conceptual change. *Child Development*, *72*, 702–707. doi:10.1111/1467-8624.00309

Wellman, H. M., Lopez-Duran, S., LaBounty, J., & Hamilton, B. (2008). Infant attention to intentional action predicts preschool theory of mind. *Developmental Psychology*, *44*, 618–623. doi:10.1037/0012-1649.44.2.618

Wimmer, H., & Perner, J. (1983). Beliefs about beliefs: Representation and constraining function of wrong beliefs in young children's understanding of deception. *Cognition*, *13*, 103–128. doi:10.1016/0010-0277(83)90004-5

Wohlschlager, A., Gattis, M., & Bekkering, H. (2003). Action generation and action perception in imitation: An instance of the ideomotor principle. *Philosophical Transactions of the Royal Society B: Biological Sciences*, *358*, 501–515. doi:10.1098/rstb.2002.1257

Young, G. S., Rogers, S. J., Hutman, T., Rozga, A., Sigman, M., & Ozonoff, S. (2011). Imitation from 12 to 24 months in autism and typical development: A longitudinal Rasch analysis. *Developmental Psychology*, *47*, 1565–1578. doi:10.1037/a0025418

Zack, E., Barr, R., Gerhardstein, P., Dickerson, K., & Meltzoff, A. N. (2009). Infant imitation from television using novel touch screen technology. *British Journal of Developmental Psychology*, *27*, 13–26. doi:10.1348/026151008x334700

Zack, E., Barr, R., Gerhardstein, P., & Meltzoff, A. N. (2013). Role of narrative cues on transfer from 2D to 3D and vice versa. *Journal of Scandinavian Psychology*, *54*, 20–25. doi:10.1111/sjop.12001

Zelazo, P. D., & Bauer, P. J. (in press). *National Institutes of Health Toolbox-Cognitive Function Battery* (NIH Toolbox
Q26 CFB): *Validation for children between 3 and 15 years*. Ann Arbor, MI: Society for Research on Child Development.

Zentall, T. R. (2012). Perspectives on observational learning in animals. *Journal of Comparative Psychology*, *126*, 114–128. doi:10.1037/a0025381