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Cognitive imitation in typically-developing 3- and 4-year olds and individuals with autism

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Abstract

Individuals diagnosed with autism suffer from numerous social, affective and linguistic impairments. It has also been suggested that they have a global imitation deficit. That hypothesis, however, is compromised by the fact that individuals with autism suffer from various motor impairments. Here we describe an experiment on cognitive imitation, a type of imitation that doesn't require motor learning. Nine male autistic subjects and 20 typically-developing 3- and 4-year olds were trained to respond, in a prescribed order, to different lists of photographs that were displayed simultaneously on a touch-sensitive monitor. Because the position of the photographs varied randomly from trial to trial, sequences could not be learned by motor imitation. In three different imitation treatments, including a ghost control, autistic subjects learned new sequences more rapidly after observing a model execute those sequences than when they had to learn new sequences entirely by trial and error. Moreover, the performance of autistic subjects did not significantly differ from the performance of typically-developing controls. The result of this and other studies suggests that individuals with autism suffer from a specific novel motor imitation deficit.

Keywords: Autism; Social learning; Cognitive imitation; Ghost control; Emulation; Cognitive development; Children

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1. Introduction

Can individuals with autism imitate? A growing number of investigators argue that they cannot (Curcio, 1978; DeMeyer et al., 1972; Receveur et al., 2005; Rogers, Hepburn, Stackhouse, & Wehner, 2003; Rogers & Pennington, 1991; Smith & Bryson, 1994, Stone, Ousley, & Littleford, 1997, for exceptions see: Charman & Baron-Cohen, 1994; Hobson & Lee, 1999). However, a detailed meta-analysis of the performance of individuals with autism on a variety of imitation tasks revealed that people with autism are unimpaired when copying familiar motor/action rules but are significantly impaired when copying novel motor/actions rules as well as sequential rules (Williams, Whiten, & Singh, 2004). This meta-analysis indicates that individuals with autism may have a global impairment in novel imitation (i.e., copying novel rules) but not familiar imitation (i.e., copying familiar rules).

Nevertheless, this pattern of performance stands in contrast to that of typically-developing children who can copy a broad range of novel (as well as familiar) rules from a very early age (Bauer, 1992; Bekkering, Wohlschlager, & Gattis, 2000; Carpenter, Akhtar, & Tomasello, 1998; Fontaine, 1984; Meltzoff, 1988; Meltzoff & Moore, 1977; Piaget, 1962; Whiten, Flynn, Brown, & Lee, 2006; Williamson & Markman, 2006). The poor performance of individuals with autism when copying novel motor rules has led some investigators to argue that an imitation deficit is a "universal" or global characteristic of autism (e.g., Rogers & Pennington, 1991). That hypothesis, however, has minimized other factors that might interfere with novel imitation performance. For example, it is well known that individuals with autism have poor body schemas and suffer from impairments in motor functioning, planning, and coordination (Curcio & Piserchia, 1978; Damasio & Maurer, 1978; DeMeyer et al., 1972; Green et al., 2002; Hughes, 1996; Jones & Prior, 1985; Mari, Castiello, Marks, Marraffa, & Prior, 2003; Morgan, Cutrer, Coplin, & Rodrigue, 1989; Mostofsky et al., 2006; Noterdaeme, Mildenberger, Minow, & Amorosa, 2002; Ohta, 1987; Rogers, Bennetto, McEvoy, & Pennington, 1996; Smith & Bryson, 1994; Wing, 1969). While these problems have been acknowledged by a number of scientists (e.g., Curcio, 1978; Rogers, Hepburn, Stackhouse, & Wehner, 2002; Mostofsky et al., 2006; Smith & Bryson, 1994), the fact remains that all imitation studies have relied exclusively on motor tasks. No study to our knowledge has explored whether individuals diagnosed with an autism spectrum disorder are also impaired when copying novel cognitive rules (cognitive imitation) executed independently of specific motor rules (motor imitation).

Here we describe an example of cognitive imitation, a type of imitation learning in which a naïve student copies an expert's use of a cognitive rule (Subiaul, 2004; Subiaul, Cantlon, Holloway, & Terrace, 2004), for example, learning someone's password at an automated teller machine (ATM) by looking over that person's shoulder. Since the observer already knows how to enter numbers on the keypad, no motor learning is necessary. Although the simultaneous chaining task differs somewhat from this example (because the items that are touched change spatial position every trial), the ATM example illustrates how cognitive and motor imitation may be dissociated in the minds of observers. For instance, when copying someone's password, observers may copy a spatial/motor rule (i.e., up, down, left, right) and ignore the sequence of numbers being pressed. Conversely, someone may copy the numbers pressed by the model (i.e., 2, 8, 4, 6), but disregard the actual motor movements executed. In both instances the observer is copying a rule; the principal difference is the type of rule: spatial/motor versus abstract/cognitive.

Despite the different types of representations (motor/spatial in the case of motor imitation and abstract/cognitive in the case of cognitive imitation), cognitive imitation, like motor imitation, involves learning and copying specific responses from a model. The principal difference between these two concepts is the type of rule (and stimulus) that is learned and copied by the observer. So, whereas in the typical imitation learning experiment participants must copy novel actions on objects or novel sequences of specific actions (*novel motor imitation*), in this imitation paradigm participants have to copy novel sequences, independently of specific actions or movement patterns (*novel cognitive imitation*). In both instances, individuals must copy novel rules after observing a model execute the same rule.

The distinction between cognitive and motor imitation is premised on the same logic that distinguishes vocal and motor imitation (Shettleworth, 1998; Skinner, 1957; Thorndike, 1911) in recognition of the fact that vocal imitation involves a unimodal match (sound perception—[match]—sound production), whereas copying actions involves a multimodal match (visual perception—[match]—motor production). However, individuals imitate social conventions, goals/intentions and serial rules (to name a few) which can neither be described as examples of vocal nor motor imitation because the stimuli that is to be copied is not immediately available to the senses, but is inferred (i.e., cognitive stimuli). It is the copying this class of (non-motor, non-vocal) rules that are unobservable (Povinelli & Vonk, 2003) and must be inferred which we have called cognitive imitation (Subiaul, 2004; Subiaul et al., 2004). We must stress, though, that the term cognitive imitation is not meant to describe underlying mechanisms or to suggest that either motor or vocal imitation are non-cognitive processes; no more so than proponents of a differentiation between vocal and motor imitation believe that vocal imitation does not involve specific motor processes.[1] Like motor and vocal imitation, cognitive imitation refers to the type of stimuli that is to be copied by an observer.

To investigate cognitive imitation, we trained autistic and typically-developing control participants to execute simultaneous chains (Terrace, 2005). Simultaneous chains consist of lists of pictures, the order of which is typically learned by trial and error from computer-generated feedback that follows each response, correct or incorrect. In this study, participants were provided with the opportunity to learn new 4-item simultaneous chains by cognitive imitation rather than by trial and error.

2. Methods

2.1. Participants

Our participants were nine male individuals diagnosed with autism enrolled in the Eden Autism Institute in Princeton, New Jersey.[2] Either a licensed pediatrician or a neurologist diagnosed all participants. They all met the standard diagnostic criteria of Autism as specified by the DSM-IV (APA, 2000). Chronological ages of these participants ranged from 8 to 20 years (mean age: 14.91; S.D.: 4.29). Adaptive mental ages were assessed using the Vineland Adaptive Behavior Scales,[3] a scale that measures adaptive behavior in several specifically enumerated domains (including "Socialization" and "Communication") and that is norm-referenced to representative national

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[1] In fact, to copy specific sounds conspecifics must also copy, albeit indirectly, motor actions in the vocal tract.

[2] Eden is a non-profit organization founded in 1975 to meet the lifespan needs of individuals with autism (Holmes, 1998).

[3] The communication (both expressive and receptive), attentional, and behavioral problems commonly associated with individuals diagnosed with autism and present to varying degrees in our participants, specifically, dictated our use of the Vineland. Use of the Vineland in assessing autistic populations is as well-supported, as standardized tests, including typical IQ tests.

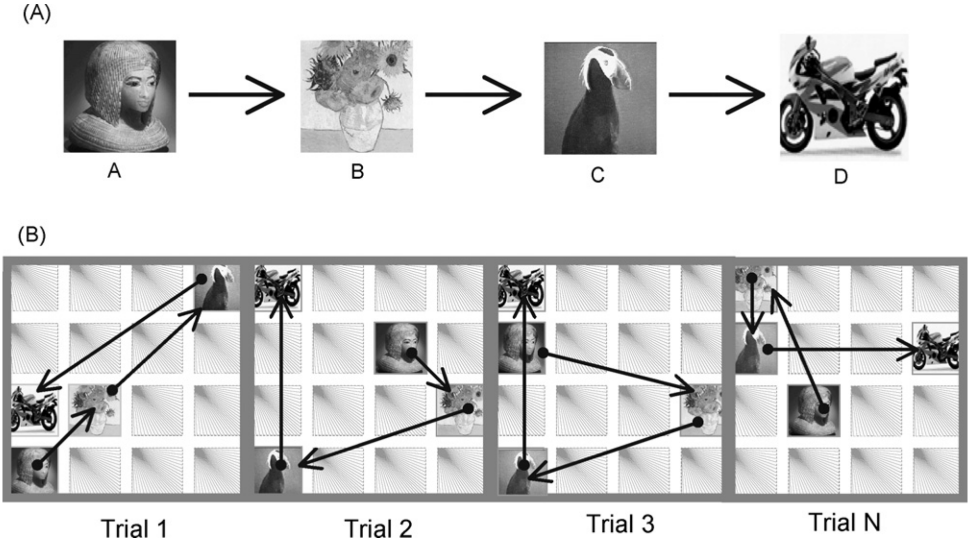

Fig. 1. Simultaneous chaining paradigm: (A) sample of a 4-item simultaneous chain (i.e., 4 arbitrary pictures comprising a serial list) and (B) example of how list items (pictures) change spatial configuration from trial to trail on a 4 × 4 grid. Arrows indicate the target sequence between trials.

standardization samples (Sparrow, Balla, & Cicchetti, 1985).[4] "Socialization" ages among the autistic participants ranged from 2.5 to 5.58 years (mean age: 3.94; S.D.: 1.21), and "Communication" ages, a measure of verbal mental age (VMA), ranged from 2.0 to 7.33 years (mean age: 4.79; S.D.: 2.0). These scores are consistent with the socialization and communication impairments associated with autism spectrum disorders. The training and testing of the individuals with autism occurred in various visits to the Eden Autism Institute.

The comparison groups consisted of sixteen 3-year-olds (3-YO), 10 males and 6 females (mean age: 3.55; S.D.: .23), and twenty 4-year-olds (4-YO), 7 males and 13 females (mean age: 4.53; S.D.: .35) without a history of psychiatric disorders. These participants were recruited through Barnard College's Toddler Development Center in New York City and from several other preschools in the area neighboring Columbia University. Mean verbal mental ages were considered to be equivalent to mean chronological ages. Training and testing occurred in a single visit to the participant's home.

2.2. Simultaneous chaining paradigm (SCP)

In the simultaneous chaining paradigm list items are displayed concurrently throughout each trial on a touch-sensitive video monitor and each item's position is varied randomly from trial to trial. The participants' task is to respond to each item in a particular order (Fig. 1A), regardless of its spatial position (cf., Fig. 1B). Variation of spatial position prevents participants from performing the required sequence as a fixed motor pattern or as a discrete set of responses to specific external spatial cues, such as the choice points of a maze (cf., Fig. 1B). The variation of the spatial position

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[4] Various studies support the validity of the Vineland Adaptive Behavior Scales for use with developmentally delayed individuals, including autistic populations (Atkinson, Beve, Dickens, & Blackwell, 1992; Carter et al., 1998).

of list items also eliminates the need for participants to form a representation of specific motor responses or from having to rely on a body schema to guide individual responses. Eliminating those possibilities is important because, as noted above, individuals with autism frequently suffer from deficits in motor coordination, planning, and execution (cf., Mostofsky et al., 2006; Smith & Bryson, 1994).

The lists on which our participants were trained were composed of color photographs. These were presented to each participant on a Macintosh iBook (laptop) computer with a Magic-Touch detachable screen. Photographs (1.5 in. × 2 in.) were used as list items because they were easier to discriminate than colors or geometric forms and because they were in plentiful supply. They were selected from a library of more than 3000 digital images of natural and man-made objects (e.g., animals, people, scenery, flowers, cars, bridges, etc.). Before each trial, the configuration of the list items was selected randomly from a set of 43,680 possible spatial configurations.

2.3. Procedure

Prior to testing, all participants were introduced to the task in three steps. First the investigator, acting as a model, demonstrated to the participant the consequences of responding to a single item on the touch screen. Following a response, a border would appear around the stimuli, the computer would generate a 1000 Hz tone and, after a 1 s interval, the picture would disappear and re-appear in a different position on the screen. Following this demonstration, the investigator encouraged participants to respond to the item on their own. Once participants responded to the touch screen reliably, they were introduced to a 3-item list of arbitrary photographs. With the aid of the investigators, participants were encouraged to respond to all three pictures and to discover the correct sequence by trial and error. On a 3-item list the probability of a participant guessing the correct sequence on the first trial is $1/3! = .17$. Each correct response produced brief (.5 s) visual and auditory cues (a border that was flashed around the correct item and a 1000 Hz tone). Each error resulted in a 5-s time out (TO). Reinforcement consisted of a 3-s movie clip, accompanied by music, of a man doing a backward summersault (“jumping man”). Participants saw “jumping man” only when they touched all the items on the screen in the correct order. When participants responded correctly to each of the three list items on two consecutive trials, they were presented with a four-item list. Again, participants were encouraged to discover the correct order of the pictures by trial and error. On a 4-item list the probability of a participant guessing the correct sequence on the first trial is $1/4! = .04$ (cf., Terrace, Son, & Brannon, 2003). Training ended once participants responded correctly to a 4-item list of photographs on two consecutive trials. All participants met the criterion for testing.

Following training, participants were randomly tested under four different conditions that varied in the type of cue(s) provided by the experimenter/model during a demonstration phase that preceded Testing. These conditions included: (1) baseline, (2) computer plus social cues [CS], (3) computer only cues [CO] and (4) social only cues [SO]. Here, ‘cues’ refer to the information provided to participants during demonstration as to the ordinality of individual list items. Table 1 provides a description of the different types of cues provided to participants during the demonstration phase of each condition.

In the *baseline* condition participants had to discover the serial position of each item entirely by trial and error. In the *computer plus social* condition (CS) the model provided participants with both social and non-social (computer) cues as to the correct serial order of each item prior to Testing. In the *computer only* (CO) condition, the computer—acting as the model—automatically

Table 1
Cues provided to participants during the demonstration phase, prior to the start of testing where participants were given the opportunity to respond

Condition (cue type)	Cues provided by experimenter	Cues provided by computer	Rule learned by observation/inference
Baseline	None	None	None
Computer + Social (CS)	The experimenter directs the subject's (visual) attention to individual items on the screen while pointing to each in the correct serial order.	A 1000 Hz sound and a border accompanies each response by the experimenter to individual items. Following a correct trial, items appear in a novel spatial configuration on the screen.	Subjects could learn the target serial rule by (1) attending to the model's individual responses to the stimuli, (2) attending to the consequences of each response provided by the computer [sound and borders around the pictures] and/or (3) both.
Computer Only (CO)	None	Computer automatically emits a 1000 Hz sound as a border appears sequentially around each item on the screen in the correct serial order. From trial to trial items change spatial configuration.	Subjects could infer the serial rule by attendeding to the pattern of sounds and borders that appear around each item on the screen in the correct serial order.
Social Only (SO)	The experimenter directs the subject's (visual) attention to the items on the screen and says, "One, two, three, four" while pointing to each item in that order.	None	Subject could learn the serial rule only by attending to the individual responses made by the experimenter (e.g., when counting and pointing to the pictures).

highlighted each item in the correct serial order without any intervention by the human experimenter. This condition constitutes a "ghost control". In the *social only* (SO) condition, participants were given the opportunity to learn the serial position of list items during Demonstration using only social and linguistic cues provided by the experimenter. All computer-generated feedback (that typically follows each response) was eliminated. At the beginning of each SO condition the investigator made eye contact with the participant and said, 'Watch me' and proceeded to touch each picture in the correct order, verbally labeling them for the participant as "One, two, three, four." This procedure was repeated three times. List items remained in a fixed position on the screen throughout. This was the only condition in which items remained in a fixed spatial position (as this represented a type of computer feedback). In all other conditions pictures changed spatial configuration on the screen from trial to trial. If during Demonstration participants associated specific list items with a specific position on the screen, then performance (in this condition) should be particularly poor because during Testing list items always appeared in a different spatial configuration.

New lists were used in each condition and were never repeated. Consequently, our measures of learning by cognitive imitation were based entirely on the acquisition of those items and not their retention. As a result, savings cannot explain any performance difference between lists or conditions since the rule used to execute list X could not be applied to execute list Y.

Each testing session (corresponding with a specific condition) consisted of a maximum of 20 trials. *Trials* were terminated either when the child made a mistake (incorrect trial) or when the child responded correctly to all items on the screen (correct trial). *Sessions* were terminated following the first correct trial or in the event that they refused to participate.

Participants that are capable of learning by cognitive imitation should acquire a new list more rapidly during sessions in which they were given cues as to the correct order of list items prior to being tested on those same list items (i.e., CS, SO, and CO), than in the session in which they had to learn the serial order of new lists items entirely by trial and error (i.e., baseline). Our measure was the number of responses a participant made on a new list before completing the first trial correctly. This is a very sensitive measure of learning because after the first correct trial it would be impossible to isolate what (if any) rule was learned from the model by cognitive imitation and what was learned by trial-and-error. If individuals suffering from autism have a global or "universal" imitation learning deficit, performance in a baseline (trial-and-error learning) condition should not differ from performance in any of the social learning conditions where students are given the opportunity to learn new lists by observing a model prior to Testing. Any significant difference between baseline (or chance) and the other (social learning) conditions would demonstrate that participants could learn by imitation.

3. Results

3.1. Average number of responses/errors (rate of learning)

Results show that the participants with autism we observed in the present study can copy novel cognitive rules. A repeated measures ANOVA was used to analyze the data of autistic participants. Assumptions of homogeneity of variance [Levene's Statistic $(3,32) = 1.23$; $p = .315$] and sphericity [$W(5) = .517$; $p = .493$] were met. Autistic participants' performance was significantly affected by condition (baseline, CS, SO, CO) [$F(3,24) = 6.46$, $p < .01$]. The overall effect size was .78 (Eta^2). Pairwise comparisons between the different conditions demonstrated that baseline performance significantly differed from performance in the CS ($p < .01$) and CO ($p < .05$) condition. The difference between baseline and the SO condition was marginally significant ($p = .05$). The relevant data are summarized in Fig. 2A.

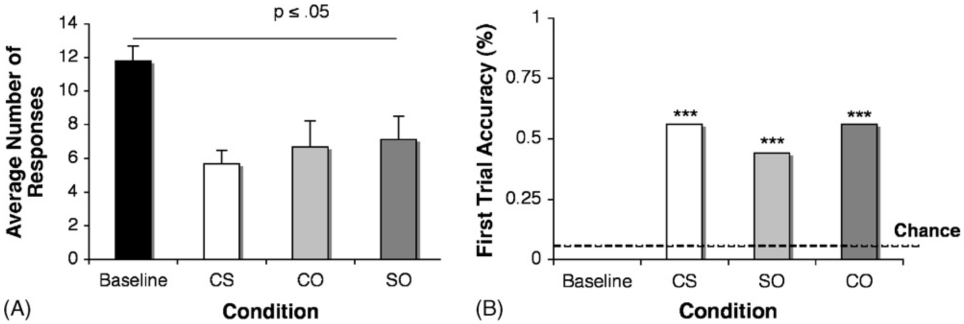

Fig. 2. Performance of individuals with autism. (A) The autistic group's average number of responses prior to the first correct trial. When compared to baseline performance, individuals with autism learned significantly faster in all three imitation conditions [CS, SO, CO]. (B) The autistic group's accuracy responding to all four items in the correct serial order in the first trial. Accuracy was recorded as correct (1) if participants responded to all four items ($A \rightarrow B \rightarrow C \rightarrow D$) on the first trial (without making any errors) or as incorrect (0) if participants made an incorrect response. This measures represents the most conservative measure of imitation learning [Binomial Test: $^{***}p = .000$, chance = .04].

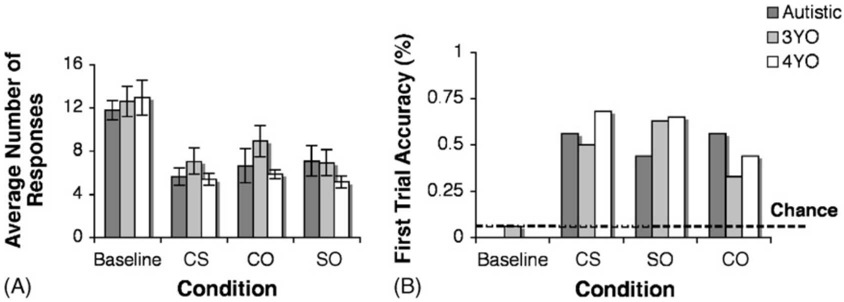

Fig. 3. Comparison of autistic and typically-developing groups. (A) Average number of responses before first correct trial. All participants learned significantly faster, making fewer errors, in the imitation conditions (CS, SO, and CO) than in the baseline condition. The performance of individuals with autism did not differ from that of typically-developing 3- or 4-year olds. (B) First trial accuracy. Participant's accuracy responding to all four items in the sequence correctly (i.e., A → B → C → D) in the first trial [chance probability = .04] did not differ between groups. In all three imitation conditions (CS, SO, CO), the participants tested knew the correct order of the 4 items in the very first trial significant above chance levels (cf., Fig. 2B).

We also sought to compare the performance of autistic participants with that of typically-developing participants matched for mean mental age. A univariate ANOVA of Group (autistic, 3-YO, and 4-YO) by Condition (baseline, CS, SO, CO) produced a main effect for Condition [$F(3) = 17.89$, $p < .001$], but not for Group [$F(2) = 1.98$, $p = .14$]. The Group by Condition interaction was not significant [$F(6) = .59$, $p = .74$) (see Fig. 3A)]. Because variance did not meet the assumption of homogeneity (Levene's Statistic: $F(3, 32) = 35.4$, $p < .001$), a Games–Howell post hoc test was used to compare the different conditions. Using this corrective measure, baseline performance significantly differed from performance in the CS, SO and CO conditions across groups ($p < .001$).

3.2. *Trial 1 accuracy*

Another measure of cognitive imitation is whether or not participants responded correctly to all four new list items on the very first trial. While such errorless learning is not necessary to demonstrate imitation, copying a novel rule without making any type of error represents the most conservative estimation of imitation learning. To assess first trial accuracy, we evaluated participants' responses on their very first opportunity to respond to a new 4-item list of pictures. Correct responses on trial 1 (e.g., A → B → C → D) were coded as 1, incorrect or partially correct (e.g., A → B → D) responses on the first trial were coded as 0. The probability of responding to all four new list items in the correct serial order on the first trial is 1/4! [P(A) .25 × P(B) .33 × P(C) .5 × P(D) 1.0 = .04]. Fig. 2B summarizes the autistic group's first trial accuracy. Autistic participants responded significantly above chance levels on trial 1 in all three imitation conditions (CS, SO, CO) [Binomial Test: $p = .000$, one-tailed; test probability = .04], but not in the baseline condition, where first trial accuracy was 0.

We also evaluated the performance of individuals with autism within the different imitation conditions to assess the efficacy of SO, CO and CS cues. Results revealed no significant differences between treatments groups [($\chi^2(2) = .68$, $p = .72$, Friedman Test; paired contrasts: (CS, SO): $Z = -.58$, $p = .28$; (CS, CO): $Z = 0$, $p = 1.0$; (CO, SO): $Z = -1.0$, $p = .16$, Wilcoxon Signed Ranks Test, one-tailed)].

A Kruskal–Wallis Test was used to assess whether there were any group difference in first trial accuracy. As can be seen in Fig. 3B, there were no statistically significant differences between groups in any condition ($\chi^2(8) = 6.23$, $p = .62$). Three- and 4-year olds, like individuals with autism, accurately copied the serial order of new 4-item lists in the CS, SO, and CO treatments at levels significantly above chance (Binomial Test: $p = .000$, one tailed; test probability = .04).

3.3. Conditional probabilities (item-by-item accuracy)

To obtain a detailed picture of what was learned in each imitation condition (CS, CO, and SO) we performed an analysis of the conditional probability of a correct response at each position in the sequence prior to the first correct trial. The extent to which a participant's accuracy when responding to individual items differed from chance represents a microanalysis of cognitive imitation. In a new 4-item list of arbitrary pictures the probability of responding correctly to a list item by chance was calculated with the assumption that participants could select any of 4 items for their 1st response (1/4 = .25), any of 3 items for their 2nd response (1/3 = .33), any of 2 items for their 3rd response (1/2 = .50) and 1 item for their 4th response (1/1 = 1.0). This is a very conservative estimation of chance because participants can make backward errors (e.g., $A \rightarrow B \rightarrow A$) when learning simultaneous chains. We judged this estimation of chance to be appropriate because these errors occur in very low frequencies (Swartz, Chen, & Terrace, 1991). A binomial test was used to compare autistic participants' responses to chance. Participants' accuracy when responding to item A significantly differed from chance (.25) in the CS, SO, and CO conditions ($p < .05$, one-tailed). Participant's accuracy responding to item B significantly differed from chance (.33) in the CS and SO conditions ($p < .05$, one-tailed) and approached significance in the CO condition ($p = .14$, one-tailed). Participants' accuracy responding to item C significantly differed from chance (.5) in the CS conditions ($p < .05$, one-tailed) and approached significance in the SO condition ($p = .09$, one-tailed). Participants were 100% accurate when responding to the last item in the list [D] in the CS, SO, and CO conditions. These results demonstrate that regardless of the type of cue(s) provided during demonstration, individuals with autism learned the ordinal position of at least 2 (of the 4) items in the new list by cognitive imitation.

We also wanted to assess whether the autistic groups' pattern of performance significantly differed from that of the typically-developing participants. A univariate ANOVA comparing Group (Autistic, 3YO, 4YO), Position (A, B, C, D), and imitation learning Condition (CS, CO, SO) revealed no significant interactions [Group × Position; Group × Condition; Position × Condition; Group × Position × Condition ($p = ns$)] but significant main effects for Group ($p < .05$), Position ($p < .001$), and Condition ($p < .001$). Because between group variances were unequal (Levene's $F(11,160) = 32.34$, $p < .001$) a Games–Howell post hoc test was used for multiple comparisons. Results revealed that the performance of autistic participants neither differed from the performance of 3YO ($p = .79$) nor 4YO ($p = .40$). However, the performance of 3YO differed from that of 4YO ($p = .05$). Group's accuracy when responding to the first [A], the second [B], and the third [C] item significantly different from the accuracy responding to the last item [D] in the CS, SO, and CO conditions ($p < .001$). Performance in the CO condition significantly differed from performance in the CS ($p < .01$) and the SO conditions ($p < .01$).

4. Discussion

Various studies have reported that when compared to control populations, individuals with autism show significant impairments on tasks that involve copying novel motor rules (Mostofsky et al., 2006; Rogers & Pennington, 1991; Rogers et al., 2003; Smith & Bryson, 1994; Williams et al., 2004). But as noted above, a detailed meta-analysis of many of these studies revealed that individuals with autism are unimpaired when copying familiar motor/action rules. A handicap emerges only in those tasks that involve the imitation of novel (arbitrary) rules such as when participants must copy specific actions on objects, on the body, or when copying novel sequences (Williams et al., 2004). The present study assessed whether individuals with autism were similarly impaired when copying novel cognitive rules, a result that would be consistent with a global deficit in imitation learning (e.g., Rogers & Pennington, 1991).

Results revealed, however, that individuals with autism copied novel sequences in three different imitation conditions (i.e., CS, CO, SO). Moreover, their performance did not statistically differ from that of typically-developing 3- or 4-year olds in any of the four conditions (baseline, CS, CO, and SO). These results cannot be explained by alternative social learning mechanisms, which may resemble imitation learning. For example, theories of *stimulus* (Spence, 1937) or *local* enhancement (Thorpe, 1956) state that, in experiments on imitation, the model may simply direct the participant's attention to the relevant stimuli. The simultaneous chaining task employed in the present study excludes stimulus or local enhancement as explanations for our results. Because the model responded to all of the list items that were displayed during the social condition, participants' attention should be directed equally to each item. Thus, all of the items should derive the same benefit from stimulus enhancement. Local enhancement is not relevant because variation of the spatial configuration of the list items from trial to trial insured that there was no relationship between an item and a particular position on the screen. Improved performance due to the mere presence of an investigator [*social facilitation* (Zajonc, 1965)] cannot explain the differences in performance between baseline and the various imitation conditions (CS, CO, SO) since the instructor was present during all testing conditions. Theories of *emulation learning* (Tomasello, 1990) cannot explain cognitive imitation because there was no individual response to emulate and because participants had to respond to all of the list items in the correct order to obtain a reward. That is, participants could not avoid responding to the first three items on the list and respond only to the last item, which was most strongly associated with a reward. Had participants only associated the last item with the administration of reward or had a preference to respond to the last item first, accuracy responding to the first item in the correct serial order would have been significantly depressed. Yet our results demonstrate that, on average, the accuracy when responding to the first item by the individuals with autism was significantly above chance.

Furthermore, ceiling effects cannot explain the performance of the individuals with autism in the present study—a criticism that has been leveled at other studies reporting imitation learning in people with autism (e.g., Charman & Baron-Cohen, 1994). That concept might be relevant if the number of responses needed to complete the first trial correctly approached 4 (the total number of items in a list), if the conditional probabilities approached 100% for each position, or if first trial accuracy approach 100%. However, the average number of responses by individuals with autism under the CS, CO, and SO conditions was 6.48 (range 4–15), the range of the difference between item-by-item accuracies and those predicted by chance was 0–53% and first trial accuracy varied from 44 to 56%.

Perhaps, surprisingly, participants tested under the CO condition ('ghost control') learned the ordinal position of *some* list items. At least two other studies employing a 'ghost' condition have reported learning among 14–26-month-old human participants (Huang & Charman, 2005; Thompson & Russell, 2004). Children in those two studies learned equally well in the ghost condition—where the target actions occurred automatically and independently of the actions of a human model—as in the full demonstration condition—where a human model demonstrated the target action. This pattern of performance suggests that humans use a variety of rules and make a number of inferences based, at times, on limited information (as is the case in the ghost control; CO condition in the present study) when learning by observation.

In addition to the motor confound present in all motor imitation experiments, the performance of the autistic group in the present study may contrast with the results reported by other investigators because the task involved the use of a computer. There is some evidence which suggests that individuals with autism respond to reinforcement contingencies more effectively when the treatment is administered by a model appearing in a video monitor rather than in vivo (Charlop-Christy, Le, & Freeman, 2000). However other investigators have failed to find significant differences between video and in vivo models (Gena, Coulouras, & Kymississ, 2005; Russo, Koegel, & Lovaas, 1978). While the model used in the present study did not appear in a video but in vivo, and reinforcement was administered by both the computer and by the live model, the results reported here are, nonetheless, at odds with the theory that individuals with autism learn best from visual displays. Although participants learned in a condition where only computer cues were available (CO), they also learned in a condition were only social cues (SO) were provided to the participant. In order to learn the serial order of individual list items in the SO condition, participants had to focus their attention on the live experimenter rather than the computer (cf., Table 1). If autistic individuals found the live model distracting or mildly aversive as the non-social (visual display) learning model predicts (e.g., Charlop-Christy et al., 2000), then performance in the CO treatment should have been better relative to the SO treatment. But the differences between the CO and SO treatments were neither significant within the autistic group nor from the performance of normally-developing controls. Thus, the present study is more consisted with the view that individuals with autism benefit equally from social and non-social models (e.g., Gena et al., 2005; Russo et al., 1978).

Nevertheless, the fact that individuals with autism may learn better in paradigms that use visual displays is secondary to the question addressed by the present study: can individuals with autism learn and copy a novel rule from a model? Here we demonstrate that when the task involves learning and copying a novel serial (cognitive) rule, rather than a novel motor/action rule, the performance of individuals with autism significantly differs from baseline performance and is significantly above chance levels (.04) on the first trial. Moreover, it is indistinguishable from the performance of typically-developing age-matched controls (cf., Figs. 2 and 3). The fact that individuals with autism, as well as typically-developing 3- and 4-year olds, reproduced such a complex rule (cf., Fig. 1) on trial 1 in all three imitation conditions—where a model demonstrated the rule—but never in the baseline condition—where the rule had to be discovered by trial and error—can only be explained by imitation learning. That participants in the present study learned and copied a novel serial (cognitive) rule, rather than a novel motor/action rule does not diminish this fact.

But why did children learn in the CO [ghost] condition? One possibility is that despite the fact that the computer was an inanimate object and not a social agent, it behaved as if it were animate and displayed the characteristics of social agents including, agency and goal-directedness. There are a number of studies that demonstrate that children, from infancy, are sensitive to cues that index animacy and goal-directedness (e.g., Csibra, Gergely, Biro, Koos, & Brockbank, 1999; Gelman & Koenig, 2001). Future research should investigate whether children that attribute agency and animacy to the computer in the CO treatment learn better than children who do not.

5. Conclusions

A number of investigators have expressed doubt that the poor performance of autistic participants on imitation tasks can be adequately explained by motor impairments (e.g., Rogers, 1999; Williams et al., 2004). Though the aim of the present study was to assess whether individuals with autism could copy novel cognitive rules independently of copying specific motor responses (cognitive imitation), our results are consistent with the view that motor impairments adversely affect the performance of individuals with autism in tasks where participants must copy novel (arbitrary) motor/actions rules from a model (i.e., motor imitation). It should not be surprising that individuals with motor impairments perform normally when imitating ‘meaningful’ actions because the familiarity and/or rehearsal of such actions are likely to mask motor deficits. The same, however, cannot be said of novel motor actions that, by definition, are unfamiliar and unlikely to have been rehearsed. Consequently, the execution of novel motor actions is a better index of motor impairments than the execution of familiar actions. Yet, the present results demonstrate that individuals with autism do not have a global novel imitation deficit, as evidenced by the fact that individuals diagnosed with autism successfully and accurately learned from a model the order of novel list items in three different imitation conditions, but did not do so in a baseline condition or as expected by chance (cf., Fig. 2).

In sum, the performance of individuals with autism in the current study has important implications for the developmental and cognitive sciences and may contribute to better educational opportunities for individuals diagnosed with autism and other disabilities. Foremost, the present study demonstrates that despite autistic individual’s widely reported impairments in tasks that involve copying novel motor rules (motor imitation), they are not similarly impaired in tasks that involve copying novel cognitive rules (cognitive imitation); a result that is inconsistent with a global imitation learning deficit.

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