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Outcome-Based Observational Learning in Human Infants

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Previous work shows that infants manifest emulation learning in the use of end-state information. Outcome-based emulation has been interpreted as affordance learning or goal attribution. The present paper explores whether these two learning possibilities might be related. In 3 experiments, 17-month-old infants ($N = 180$) were presented with action outcomes across a variety of contexts and tasks: They observed either the full demonstration or the model's starting and final postures, plus the initial and end states of the object, or the latter portion of the foregoing display, or the end state of the object alone. The tasks included combinatory, noncombinatory, and body movement acts. Infants reproduced observed outcomes most often by observing the full demonstration. A similar effect was attained by exposure to both posture and configuration changes, but the effect was subject to the combinatory nature of the apparatus. In contrast, performance was less efficient after seeing the object's end state alone, suggesting that infants in the previous conditions did not simply emulate in association with the affordances. These findings support the notion that goal attribution based on sensitivity to bodily cues is reliant on the clarity of the affordances of a task.

Keywords: social learning, imitation, emulation, goal attribution, object affordances

Children acquire many cognitive skills through their attempts to imitate acts on objects after observing others. Variations of an imitative match arise from children's use of information sources potentially available in a demonstration, such as goals, actions, and results (Call & Carpenter, 2002). For example, children may prefer to copy rather than to omit a causally irrelevant act that they realize is unnecessary to achieve a certain outcome; they may emulate another person's intended but unconsummated acts as a consequence of intention reading; or they may devise their own strategies to induce an environmental result in the absence of observed contextual acts. These distinctions suggest that different processes of social learning may be distinguished by the relative involvement of information sources. The study of how children learn others' acts in contexts of observational learning is thus an important topic for our understanding of social–cognitive development in early childhood.

A growing body of research has been interested in mechanisms of social learning during childhood. By applying concepts and methods from comparative sciences, what is typically called imitation in developmental psychology has been questioned by contemplating an array of other nonimitative social learning processes, including stimulus (local) enhancement, mimicry, and emulation (Want & Harris, 2002). Many of these distinctions are filtering through to the developmental study of imitation. The present study aims to analyze the process of emulation learning, an observer's tendency to reproduce action effects at the cost of details of the model's strategy (Tomasello, 1990).

To better understand how different sources of information influence the tendency to emulate, Whiten and colleagues identify four learning possibilities: end-state emulation, goal emulation, object movement reenactment, and affordance learning (Whiten, Horner, Litchfield, & Marshall-Pescini, 2004; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009). In end-state emulation, an observer simply copies the outcome of a modeled sequence without evaluating its goal-directedness. In goal emulation, the observer has insight into goal-directed actions but attempts to devise his or her own strategy to reproduce the outcome. Object movement reenactment occurs when the observer copies the way in which an apparatus moves and the outcome following that movement. Affordance learning involves the observer learning about the dynamic properties of, or temporal-spatial causal relations between, objects through seeing object motions or action outcomes.

To tease apart alternative processes of emulation, one would need a technique in which specific source information about the model is degraded. Recent research has documented infants' capability to emulate in a "ghost" condition, where only the object movements required to produce a desirable result are displayed (Huang & Charman, 2005; Slaughter & Corbett, 2007; Thompson & Russell, 2004). Because the absence of observable outcomes has been shown not to detract from this tendency (by presenting the object movements extracted from the film consisting of a person's unsuccessful acts), a more plausible explanation for emulation in

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the context of a ghost display thus seems to be affordance learning rather than object movement reenactment (Huang & Charman, 2005).

In a further approach, emulation is evidenced by the opportunity to learn from end-state displays (Call, Carpenter, & Tomasello, 2005; Huang, Heyes, & Charman, 2002, 2006). Huang et al. (2002, Experiment 1) explored whether imitative performance elicited by Meltzoff's (1995) behavioral reenactment technique could be due to learning about object affordances. Meltzoff (1995) showed that 18-month-old infants are as likely, for example, to drape a loop over a prong protruding above a board when they have observed an adult attempt but fail to consummate this end result, as when they have seen the adult successfully perform it. Using a novel condition of emulation learning, Huang et al. (2002) exposed infants to the initial and end states of the object set only, by deploying a screen. For example, infants saw the loop lying on the table next to the board and then the loop resting on the upper prong after the occluding process. Infants produced the target act as their first response most often after seeing the full demonstration. However, they produced as many target acts after exposure to the end-state display as in the behavioral reenactment procedure where they did not actually see the end states completed. Because end configurations specify affordances between objects, Huang et al. (2002) suggested that affordance learning plays a role in the emulation-learning condition and in the behavioral reenactment procedure. If infants' reenactment of intended acts is attained by imitation, one would predict that they should have benefited from the model's body movements as clues to unconsummated intentions. Given that the end state in the emulation-learning condition does not include the model's final posture, it seems unlikely that infants' performance in the behavioral reenactment procedure has been necessarily guided by sensitivity to the model's body movements. However, it could be argued that seeing the initial and end states of the object might recruit goal emulation through causal attributions for the observed outcome and the model (Hopper, 2010; Whiten et al., 2004). That is, rather than simply emulating the physical affordance of the end state, the child might have interpreted the outcome as the goal of the model attempting to produce the target act.

The present research sought to replicate and extend the end-state paradigm with a novel condition where the child had no information about initial states and accessed end states directly. This new comparison is important to delineate the processes of goal emulation and affordance learning. If emulation involves causal attributions based upon changes between initial and end states, the lack of initial-state information would detract from the child's drawing inferences. Alternatively, it might be the case that the child simply produces motor features associated with afforded properties, in which case mere perception of an end state itself would be sufficient to enable emulation.

The second addition was a novel condition where the model's postures accompanying the object's initial and end states were also displayed. Given that early goal attribution is sensitive to human agency (Meltzoff, 1995; Woodward, 1998), if seeing the initial and end states promotes causal attributions, extra information about the initial- and end-state difference in hand position would enhance the tendency toward goal emulation. Therefore, performance in this condition would resemble that produced by sight of fully demonstrated acts.

A further addition was the inclusion of a noncombinatory task. In the Huang et al. (2002) study, the task consisted of combinatory acts only. Two different parts of the object set were separate in the initial state and then related to one another configurally in the end state. Affordance learning may be more likely to occur because the end configuration, in this case, specified both the affordances between object parts and the implied trajectory of displacement. Indeed, several previous studies have indicated that task demands modulate a child's social learning strategy (Bauer & Kleinknecht, 2002). To compare emulation across tasks, both combinatory and noncombinatory object manipulations were employed in the present study. Unlike the combinatory task, the noncombinatory task had a movable embedded accessory that could be manipulated to bring about an end result. Although the configuration change accompanying the end result was relatively nonsalient, the movement of the accessory was suggestive of the object's dynamic properties. The availability of affordances should make emulation equally likely.

Experiment 1A

End-State Configuration Versus Posture Change

The first experiment investigated infants' use of action outcomes to observationally learn about combinatory or noncombinatory manipulation of objects in a variety of contexts. They were either watching the acts and outcomes fully demonstrated, or watching the initial and end states of the objects presented with the accompaniment of the experimenter's starting and final postures, or receiving the end states of the objects only. It was predicted that, if infants simply learned about motor features associated with object affordances without making causal attributions for the outcomes, similar performance would be obtained in these latter two conditions, and that, if configural end results provided more information about affordances between objects, performance on the combinatory task would be higher than that on the noncombinatory task.

Method

Participants. Eighty 17-month-old (M = 17.14, $SD = 0.74$) infants (45 males) participated in Experiment 1A. The sample was 94% ethnic Chinese in Taiwan and 6% mixed ethnicity. Six additional infants were tested but not included in the final sample due to noncooperation ($n = 4$), fussiness ($n = 1$), or procedure error ($n = 1$).

Apparatus. There were two tasks. Each consisted of two object sets that could be manipulated with either noncombinatory or combinatory acts (see Figure 1). In each task, the outcome of one object set was characterized primarily by visual features and the other primarily by auditory features. The object sets of dumbbell and triangle comprised the noncombinatory task. They were all-in-one items, accessorized with an embedded attachment that could be moved to produce a specific outcome with one single-step action. The object sets of stick-box and loop-prong comprised the combinatory task. They had two separate parts that could be combined into a novel end configuration. All but the triangle were replicated or adapted from the stimuli used in previous studies (Meltzoff, 1995; Huang et al., 2002).

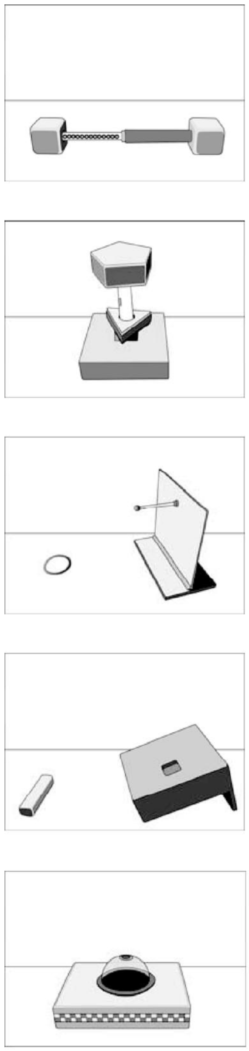

Figure 1. Test stimuli used in Experiments 1A and 1B (1–4) and Experiment 2 (5).

This dumbbell-shaped toy consisted of two cubes, each with a plastic tube extending from it on one side. One tube is painted yellow; the other is transparent and filled with colorful beads. The transparent tube was fitted snugly inside the yellow tube before the main display began. Once the cubes were pulled outward, the beads inside the transparent tube were explicitly observable. In previous research, the dumbbell came into two halves when pulled outward. In order to diminish information about configuration change, alterations were made to the original design so that the tubes never disconnected with each other.

The triangle consisted of a square acrylic box and a pentagon acrylic box, respectively connected to the lower end and upper end of a vertical tube that penetrated a triangle that had a round hole cut out of the center. The triangle could be moved up and down along the tube. When it passed through the middle of the tube, a beeper inside the base was activated.

The third object consisted of a rubber loop and a vertical rectangular board set on a wooden base. A plastic prong with a bulbous point protruded horizontally from the board at a position slightly beneath its upper edge. The loop could be draped over the prong.

The fourth object consisted of a wooden block and a box. A recessed rectangular button, which activated a beeper inside the box, lay on the front surface of the box. The end of the block could fit inside the recess to push the button to activate the beeper.

Experimental design. All participants were tested individually in a laboratory at the department. Following a warm-up activity, the infant and parent were led to a testing room. The infant was seated in a high chair with the parent sitting next to her (or on the parent's lap if she refused to sit in the high chair) in front of a table (0.75 × 1.5 m) opposite the experimenter. A curtain (0.6 × 1.5 m) was set on the table between the infant and the experimenter. An assistant operated the curtain out of the infant's view. If the child appeared frightened by the creak during operation of the curtain, a cardboard (0.6 × 0.8 m) was used as a replacement. After the infant was settled, the experimenter reminded the parent not to speak or act in any way that might influence the child's response and then started the first presentation. Participants were randomly assigned to one of the four conditions, resulting in 20 infants per condition. Sequences for the four items were counterbalanced within each condition. The pilot study showed that repeatedly opening and shutting the curtain distracted the child. Hence, each demonstration was presented once instead of twice (Huang & Charman, 2005) or three times (Meltzoff, 1995; Nielsen, 2006). Therefore, the present study provided a conservative estimate of observational learning. There were four conditions in the study: the full-demonstration, initial-end (object, posture), end (object), and baseline conditions. Table 1 compares aspects of information comprising the main displays across experiments.

In the full-demonstration condition, the experimenter produced a specific target act with each object. The object was set in the initial state, lying between the experimenter's hands. The experimenter said, "Look over here," to attract the infant's attention each time he started to model the target act. Following the end state that lasted for approximately 5 s, the curtain was closed. The experimenter disassembled the end state behind the curtain. Lastly, the curtain was opened, displaying the initial state of the object lying between the experimenter's hands.[1] For the dumbbell, the demonstrated act was to pick it up by the two cubes and to pull it outward, displaying the colorful beads inside the inner tube. For the triangle, the demonstrated act was to move the triangle upward with both hands until it passed the middle of the tube and activated the beeper inside the base. For the stick-box, the demonstrated act was to use the stick to push in the recessed button to activate the beeper inside the box. For the loop-prong, the demonstrated act was to raise the loop up to drape it over the prong so that the loop rested on the prong.

[1] In order to reduce exposure to the experimenter's manipulation of the object, the end state of the object was disassembled into its constituent components behind the curtain before it was given to the child. Although previous research has not examined whether the way the experimenter relocates test materials might influence observational learning, I think that the initial state places the object in a neutral position that makes infants less likely to visually explore various properties of the object.

Table 1
Comparisons of Source Information Comprising Observational Conditions Across Experiments

Component and condition	Baseline	Full model	End (object)	Initial-end (object, posture)	Initial-end (object)
Initial state					
Object	Yes	Yes	No	Yes	Yes
Posture	Yes	Yes	No	Yes	No
Action	No	Yes	No	No	No
End state					
Object	No	Yes	Yes	Yes	Yes
Posture	No	Yes	No	Yes	No
Occluding process					
No. Opening	Visual: 0; auditory: 0	Visual: 1; auditory: 1	Visual: 2; auditory: 1	Visual: 2; auditory: 2	Visual: 2; auditory: 1
No. Closing	Visual: 0; auditory: 0	Visual: 1; auditory: 1	Visual: 1; auditory: 1	Visual: 2; auditory: 2	Visual: 2; auditory: 1

Note. Visual = the objects affording primarily visual outcomes (dumbbell, loop-prong, and light-box); auditory = the objects affording primarily auditory outcomes (triangle and stick-box); occluding process = the number of the times the curtain was opened and closed during demonstration.

In the initial-end (object, posture) condition, the experimenter presented the initial and end states of the object, which were accompanied by the starting and final positions of his hands. As in the full-demonstration condition, the object was set on the table, lying between the experimenter's hands. This lasted for about 5 s. The assistant then closed the curtain. The experimenter produced the target act unseen by the infant. Once the end state was achieved, the curtain was opened to display the end state of the object and the final posture for another 5 s. For the dumbbell, the end state was the transparent tube extending from one cube and the colorful beads inside the tube; the final posture was the experimenter holding the dumbbell with one hand over each end. For the triangle, the end state was the triangle staying halfway between two ends, with a beeping sound coming from the base; the final posture was the experimenter holding the triangle with both hands. For the loop-prong, the end state was the loop resting on the prong; the final posture was the experimenter's right hand staying in front of the bulbous tip of the prong. For the stick-box, the end state was the stick resting on the button, with a beeping noise coming from the box; the final posture was the experimenter's right hand holding the stick upright. As in the full-demonstration condition, the experimenter said, "Look over here," when the curtain was opened to reveal the main display. Note that, for the triangle and stick-box, the experimenter activated the beeper before the curtain was opened. This was to minimize the opportunity for infants to witness the experimenter complete the last part of the target act. During the main display, the model looked at the infant but without giving affective or linguistic cues. After that, the curtain was closed. The result was disassembled. Lastly, the curtain was opened, showing the initial state of the object and the starting posture.

In the end (object) condition, the child was exposed to the end state of the object without prior exposure to its initial state. The curtain was closed at first. The experimenter produced the target act behind the curtain. For the dumbbell and loop-prong sets, the end states were in visual mode. When the curtain was opened, the child was exposed to the beads inside the transparent tube or the loop resting on the prong (the experimenter had put the hands back under the table after completing the act). As before, the experimenter said, "Look over here," when the curtain was fully opened. During the presentation, the model looked at the infant but without giving affective or linguistic cues. The display lasted for 10 s. The curtain was then closed. When the curtain was opened again, the object was set in the initial state. For the triangle and stick-box, the end states were in auditory mode. The experimenter activated the beeper while the curtain was closed. The object's end configuration is never revealed. He said, "Look over here," before he started to activate the beeper. The sound lasted for 10 s. After that, the curtain was opened and the object was set in the initial state.[2]

In the baseline condition, the child did not see any act with each object. The curtain stayed open throughout the testing. The experimenter set the object in the initial state out of the child's reach. His hands lay on the table beside the object. He used the words "look over here" to engage the child to look at the object. The static presentation lasted for 10 s. Then the object was placed in front of the child. This procedure was repeated for each of the four objects.

Scoring. Infants were allowed 20 s from the time they initially touched the object in which to reproduce the target act. The presence of the target act was noted at the infant's first act and in the 20-s response period. The adoption of a comprehensive scoring strategy was important for two reasons. First, if infants imitatively learn an observed act, they should reproduce it in a direct manner without trial and error. Indeed, several previous studies have found that an observer's initial response after a demonstration is maximally informative about imitation (Whiten, Custance, Gomez, Teixidor, & Bard, 1996; Heyes & Saggerson, 2002; Huang et al., 2002). Second, coding the presence of the target act in a 20-s response period is a more common strategy reported in developmental studies (Meltzoff, 1988, 1995; Nielsen, 2006). A comparison of participants' performance between the two measures may allow imitative and nonimitative social learning to be explored further.

[2] The experimenter was unable to make eye contact with the child when only sounds were presented behind the curtain in the end (object) condition, but he actually made eye contact with the child when handing the object to her. The current study aimed at identifying the relative influences of various components normally comprising an object-directed act. Although gaze was not eliminated as a potential source of information, the child was directed to notice the object and/or the experimenter's hands (rather than his face) during the presentation.

The behavioral criteria of the target acts were as follows. For the dumbbell, the child pulled the dumbbell outward so that the beads inside the transparent tube were revealed. For the triangle, the child moved the triangle upward until it passed the middle of the tube so that the switch inside the tube was turned on. For the loop-prong, the child picked up and draped the loop over the prong so that the loop rested on the prong. For the stick-box, the child used the stick to push the recessed button on the top of the box so that the beeper inside the box was activated.

One research assistant scored all videotaped test sessions. To assess interrater reliability, an observer who was naïve to the hypotheses of the experiment independently coded 25% of the total sample (five infants per condition). Interrater agreement was 100% for both target acts produced at the first act and in the 20-s response period.

Results

There were no significant differences between sexes or orders of presentation of the items for the dependent variables. Therefore, sex and order were collapsed in subsequent analyses.

Because no significant differences in production of the target act were found between items comprising each task either at the first act (McNemar tests: $p > .08$, noncombinatory; $p > .70$, combinatory) or in the 20-s response period (McNemar tests: $p > .09$ and $p > .70$, respectively), the scores from the items of each task were combined to form a composite score. Figure 2 presents mean target acts produced by infants at the first act and in the 20-s response period as a function of experimental condition. Condition differences were assessed by separate ANOVAs within each task.

For the noncombinatory task, there was a main effect of condition on the mean number of target acts produced at the first act, $F(3, 76) = 11.5$, $p < .001$, and in the 20-s response period, $F(3, 76) = 7.37$, $p < .001$. Follow-up Ryan's tests ($p = .05$) within each measure showed a similar pattern of group differences: the full-demonstration group produced more target acts than did the initial-end (object, posture), end (object), and baseline groups. There was no difference between the latter three conditions.

For the combinatory task, there was a main effect of condition on the mean number of target acts produced at the first act, $F(3, 76) = 10.5$, $p < .001$, and in the 20-s response period, $F(3, 76) = 16.19$, $p < .001$. Follow-up comparisons using Ryan's tests ($p = .05$) showed that the full-demonstration and initial-end (object, posture) groups performed equally well on each measure, both of whom outperformed the end (object) and baseline groups. Although the first act analysis revealed no difference between the latter two conditions, the end (object) group was superior to the baseline based on production of target acts in the 20-s response period.

It should be noted that while the end states of triangle and stick-box were presented in auditory-visual mode in the initial-end (object, posture) condition, they were presented in auditory mode only in the end (object) condition. To examine the unimodal versus bimodal difference in displaying the end states, these two conditions were compared for each item. For the stick-box, infants in the initial-end (object, posture) condition (19 of 20) produced the target act more often than infants in the end (object) condition (8 of 20), $\chi^2(1, N = 40) = 13.79$, $p < .001$. For the triangle, infants in these two conditions (8 and 7 of 20, respectively) were equally likely to produce the target act, $\chi^2(1, N = 40) < 1$.

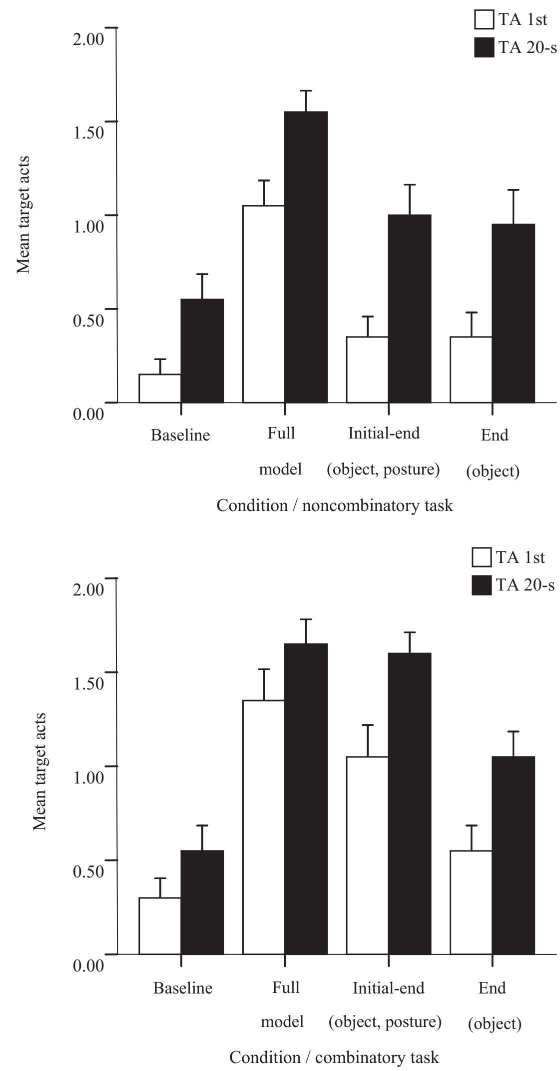

Figure 2. Mean target acts (+1 *SE*) produced at the first act (TA 1st) and in the 20-s response period (TA 20-s) on each task in Experiment 1A.

On the other hand, in the end (object) condition, the end states of dumbbell and loop-prong were presented in visual configurations, as opposed to the end states of triangle and stick-box that were presented in sounds (divorced from their sources) behind the curtain. To determine whether perceptual features of the displayed outcomes bias the tendency to emulate, item differences were examined for each task using McNemar's tests. The proportions of children producing the target act with each item in this condition were as follows: dumbbell, 45%; triangle, 35%; stick-box, 40%; loop-prong, 65%. No difference was found either between dumbbell and triangle ($p = .13$, noncombinatory task) or between stick-box and loop-prong ($p = .27$, combinatory task).

Finally, the conditions also differed in terms of the number of times that the curtain was opened and closed (see Table 1). To clarify whether the occluding process might have drawn attention to various aspects of the objects, and thereby encouraged exploratory activity, mean numbers of responses produced within 20 s (see Figure 3) were further analyzed. Because the number of openings and closings involved in setting a visual or auditory exposure in the end (object) condition varied (3 vs. 1), the effects of the occlusion process on exploratory activity were examined using separate one-way ANOVAs on each item. None of these comparisons revealed significant effects of the occlusion process: all $ps > .10$.

To determine whether different perceptual features of the outcomes the objects afforded might influence object exploration, mean numbers of responses produced in the response period were subject to separate 4 (condition) × 2 (item) mixed-model ANOVAs on each task. Significant differences were found between items for each: noncombinatory, $F(3, 76) = 14.34$; combinatory, $F(3, 76) = 29.71$, both $ps < .001$. There were no significant effects of condition: $p = .288$ and $p = .110$, respectively. Overall, infants interacted with objects that afforded sounds (i.e., triangle and stick-box) more frequently than with objects that afforded visual configurations only (i.e., dumbbell and loop-prong). Although the sounds were presented behind the closed curtain, the auditory feature was sufficient to induce infants to explore a subsequently presented object.

Discussion

Experiment 1A extends the results of the Huang et al. (2002) study in two ways. First, it demonstrated that emulation is relatively efficient when the end state specifies a combinatory outcome. No evidence of emulation was found with the noncombinatory task. Second, the role of end configuration in inferring acts is context-dependent. Whereas exposure to the full demonstration or to the initial and end states of the object, and the starting and final postures induced a similar performance of the target act, emulation is much less successful by seeing the end state of the object alone.

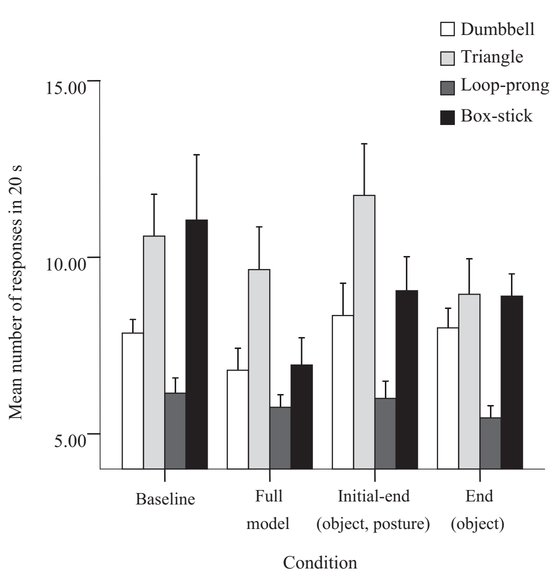

Figure 3. Mean number of responses (+1 *SE*) produced in the 20-s response period for each item in Experiment 1A.

Given that differences between hand positions are highly suggestive of the model's intentional stance, it is very likely that infants in the initial-end (object, posture) condition benefited from goal emulation. However, if they were making causal attributions for the model and the outcome, emulation should have been equally efficient across tasks. Goal attribution thus appears not the only mechanism. It remains to be shown whether seeing the initial and end states of the combinatory task is more likely to induce affordance detection than seeing the end state alone. If so, the tendency to emulate with the combinatory task may be interpreted as the combined effects of affordance learning and goal emulation. Experiment 1B was designed to test whether the superior emulative performance on the combinatory task was due to seeing changes in posture or changes in object configuration.

Experiment 1B

The Role of Posture Change in Initial- and End-State Difference

The results of Experiment 1A suggest that seeing the object's end state is not sufficient for a child to derive the combinatory act associated with the affordances specified. Nevertheless, it is not clear whether it was due to the lack of prior knowledge about the object's initial state or the absence of the model's accompanying postures. Exposure to the initial and end states of the object might be sufficient to support causal inference about the target act. The purpose of Experiment 1B was thus to investigate whether information about posture change was critical to the effect of the initial-end (object, posture) condition in Experiment 1A.

Method

Participants. Forty 17-month-old (M = 17.38, *SD* = 0.57) infants (23 males) participated in Experiment 1B. All were ethnic Chinese in Taiwan. Ten additional infants were tested but not included in the final sample due to noncooperation ($n = 5$), fussiness ($n = 3$) or procedure error ($n = 2$).

Apparatus, procedure, and scoring. The test stimuli were identical to those used in Experiment 1A. The setting and warm-up followed those described in Experiment 1A. The experimental design included an initial-end (object, posture) condition and an initial-end (object) condition (see Table 1). The initial-end (object, posture) condition was identical to that involved in Experiment 1A. The initial-end (object) condition followed the logic of the emulation-learning condition used in the Huang et al. study (2002, Experiment 1). At first, the initial state of the object was set on the table, which lasted for about 5 s. The assistant closed the curtain. The experimenter produced the target act behind the curtain. Once the act was completed, the curtain was opened. The end state of the object was presented to the child for another 5 s. After that, the curtain was closed. The end state was disassembled, unseen by the child. Lastly, the curtain was opened. The initial state of the object was presented again. To preclude information about posture change, the experimenter's hands were always under the table during the main display.

As before, infants were allowed 20 s from the time they first touched the object in which to reproduce the target act. The behavioral definitions of coding the target acts were identical to those described in Experiment 1A. A research assistant scored all videotaped test sessions. A second observer, who was naïve to the hypotheses of Experiment 1B, scored 25% of the total sample (five infants per condition). Interrater agreement was 100% for both target acts produced at the first act and in the 20-s response period.

Results

No significant differences were found between sexes or orders of presentation of the items for the dependent variables. Therefore, sex and order were collapsed in subsequent analyses. As in Experiment 1A, no significant differences in production of the target act were found between items comprising each task either at the first act (McNemar tests: both *p*s = 1.00, noncombinatory and combinatory) or in the 20-s response period (McNemar tests: $p >$ .83 and $p = 1.00$, respectively); the scores from the items of each task were thus combined to form a composite score. Figure 4 presents mean target acts infants produced at the first act and in the 20-s response period as a function of condition. Performance on each task was assessed using independent *t* tests.

For the noncombinatory task, infants produced a similar number of target acts in these two conditions, either at the first act, $t(38) < 1$, or in the 20-s response period, $t(38) = 1.59$, $p = .12$. For the combinatory task, infants produced more target acts in the initial-end (object, posture) condition than in the initial-end (object) condition, both at the first act, $t(38) = 3.82$, $p < .001$, and in the 20-s response period, $t(38) = 2.62$, $p = .013$.

To confirm whether infants in the initial-end (object) condition actually benefited from additional information about the object's initial state, cross-experiment comparisons were made between the initial-end (object) condition and the end (object) condition from Experiment 1A. The results showed that there were no group differences on any of the tasks either at the first act or in the 20-s response period; all $t(38) < 1$.

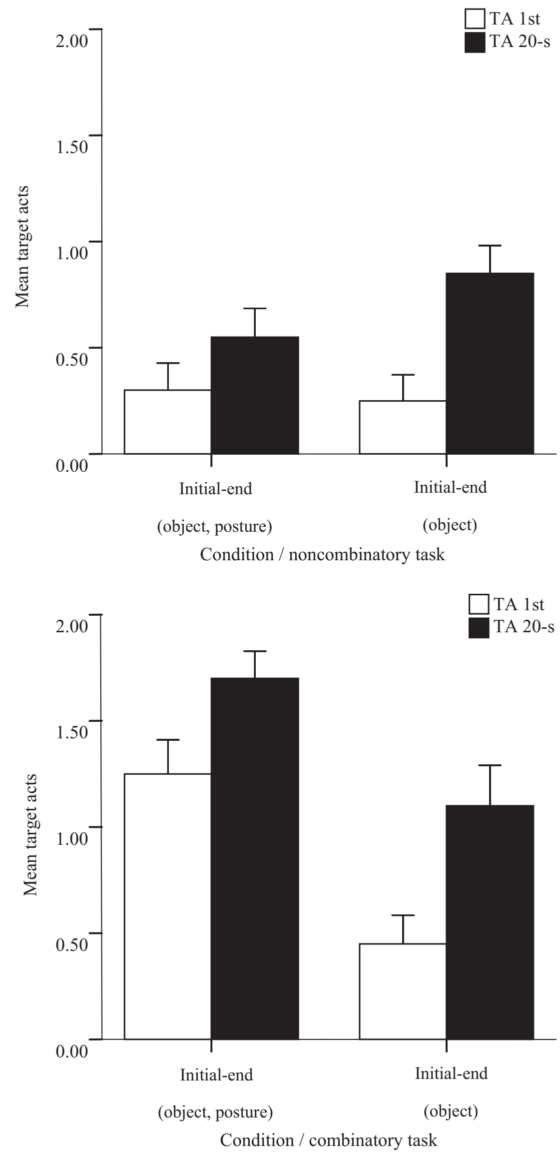

Figure 4. Mean target acts (+1 *SE*) produced at the first act (TA 1st) and in the 20-s response period (TA 20-s) on the each task in Experiment 1B.

Discussion

In Experiment 1B, infants in the initial-end (object) group were exposed to the initial and end states of the object, but in neither the noncombinatory nor the combinatory task was there a significant difference between the performance of this group and the end (object) group (Experiment 1A). Infants in the initial-end (object, posture) condition were given additional information about the model's postures, and they outperformed infants in the initial-end (object) condition. Experiment 1B replicates the results from Experiment 1A in confirming the superior tendency to emulate combinatory outcomes in the same age group.

The superior performance of infants in the initial-end (object, posture) condition reveals that their exploitation of information sources is maximized by the presence of the model's static postures. Such sensitivity to bodily cues suggests that they may have engaged in goal emulation through causal attribution for the model and the observed outcome. However, given that the final posture and the end configuration were causally related, it may be that goal attribution in this case is susceptible to the salience of the affordances involved. That is, infants in the initial-end (object, posture) condition were more successful in emulation, perhaps, because they were aware that the posture change bore a causal relationship to the resultant configuration. Further, the combinatory and noncombinatory outcomes differ in the salient features inherent in their end configurations. This may explain why emulation differentially occurred between tasks. If goal attribution interacts with affordance learning, a diminution of the causal relationship between object transformation and posture change would detract from the tendency to emulate. In Experiment 2, we test if a similar matching performance would be replicated in the initial-end (object, posture) condition where posture change is presented in such a way as to preclude affordance learning (by making observable object motions unavailable).

Experiment 2

Posture Matching and Elimination of Affordances

Experiments 1A and 1B demonstrated that the saliency of differences in posture and object configuration influences infants' abilities to learn by emulation. Experiment 2 specifically looked at their sensitivity to posture change in a situation, where causal information about object transformation was not available. The classical head touch imitation task that Meltzoff (1988) had used with preverbal infants served this purpose. The head touch task has the benefit of presenting the topography of the experimenter's body movement (head action) without bringing about object motions. It was therefore used to eliminate the operation of affordance learning.

Previous studies have reported that infants as young as 12 to 14 months old readily copy a model's use of the head to turn on the light box by observation (Gergely, Bekkering, & Kiraly, 2002; Meltzoff, 1988; Schwier, van Maanen, Carpenter, & Tomasello, 2006; Zmyj, Daum, & Aschersleben, 2009). Following the initial-end (object, posture) condition used in Experiments 1A and 1B, the child was required to reproduce the particular movement associated with the light effect based on changes in effect saliency and posture. Given young children's susceptibility to causal information (McGuigan & Whiten, 2009; McGuigan, Whiten, Flynn, & Horner, 2007), it was predicted that when information on configuration change was made unavailable, 17-month-old infants might be less likely to reproduce the topography of the static final posture. However, given that using the hands to touch the box is the default action for light activation, and a full head touch is required to justify outcomes of observational learning (Paulus, Hunnius, Vissers, & Bekkering, 2011), it may become difficult to differentiate imitation and emulation in this particular case. It should be noted that, by design, posture change is a means to light activation. Experiment 2 endorsed the possibility that the initial- and end-state difference provides the basis for making causal attributions about changes in posture and effect saliency. As a successful attempt involves reproducing both the posture and the effect, we use "goal emulation" here to refer to light activation based on infants' own recreation of the intermediate movement, which is unobserved and needs to be inferred in some way.

Method

Participants. Sixty 17-month-old (M = 16.75, *SD* = 1.47) infants (39 males) participated in Experiment 2. All were ethnic Chinese in Taiwan. Eight additional children were excluded from the final sample due to fussiness ($n = 3$), procedure error ($n = 1$), or noncooperation ($n = 4$).

Apparatus, procedure, and scoring. The setting and warm-up were identical to those described in Experiments 1A and 1B. The head touch task (see Figure 1) was a light box adapted from that used in the Meltzoff study (1988). It was a translucent green plastic box (15 × 20 × 5 cm) with a translucent plastic half-globe (11.5 cm in diameter) on its top. The half-globe was connected to a switch inside the box, and, when touched, the box and the half-globe were illuminated by the lamps inside.

The experimental design included three conditions: the full-demonstration, initial-end (object, posture), and baseline conditions. The demonstration and test procedures for these conditions were identical to those described in Experiment 1A. In the full-demonstration condition, at first, the light box lay between the experimenter's hands; the experimenter said, "Look over here," then leaned forward and attempted to touch the half-globe with the forehead; finally, the experimenter's head rested on the half-globe, which activated the lamps inside the box. In the initial-end (object, posture) condition, the light box lay on the table between the experimenter's hands; the assistant closed the curtain; the experimenter leaned forward and touched the half-globe with the forehead behind the curtain; the curtain was opened; and the illuminated box was shown with the experimenter's head resting on the top. As in the preceding experiments, the experimenter said, "Look over here," when the curtain was fully opened. In both conditions, the curtain was closed after the main display, which lasted for 5 s, and then the initial state was restored unseen by the infant. In the baseline condition, neither the action nor the result was presented on the light box. The experimenter used the words "look over here" to engage the child to look at the object. The static presentation lasted for about 10 s.

Performance of the target act was coded if the child leaned forward and made contact with the half-globe with any part of the face to activate the light. A research assistant scored all videotaped test sessions. A second observer, who was blind to the hypotheses of the study, scored 30% of the total sample (six infants per condition). Interrater agreement was 89% and 100% for the target act produced at the first act and in the 20-s response period, respectively.

Results

Figure 5 presents the number of infants whose first response was coded as producing the target act. The rate of reproductions with the light box was, overall, very low. Only three infants used their head to activate the light, compared with 36 infants who manually turned on the light. Overall, 93% of infants (56 of 60) touched the box with hands as their first act. When considering performance in the 20-s response period, the full-demonstration group (9 of 20) produced the target act more often than the baseline (0 of 20), Fisher test, $p = .001$. The initial-end (object, posture) group (4 of 20) did not differ from each of two other groups, both Fisher tests, *ns*.

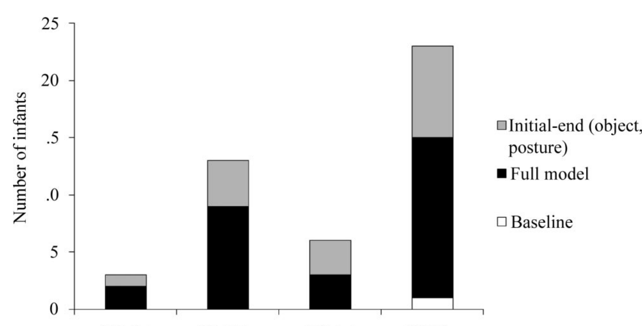

Figure 5. Number of infants who produced the target act (TA) or copied the posture (CP; including both unsuccessful and successful attempts) at the first act (1st) and in the 20-s response period (20-s) in Experiment 2.

To check if infants had attempted to produce the head touch but without success, we followed Meltzoff's (1988) procedure to recode whether infants bent their waist but failed to touch the box with their forehead (missing contact by no more than 10 cm). As seen in Figure 5, Fisher tests showed that the full-demonstration and initial-end (object, posture) groups were more likely to copy the posture at least on one occasion in the 20-s response period than the baseline, $p < .001$ and $p = .02$, respectively. There was a marginally significant difference between the full-demonstration and initial-end (object, posture) groups, χ^2 (1, $N = 40$) = 3.64, $p = .057$.

Discussion

When the experimenter's "forehead" served as the means of illuminating the box, there was no evidence that infants could reproduce intermediate body movements based on static body postures. Imitation was evidenced only after exposure to the full head touch. Although seeing the starting and final postures is suggestive of intentions, such experience does not enable goal emulation when the dynamic affordances of the object are not available. In light of the results of Experiments 1A and 1B, it now seems likely that infants in the initial-end (object, posture) condition failed to encode sufficient information about the target act from the noncombinatory task in the first place. One possible explanation may be that the object's spatial transformation was so small that infants might have neglected the relevant aspects of the posture. In other words, the initial- and end-state difference in object configuration may play a role in detecting posture change as the relevant portion of the demonstration. Relatively unsuccessful performance of the target act in this particular case suggests that infants' encoding of bodily cues from static body postures may be susceptible to the concurrence of the spatiotemporal causal relations of objects.

General Discussion

As an extension of previous research, which found that seeing the initial and end states of the object induces emulation learning in 19-month-olds (Huang et al., 2002), the present results suggest that the saliency of posture change and object transformation can mediate this effect. This is implied by similar effects of watching a full or partial solution on imitation of combinatory acts on objects. Like infants who saw the full demonstration, infants who were exposed to the initial and end states of the object, and the model's starting and final postures, reproduced the specific target act directly as their first response. The present study contrasts with the Huang et al. (2002) study that showed that observing the initial and end states induced a similar performance of the target act as observing the full demonstration only when scoring all acts produced in the 20-s response period. The detection of sensitivity to a model's posture change on infants' first responses is compelling given that the stimulus display is modest and presented only once. The effect detected over responses in the 20-s response period also suggests that infants who were exposed to the end state alone did not benefit from exploration of the object. Here we explore some possible reasons for infants' use of information on posture change in the context of emulation learning.

First, the ability to use information on posture change in reproduction of the displayed outcome could not be solely due to goal attribution. If posture change was the only potential source of information, the superiority of seeing the starting and final postures would have been shown conclusively, promoting observational learning of not only combinatory acts but also noncombinatory acts and novel body movements. Nevertheless, reliable reproduction of these latter acts was observed only after seeing a full demonstration.

Similarly, the effect is unlikely to be due solely to affordance learning. The end state of the object set presented in each partial solution provided equal access to the affordances between objects. If infants were attracted to motor features associated with specified affordances, they should have performed similarly within each task regardless of observational conditions. In fact, they learned much more than object affordances. The addition of accompanying postures facilitated infants' emulative performance, despite the relative tendency to emulate salient changes in object configuration.

We can also rule out the occluding procedure as distraction or facilitation, given that infants across the four conditions (Experiment 1A) were equally likely to explore the objects, yet they differed in production of the target acts. We also rule out item differences in performance of the target acts, despite a greater tendency to act toward the objects that afforded auditory features. It is worth noting that auditory exposure produced better combinatory performance in the initial-end (object, posture) condition where the curtain was opened and closed for four times than in the end (object) condition where there was only one opening, but these two conditions did not differ in noncombinatory performance. Additionally, while noncombinatory performance was most successful in the full demonstration condition, where there was one closing and one opening, combinatory performance in this condition was not different from that in the initial-end (object, posture) condition. These findings make it unlikely that the tendency to produce the target act was due to the occluding procedure or item features alone. Instead, infants learned from the highlighted components of a main display as clues to the target act.

The lack of a manipulation control might make "stimulus enhancement" a likely source of the effect, because the experimenter's hands (or head) were left in contact with the objects in the end state. While this is possible, it does not explain infants' readiness to perform the combinatory target act as their first responses, contrasting with the finding of Huang et al. (2002; Experiment 2) that infants who observed the spatial-contiguity display achieved the same level of performance as infants who observed the full demonstration only on subsequent occasions following exploration of the object. In addition, it does not explain why infants failed to replicate the postures displayed on the noncombinatory task, which were equally likely to draw attention to the relevant object parts. Similarly, infants did not show a reliable tendency to reproduce the novel posture by seeing the experimenter's head resting on the illuminated box, despite the saliency of this interesting sight.

A more possible explanation is that infants' use of bodily cues in emulative contexts is dependent on the clarity of the affordances of a task (see also Nielsen, 2009). This is likely, given that infants responded differently to end-state displays according to task requirements. Overall, only infants who observed the full demonstration imitatively learned the target acts across differing tasks. A similar effect of imitation was achieved by the display that consisted of both posture and configuration changes, in which case emulation was subject to the combinatory nature of the manipulated object. It should be noted that the tasks used in the current experiments contained different saliencies for physical affordances specified in end configurations. The order from the most salient to the least is the combinatory, noncombinatory, and light-box tasks. Under this interpretation, it is the lack of dynamic affordances (light box) or lack of salient affordance features (noncombinatory task) that causes the failure to emulate the final posture from an observed partial solution. Thus, the failure to benefit from end-state conditions as was shown in previous studies (Bellagamba & Tomasello, 1999; Meltzoff, 1985) could be due not to lack of emulative abilities but to lack of posture cues and the limitations of the particular test apparatuses used (Hopper, 2010). As far as we are aware, the present study investigated, for the first time, the interplay between infants' goal attribution and affordances.

However, these findings are subject to another interpretative problem: Emulation based on changes in posture and object configuration could be due simply to seeing the end state of the object and the model's final posture. If initial-state exposure was not necessary for successful emulation, the effect of seeing posture change on goal attribution would be vulnerable to this interpretative problem. This is likely, given that the inclusion of the initial state of the object did not promote the emulative tendency in the end (object) condition, but has not been ruled out in the initial-end (object, posture) condition. This could be achieved by comparing this condition to a new condition where infants are exposed to the final state of the object and the actor's terminal posture. Even though the starting posture was always the same across test apparatuses and conditions (the hands lying on the table), solution of this issue can serve theoretical purposes. In a study of the mirror neurons of the macaque monkey, Umilta et al. (2001) reported that seeing a person grasp an occluded object elicits similar mirror neuron activation as seeing the actual grasping of the object. However, mirror neurons do not discharge when the monkey does not know before the demonstration the presence of an object behind the occluder. If understanding of inferred acts is based on context knowledge, and given that seeing an agent perform acts is necessary for the operation of mirror neurons (Flanagan & Johansson, 2003), it is very likely that the absence of initial-state information about the object and the model would detract from infants' tendency to emulate.

Some readers may doubt that Experiment 2 shows that sensitivity to intentions underlying the starting and final postures is made vulnerable solely due to lack of dynamic affordances of the light box. The final posture might simply suggest the model's intention to rest on the box, thereby obscuring the intention of light activation. While this is possible, it can be ruled out, given that an infant's response was counted as performing the target act only when both means and end of the target act were reproduced. It also does not explain why perceiving the intention of resting on the light should have distracted from the tendency to produce the target act in the initial-end (object, posture) condition rather than in the full-demonstration condition. It should, however, be noted that, given that infants' attempts to match the observed posture in the initial-end (object, posture) condition were above baseline rates, it remains to be shown whether they were physically unable to touch the box or simply mimicking the model's manners without being aware of the goal. A novel condition where infants are exposed to the initial and final states without seeing the illumination would suffice to clarify the issue. However, given that children do not copy meaningless or causally irrelevant acts in the absence of perceivable outcomes until 2 to 3 years of age (Huang, Heyes, & Charman, 2006; McGuigan et al., 2007), it is not clear what theoretical purpose would be served by resolution of this issue.

We do not claim that an object's end configuration can inform infants only about its affordances but, rather, that it can interact with other sources of information depending on the contexts. For example, Carpenter, Call, and Tomasello (2002) demonstrated that toddlers could benefit from access to the end state of a complex task before a solution was presented to them in which case they solved the task more successfully than children who saw only the solution. Whereas it is arguable whether end-state information specifies object affordances or prior intentions per se, it should be noted that availability of affordances (or causal information) does not have to invariably detract from children's use of social information such as bodily cues and intentions. Influenced by comparative research on social learning, developmental psychologists have recently begun to assess "imitation" by exclusion, by ruling out other forms of nonimitative social learning. Nevertheless, this approach has not been exempt from challenges. One problem is that it conceals the dynamic interplay of a variety of social learning processes. This notion is supported by infants' use of affordances to detect bodily cues, thereby engaging in in goal emulation. The present results suggest that a distinct separation between affordance detection and goal attribution may be unnecessary, at least for infants' social learning of instrumental acts on objects. Future research might fruitfully explore the extent to which infants' sensitivity to static bodily cues is a precursor to a subsequent tendency to copy causally irrelevant acts (e.g., Lyons, Young, & Keil, 2007), or the gap between affordance learning and goal emulation is a manifestation of a conceptual developmental progression or a function of manipulatory features.

In summary, the extent to which infants' tendency to emulate is a function of end-state exposure is revealed as the saliency of the affordances of the task is increased. The findings provide strong evidence for the hypothesis that emulation in end-state contexts is context-dependent. The present study therefore provides a promising approach for empirical and conceptual dissections of emulation learning in human children.

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