

Cognitive imitation in 2-year-old children (*Homo sapiens*): a comparison with rhesus monkeys (*Macaca mulatta*)

Francys Subiaul · Kathryn Romansky ·
Jessica F. Cantlon · Tovah Klein · Herbert Terrace

Received: 11 January 2006 / Revised: 2 November 2006 / Accepted: 5 December 2006 / Published online: 8 February 2007
© Springer-Verlag 2007

Abstract Here we compare the performance of 2-year-old human children with that of adult rhesus macaques on a cognitive imitation task. The task was to respond, in a particular order, to arbitrary sets of photographs that were presented simultaneously on a touch sensitive video monitor. Because the spatial position of list items was varied from trial to trial, subjects could not learn this task as a series of specific motor responses. On some lists, subjects with no knowledge of the ordinal position of the items were given the opportunity to learn the order of those items by observing an expert model. Children, like monkeys, learned new lists more rapidly in a social condition where they had the opportunity to observe an experienced model perform the list in question, than under a baseline condition in which they had to learn new lists

entirely by trial and error. No differences were observed between the accuracy of each species' responses to individual items or in the frequencies with which they made different types of errors. These results provide clear evidence that monkeys and humans share the ability to imitate novel cognitive rules (cognitive imitation).

Keywords Comparative psychology · Social learning · Cognitive imitation

Introduction

Is the ability to learn by imitation uniquely human? As Aristotle famously wrote in the *Poetics*:

“Imitation is natural to man from childhood, one of his advantages over the lower animals being this, that he is the most imitative creature in the world, and learns at first by imitation”.

Similar views were expressed by the philosophers of the Enlightenment (Hume 1739, 1911; Rousseau 1754, 1991) and by scientists in the early history of comparative (Baldwin 1902; Morgan 1900; Thorndike 1898) and developmental (Guillaume 1968; Piaget 1962) psychology. It is now widely accepted that human newborns copy facial expressions such as tongue protrusions (e.g., Anisfeld 1991; Meltzoff 1988; Meltzoff and Moore 1977), and that older children can imitate goals (Bekkering et al. 2000) and affective states, such as anger and aggression (Bandura 1977). However, there have not been any direct comparisons of the imitative abilities of monkeys and human children. This is not surprising given the widespread belief

F. Subiaul (✉)
Department of Speech and Hearing Science,
The George Washington University,
1922 F Street, NW # 406E,
Washington, DC 20001, USA
e-mail: subiaul@aol.com

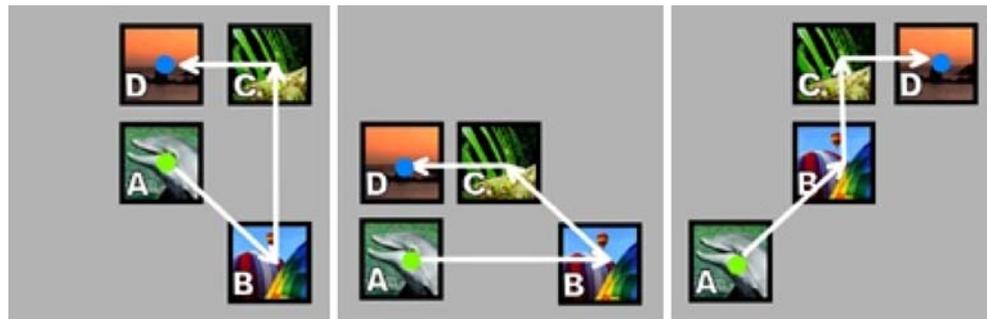
K. Romansky · H. Terrace
Department of Psychology, Columbia University,
New York, NY, USA

J. F. Cantlon
Duke University, Psychological and Brain Sciences,
Durham, NC, USA

T. Klein
Center for Toddler Development, Barnard College,
New York, NY, USA

H. Terrace
New York Psychiatric Institute,
New York, NY, USA

Fig. 1 Simultaneous chaining task. Subjects must touch each photograph in the correct sequence to receive a reward. The position of each photograph is varied randomly each trial to ensure that subjects do not learn a sequence of motor acts or spatial rules



that monkeys lack the ability to learn by imitation (Adams-Curtis 1987; Beck 1976; Tomasello et al. 1997; Visalberghi and Fragaszy 2002; Whiten and Ham 1992) and reports that young human children (ages 2–4), but not apes, can copy novel motor acts with high fidelity (Call et al. 2005; Call and Tomasello 1995; Nagell et al. 1993; Tomasello et al. 1987, 1993; see Whiten et al. 1996 for a possible exception). However, a recent demonstration of cognitive imitation in monkeys (Subiaul et al. 2004) suggests that the widely reported differences between human and non-human primates may be confounded in part by species differences in the planning and execution of novel motor actions (Johnson-Frey 2004).

Subiaul et al. (2004) showed that rhesus macaques imitate novel cognitive rules. In that study, subjects were trained to respond in a particular order to photographs that were presented simultaneously on a touch-sensitive video monitor. In a baseline condition, subjects learned the order in which to respond to list items by trial and error. In a social condition, subjects were given an opportunity to observe an experienced monkey execute a new list prior to being tested on the same list. Subjects learned new lists more rapidly when they were allowed to observe the expert execute those lists than when they had to learn new lists entirely by trial and error. This result provided a basis for directly comparing the imitative abilities of children and rhesus macaques.

To compare cognitive imitation in these two species, we trained 17 typically developing 2-year-old human children on the simultaneous chaining task (Terrace 2005). Children, like monkeys (Subiaul et al. 2004), were required to respond to lists of four simultaneously presented photographs in a particular order, irrespective of their position on a touch-sensitive monitor (Fig. 1). Random variation of the positions of the photographs from trial to trial ensured that the subject could not execute lists as a particular motor sequence and also ensured that the task could not be learned via stimulus- or local-enhancement alone (Spence 1937; Thorpe 1956).

Materials and methods

Subjects

Twenty typically developing 2-year-olds participated in this study (mean 2.52, SD 0.21). Ten were girls, and ten were boys. All the children were recruited from local daycare centers in the NYC area. Seventeen successfully completed training and of these, 15 completed at least a social or a baseline list. Only six, however, completed both a baseline and a social list. The parents of all the participants read and signed a consent form approved by the Columbia University IRB. The children's performance was compared with the performance of two adult rhesus monkeys tested in another study (Subiaul et al. 2004).

Procedures

Subjects were tested under two conditions: baseline and social. Lists trained in baseline had to be learned entirely by trial and error. Under the social condition, a naïve “student” was given the opportunity to observe an “expert” execute the list it had to learn. The student's task is analogous to memorizing someone's four-digit password by looking over their shoulder as they operate an automated banking/teller machine (ATM), with the added difficulty that the typical configuration of the numbers varied on every trial. In this task, the probability of a subject guessing the correct sequence on the first trial, and thereby earning reinforcement, is $1/4! = 0.04$. Simultaneous chains are typically learned by trial and error from feedback that follows each response, correct or incorrect. Correct responses were followed by brief (0.5 s) visual and auditory feedback; errors, by a variable time out (2–5 s) during which the screen was dark. The inter-trial-interval (ITI) was 2 s. Children were rewarded by “jumping man,” a 3 s movie clip of a man doing a backward summersault, that was accompanied by music; monkeys, by the delivery of a

190 mg banana pellet. Reward occurred only after participants responded to all four-items on the monitor correctly (the order A → B → C → D).

Training and testing: human participants

Human participants were trained and tested using one laptop computer equipped with a touch-screen in their homes by two investigators (FS and KR). Prior to testing, all participants were introduced to the task in three steps. First, the experimenter showed the subject the consequences of responding to a single item (photographs 3.8 cm × 5.8 cm) on a touch-sensitive screen (Microtouch) affixed to a laptop iBook Apple computer. Following a response—defined as making contact with an item on the screen—a border appeared around the picture, the computer generated a 1,000 Hz tone and after a 2 s ITI, the picture disappeared and reappeared in a different spatial position. Following this demonstration, the experimenter encouraged participants to respond to the single item on their own. Once participants responded comfortably to a single item on the touch-screen, they were introduced to a three-item list of arbitrary photographs. With the aid of the experimenter, participants were encouraged to respond to all three pictures and to discover the correct sequence by trial and error. As noted earlier, reinforcement consisted of “jumping man.” Participants were trained on four-item lists when they responded correctly to all three of the list items. With four-item lists, participants were encouraged to discover the correct order of the pictures by trial and error. Training ended once participants responded correctly to a four-item list. Training took approximately 30–45 min/session.

Following training, participants were tested on new lists that were presented under the baseline and the social condition in a pseudo-random order. Under the baseline condition, participants were not provided with any information as to the ordinal position of the pictures on the computer screen. At the start of the session, the laptop was placed in front of the child and the experimenters encouraged the participant to respond to the items on the screen. Because participants had to discover the serial order of each item by trial and error, this condition served as a baseline measure of trial and error learning.

Under the social condition, the investigator (“model/expert”) demonstrated how to respond to a particular list by saying “watch me” and then touching each picture on the screen in the prescribed order. Each of the model’s responses was highlighted by audio and visual feedback from the computer (described above).

This procedure was repeated three consecutive times with the same list. After the demonstration period, the computer used by the model was reconfigured (<5 s) and the child was allowed to respond.

Both baseline and social sessions were terminated once the participants responded correctly to all list items. New lists of arbitrary pictures were used under each condition and lists were never repeated. As a consequence, our measures of learning by cognitive imitation were based entirely on the acquisition of those items and not their retention.

Training and testing: monkeys

The methods used to train and test two adult rhesus macaques (Horatio and Oberon) are described in detail elsewhere (Subiaul et al. 2004). Briefly, subjects learned to execute 60 different four-item lists of arbitrarily selected photographs in two sound attenuated chambers placed next to each other. The interior walls of each chamber contained a window made of tempered glass. When an opaque partition was placed between the booths, subjects could not see each other. When the partition was removed, subjects had a full view of one another. Both monkeys were each tested on 30 four-item lists. Fifteen of those lists were collected in isolation with the partition between the chambers in place (baseline condition). On the remaining 15 lists, the partition was removed (social condition). This allowed a “student” monkey to observe an “expert” monkey execute the list on which the student would be tested.

The two monkeys tested, Horatio and Oberon, each served as a “student” and as an “expert.” The student was introduced to that same list during two successive blocks of 20 trials. The first block of 20 trials was a demonstration in which the expert executed an over-learned list. Throughout this block, the student’s monitor was dark and inactive. That arrangement allowed the student to observe, but not perform, the sequence that the expert executed in the adjacent chamber. During the second block of 20 trials (test period), the student’s monitor was activated, allowing him to respond to the new list items. The student and the expert worked side-by-side throughout the test period in full view of each other until the student completed his block of 20 trials.¹

¹ In the event that participants did not discover the serial position of list items within 20-trials, the total number of responses from the beginning to the end of the session were recorded.

Measures

Our measure of cognitive imitation was the number of responses a subject made on a new list before completing the first trial correctly. This is a very unbiased measure of cognitive imitation because, after the first correct trial (i.e., after responding correctly to all four list items—A, B, C, D—for the first time), a subject's performance could be influenced by cognitive imitation, by trial and error, or by both factors.

Results

Average rate of learning

Our results demonstrate that both human children and rhesus monkeys learned significantly faster in the social condition than in the baseline condition. As reported in an earlier study (Subiaul et al. 2004) monkeys' performance in the social condition, where subjects could glean the order of pictures from the responses of an expert monkey, significantly differed from their performance in a baseline condition ($t^{29} = 4.41$, $P < 0.001$, paired t test, one-tailed) where new items had to be learned by trial and error. Two-year olds similarly benefited from the social condition. Like monkeys, children learned significantly faster in the social condition than in the baseline condition ($t^5 = 2.06$, $P = 0.04$, paired t test, one-tailed). The relevant results are shown in Table 1.

Frequency of backward and perseverative errors

To pursue the similarity of mechanisms that children and monkeys used to discover the serial order of new list items, we performed a molecular analysis of the frequency of different types of errors that each species

made and of the accuracy with which they responded to individual list items. Previous studies have identified the relative frequencies of backward and perseverative errors (e.g., $A \rightarrow B \rightarrow A$ and $A \rightarrow C, A \rightarrow C$, respectively) as diagnostic of expertise on the simultaneous chaining task (Swartz et al. 1991; Terrace et al. 2003). Because of expertise that participants acquire while learning lists, the frequency of backward errors should be low for each species during both the social and the baseline conditions. By contrast, the relative frequency of perseverative errors should be high during the baseline condition (because participants have to learn new lists by trial and error), but low during the social condition, in which participants could learn the order of list items during the demonstration phase. As shown in Table 1, monkeys ($t^{29} = 2.96$, $P = 0.003$, paired t test, one-tailed) and children ($t^5 = 1.85$, $P = 0.06$, paired t test, one-tailed) made significantly more perseverative errors in the baseline condition than in the social condition. Monkeys across 60 new lists (30 baseline, 30 social) made a total of 10 backward errors. Children across 12 new lists (6 baseline, 6 social) made a total of 4 backward errors. For neither monkeys nor children did the number of backward errors significantly differ between social and baseline lists ($t < 0.50$, $P > 0.30$, paired t test, one-tailed).

This error pattern—a low overall frequency of backward errors, and a high frequency of perseverative errors during the baseline, but not the social condition—provides evidence that both species were performing at the same level of expertise and is consistent with the theory that both species were likely to have been using the same mechanisms when learning new lists in the social and in the baseline condition.

Accuracy of responding to individual items

To evaluate the benefit of the social condition, we calculated the conditional probabilities of a correct response at each position, from the start of a new list until the end of the first correctly completed trial [$P(A)$, $P(B|A)$, $P(C|AB)$ and $P(D|ABC)$]. Results demonstrate that both monkeys and children learned at least two items in the social condition. Monkeys' accuracy when responding to individual items in the social condition was compared to baseline and control probabilities. Results have been reported in detail elsewhere (Subiaul et al. 2004, supplementary materials; see Table 2). Briefly, in this analysis Horatio appears to have learned, on average, the first and the last items of the list the expert was executing. Whereas, Oberon appears to have learned, on average, the second and the third items on the list.

Table 1 The mean performance (SD) of monkeys and children when executing new lists in baseline and social treatments

	Monkeys	Children
Baseline	14.63 (1.85)	17.5 (2.38)
Errors		
Perseverative	4.17 (0.94)	3.2 (1.04)
Backward	0.1 (0.06)	0.1 (0.1)
Social	10.77 (1.02)****	8.45 (0.9)**
Errors		
Perseverative	2.1 (0.63)***	0.91 (0.48)*
Backward	0.133 (0.06)	0.09 (0.09)

Differences from baseline performance are in bold

**** $P < 0.001$, *** $P < 0.005$, ** $P \leq 0.05$, * $P = 0.06$

Table 2 Item-by-item accuracy

Item	A	B	C	D
Monkeys	0.23 (0.43)	0.43 (0.5)	0.51 (0.53)	0.90 (0.31)
Horatio	0.4 (0.13)**	0.27 (0.13)	0.33 (0.13)	0.87 (0.09)*
Oberon	0.07 (0.07)*	0.53 (0.12)**	0.67 (0.12)*	0.93 (0.07)
Children	0.33 (0.49)	0.53 (0.52)**	0.80 (0.41)**	0.87 (0.35)

Differences from baseline performance are in bold

Subject's mean accuracy (SD) when responding to individual new items in the correct serial order

** $P \leq 0.05$, * $P = 0.06$

Because only six children completed both a baseline and a social list there was not sufficient power to compare social and baseline item accuracies (as was done with the monkeys). Consequently, the performance of all the children that completed a social list ($n = 15$) was compared to chance probabilities in order to increase power. In a four item list the probabilities are as follows: $P(A) = 0.25$, $P(B|A) = 0.33$, $P(C|AB) = 0.5$ and $P(D|ABC) = 1.0$. As can be seen in Table 2, children, on average, learned the position of the second ($P = 0.05$, binomial test, one-tailed) and the third ($P = 0.01$, binomial test, one-tailed) items significantly faster than predicted by chance probabilities.

Discussion

Both species learned new lists faster under the social condition than under the baseline condition. It is unlikely that these similarities reflected differences in expertise because, under the same conditions, monkeys and children made the same types of errors, with equal frequency. Moreover, both monkeys and children learned the ordinal position of at least two items in the social condition. Those similarities suggest that our data cannot be explained as an artifact of different, but convergent processes.

Many discussions of imitation (e.g., Baldwin 1902; Call et al. 2005; Clayton 1978; Morgan 1900; Nagell et al. 1993; Spence 1937; Thorndike 1898, 1911; Thorpe 1956; Tomasello 1990; Tomasello and Call 1997; Visalberghi and Fragaszy 2002; Want and Harris 2002; Whiten and Ham 1992; Zajonc 1965) have identified simple perceptual and motivational mechanisms that could result in behavior that resembles imitation learning. Various features of the design of the present experiment rule out such explanations for our results. For example, it was shown that reports of imitation in human and non-human primates could be explained by the mere presence of a model/investigator (social facilitation Clayton 1978; Zajonc 1965), or by a model's

interaction with a particular object (stimulus enhancement: Spence 1937) or by a model's behavior in a particular location (local enhancement: Thorpe 1956) that draws attention to a target stimulus. Others have suggested that naïve "students" may use sophisticated modes of social learning, for example, in situations in which the student reproduces "environmental affordances" rather than a model's specific actions (emulation learning Call et al. 2005; Nagell et al. 1993; Tomasello 1990).

The simultaneous chaining task employed in the present study rules out 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, an individual's 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 ensured that there was no relationship between an item and a particular location on the screen. Improved performance due to the mere presence of an investigator or model (i.e., social facilitation) cannot explain the differences in performance between the baseline and the social conditions because the investigator was present during both testing conditions.² Finally, theories of emulation learning (Tomasello 1990) cannot explain our results because in the simultaneous chaining paradigm (1) responses are not causally related, (2) responses to the last item (associated with a reward) are not rewarded; To receive reinforcement individuals must respond correctly to all items and (3) the affordances associated with a correct response are undifferentiated (i.e., border and 1,000 Hz tone) and consequently, uninformative without the knowledge of a specific ordinal rule.

Recently, a number of investigators have employed a new control for emulation, the so-called "ghost" condition to differentiate between "imitation" and "emulation." Under the ghost condition, an observer witnesses target actions (results) that occur independently of the actions of a demonstrator (Akins and Zentall 1996; Heyes et al. 1992; Fawcett et al. 2002; Huang and Charman 2005; Klein and Zentall 2003; Subiaul et al. 2004). Non-human animals tested under the ghost control have by and large failed to learn the target actions (Akins and Zentall 1996; Fawcett et al. 2002; Heyes et al. 1994; Subiaul et al. 2004; see Klein

² Social facilitation as an explanation for the performance of non-human primates in the social condition was ruled out by a control condition in which the expert student executed a different new list while being observed by the student in the presence of another monkey (Subiaul et al. 2004).

and Zentall 2003 for an exception).³ By contrast, human children imitate in the standard and the ghost treatments (Huang and Charman 2005; Thompson and Russell 2004). Learning under such circumstances has been interpreted to mean that because only results are witnessed, individuals in the standard social learning condition (i.e., with a live model) must be learning affordances alone. The problem with this logic is two-fold. First it treats emulation and imitation as independent mechanisms rather than inter-related processes (i.e., actions are given meaning by their results). Second, and most importantly, this framework assumes that the ghost control only provide information about results, neglecting the fact that ghost controls also provide information about self-propelled movement and goal-directedness. Nevertheless, the difference between the performance of humans and animals suggests that the ghost control is a measure of something other than emulation because, at least among primates, “emulation” appears to be the default social learning strategy (e.g., Call et al. 2005; Horner and Whiten 2005).

The results of the present study differ from those observed in studies that compare the performance of young children and apes (Call and Tomasello 1995; Nagell et al. 1993; Tomasello et al. 1993, 1987). The most obvious reason for that difference is the nature of the imitative task we used. Previous studies required subjects to imitate specific novel motor acts. That was likely to have produced a confound between the ability to copy novel rules and the ability to plan and execute novel actions. On this view, human and non-human primates may differ only in their ability to imitate novel motor acts. This conclusion is consistent with research in the cognitive (Wright et al. 1985) and neural (Rizzolatti et al. 2001) sciences that have demonstrated that humans and rhesus macaques share a number of basic mechanisms and learning strategies that are essential components of imitation. Rather than challenging the uniqueness of human imitative abilities, our results can be viewed as clues about imitation’s origin and evolution.

Acknowledgments The authors would like to thank all members of the Primate Cognition Lab, the staff of the Centre for Toddler Development, and Jennifer Vonk and Daniel J. Povineilli of the Cognitive Evolution Group for their comments on

earlier versions of this manuscript. This study was supported in part by a gift from the Herb and Sheri Lurie Foundation to F. Subiaul, an NIMH grant (R01 MH40462) to H. Terrace and by a James McDonnell Foundation grant to H. Terrace, J. Metcalfe and F. Subiaul.

References

- Adams-Curtis L (1987) Social context of manipulative behavior in *Cebus apella*. *Am J Primatol* 12:325
- Akins CK, Zentall TR (1996) Imitative learning in male Japanese quail (*Coturnix japonica*) using the two-action procedure. *J Comp Psychol* 110:316–320
- Anisfeld M (1991) Neonatal imitation: review. *Dev Rev* 11:60–97
- Baldwin JM (1902) Development and evolution. McMillan, New York
- Bandura A (1977) Social learning theory. Prentice-Hall, Englewood Cliffs
- Beck BB (1976) Tool use by captive pigtailed macaques. *Primates* 17:301–310
- Bekkering H, Wohlschlagel A, Gattis M (2000) Imitation of gestures in children is goal-directed. *Q J Exp Psychol* 53A:153–164
- Call J, Tomasello M (1995) Use of social information in the problem solving of orangutans (*Pongo pygmaeus*) and human children (*Homo sapiens*). *J Comp Psychol* 109(3):308–320
- Call J, Carpenter M, Tomasello M (2005) Copying results and copying actions in the process of social learning: chimpanzees (*Pan troglodytes*) and human children (*Homo sapiens*). *Anim Cogn* 8(3):151–163
- Clayton D (1978) Socially facilitated behavior. *Q Rev Biol* 53(4):373–392
- Fawcett TW, Skinner AM, Goldsmith AR (2002) A test of imitative learning in starlings using a two-action method with an enhanced ghost control. *Anim Behav* 64:547–556
- Guillaume P (1968) Imitation in children. University of Chicago Press, Chicago
- Heyes CM, Dawson GR, Nokes T (1992) Imitation in rats: initial responding and transfer evidence. *Q J Exp Psychol* 45B:229–240
- Heyes CM, Jaldown E, Dawson GR (1994) Imitation in rats: conditions of occurrence in a bidirectional control procedure. *Learn Motiv* 25:276–287
- Horner V, Whiten A (2005) Causal knowledge and imitation/emulation switching in chimpanzees (*Pan troglodytes*) and children (*Homo sapiens*). *Anim Cogn* 8(3):164–181
- Huang C, Charman T (2005) Gradations of emulation learning in infants’ imitation of actions on objects. *J Exp Child Psychol* 92:276–302
- Hume D (1739/1911) In: Lindsay AD (ed) A treatise of human nature, vols 1–2. Dent, London
- Johnson-Frey SH (2004) The neural bases of complex tool use in humans. *Trends Cogn Sci* 8:71–78
- Klein ED, Zentall TR (2003) Imitation and affordance learning by pigeons. *J Comp Psychol* 117(4):414–419
- Meltzoff AN (1988) Infant imitation after a 1-week delay: long-term memory for novel acts and multiple stimuli. *Dev Psychol* 24:470–476
- Meltzoff AN, Moore KM (1977) Imitation of facial and manual gestures by human neonates. *Science* 198:75–78
- Meltzoff AN, Moore KM (1989) Imitation in newborn infants: exploring the range of gestures imitated and the underlying mechanisms. *Dev Psychol* 25:954–962

³ We did not use the ghost condition because the crucial parameters for that condition are not yet known and because it’s not clear why monkeys (and other animals) fail to learn under the ghost condition. Future research should directly address whether varying the salience of the computer’s responses yield results different from the negative results reported by Subiaul et al. (2004, Exp 3) and others.

- Morgan CL (1900) Animal behavior. Arnold, London
- Piaget J (1962) Play, dreams and imitation in childhood. Norton, New York
- Povinelli DJ (2000) Folk physics of apes. Oxford University Press, Oxford
- Povinelli DJ, Vonk J (2003) Chimpanzee minds: suspiciously human? *TICS* 7(4):157–160
- Nagell K, Olguin R, Tomasello M (1993) Processes of social learning in the tool use of chimpanzees (*Pan troglodytes*) and human children (*Homo sapiens*). *J Comp Psychol* 107(2):174–186
- Rizzolatti G, Fadiga L, Gallese V, Fogassi L (2001) Neurophysiological mechanisms underlying the understanding and imitation of action. *Nat Rev Neurosci* 119:593–609
- Rousseau JJ (1754/1991) The noble savage. The University of Chicago Press, Chicago
- Spence KW (1937) Experimental studies of learning and the higher mental processes in infrahuman primates. *Psychol Bull* 34:806–850
- Subiaul F, Cantlon J, Holloway R, Terrace H (2004) Cognitive imitation in rhesus macaques. *Science* 305(5682):407–410
- Swartz KB, Chen S, Terrace HS (1991) Serial learning by rhesus monkeys: II. Learning four-item lists by trial and error. *J Exp Psychol Anim Behav Proc* 17:396–410
- Terrence HS (2005) The simultaneous chain: a new approach to serial learning. *TICS* 9:202–210
- Terrence HS, Son L, Brannon E (2003) Serial expertise of rhesus macaques. *Psychol Sci* 14(1):66–73
- Thompson DE, Russell J (2004) The ghost condition: imitation versus emulation in young children's observational learning. *Dev Psychol* 40(5):882–889
- Thorpe WH (1956) Learning and instinct in animals. Methuen, London
- Thorndike EL (1898) Animal intelligence: an experimental study of the associative processes in animals. *Psychol Rev Monogr Suppl* 2:8
- Thorndike EL (1901) The mental life of the monkeys. *Psychol Rev Monogr Suppl* 3
- Thorndike EL (1911) Animal intelligence. McMillan, New York
- Tomasello M (1990) Cultural transmission in the tool use and communicatory signaling of chimpanzees? In: Gibson P (ed) "Language" and intelligence in monkeys and apes: comparative developmental perspectives. Cambridge University Press, Cambridge, pp 274–311
- Tomasello M, Call J (1997) Primate cognition. Oxford University Press, Oxford
- Tomasello M, Davis-Dasilva M, Camak L, Bard K (1987) Observational learning of tool use by young chimpanzees. *Hum Evol* 2:175–183
- Tomasello M, Savage-Rumbaugh ES, Kruger AC (1993) Imitative learning of objects by chimpanzees, enculturated chimpanzees, and human children. *Child Dev* 64:1688–1705
- Visalberghi E, Fragaszy D (2002) "Do monkeys ape?"—ten years after. In: Dautenhahn K, Nehaniv CL (eds) Imitation in animals and artifacts. MIT, Cambridge, pp 471–499
- Want SC, Harris PL (2002) How do children ape? Applying concepts from the study of non-human primates to the developmental study of 'imitation' in children. *Dev Sci* 5(1):1–13
- Whiten A, Ham R (1992) On the nature and evolution of imitation in the animal kingdom: reappraisal of a century of research. In: Slater PJB, Rosenblatt JS, Beer C, Milinsky M (eds) Advances in the study of behavior. Academic, New York, pp 239–283
- Whiten A, Cusance DM, Gomez JC, Teixidor P, Bard KA (1996) Imitative learning of artificial fruit processing in children (*Homo sapiens*) and chimpanzees (*Pan troglodytes*). *J Comp Psychol* 110:3–14
- Wright AA, Santiago HC, Sands SF, Kendrick DF, Cook RG (1985) Memory processing of serial lists by pigeons, monkeys, and people. *Science* 229:287–289
- Zajonc B (1965) Social facilitation. *Science* 149:106–109
- Zentall T (1996) An analysis of imitative learning in animals. In: Galef H (ed) Social learning in animals: the roots of culture. Academic, San Diego, pp 221–243