Cognition 142 (2015) 138–147

Contents lists available at ScienceDirect

Cognition

journal homepage: www.elsevier.com/locate/COGNIT

Learning from gesture: How early does it happen?

Miriam A. Novack *, Susan Goldin-Meadow, Amanda L. Woodward

The University of Chicago, United States

ARTICLE INFO

Article history:
Received 9 August 2014
Revised 8 May 2015
Accepted 22 May 2015
Available online 1 June 2015

Keywords:
Gesture
Iconicity
Action
Imitation

ABSTRACT

Iconic gesture is a rich source of information for conveying ideas to learners. However, in order to learn from iconic gesture, a learner must be able to interpret its iconic form—a nontrivial task for young children. Our study explores how young children interpret iconic gesture and whether they can use it to infer a previously unknown action. In Study 1, 2- and 3-year-old children were shown iconic gestures that illustrated how to operate a novel toy to achieve a target action. Children in both age groups successfully figured out the target action more often after seeing an iconic gesture demonstration than after seeing no demonstration. However, the 2-year-olds (but not the 3-year-olds) figured out fewer target actions after seeing an iconic gesture demonstration than after seeing a demonstration of an incomplete-action and, in this sense, were not yet experts at interpreting gesture. Nevertheless, both age groups seemed to understand that gesture could convey information that can be used to guide their own actions, and that gesture is thus not movement for its own sake. That is, the children in both groups produced the action displayed in gesture on the object itself, rather than producing the action in the air (in other words, they rarely imitated the experimenter's gesture as it was performed). Study 2 compared 2-year-olds' performance following iconic vs. point gesture demonstrations. Iconic gestures led children to discover more target actions than point gestures, suggesting that iconic gesture does more than just focus a learner's attention, it conveys substantive information about how to solve the problem, information that is accessible to children as young as 2. The ability to learn from iconic gesture is thus in place by toddlerhood and, although still fragile, allows children to process gesture, not as meaningless movement, but as an intentional communicative representation.

1. Learning from gesture

Gesture is a pervasive human behavior (Kendon, 1980; McNeill, 1992), one that has effects not only on communication, but also on problem-solving (Goldin-Meadow & Beilock, 2010) and thinking (Goldin-Meadow, 2003). One particularly powerful effect of gesture is that it can help a learner solve a problem by providing information in an *iconic* format. Iconic gestures are visual representations of referential meaning (McNeill, 1992). For example, imagine someone using her hands to demonstrate how to open a bottle of wine. She might cup her left hand in the air as if holding the bottle, and twist her right hand in the space above, to show you how to turn the opener. As an adult, you would interpret the gestures as intentional, symbolic forms meant to teach you an action (i.e., how to open the bottle of wine). You would infer that you need to hold the bottle while twisting the opener. Yet when actually acting on the opener and bottle, your movements would not be perfect simulations of the gestures—they would need to be adapted to the size of the bottle, the number of twists needed to drive down the screw into the cork, the exact angle of the hands, etc. That is, you would interpret the gesture as a *representation* of the movements needed to achieve a goal. Iconic gestures are excellent sources of information for learning, but a learner must be able to see gesture as a source of information in order to learn from gesture. The learner must not, for example, interpret the gesture as movement for its own sake—a movement performed in the air, perhaps to entertain. Here we examine the developmental origins of the ability to learn from iconic gesture. Specifically, we ask how 2- and 3-year-olds interpret gestural movements, and whether they use those movements to gain information and learn a novel action.

Iconic gestures are only one type of gesture that can help communicate ideas to learners. For example, *deictic*, or pointing, gestures have been found to facilitate word learning in infants by focusing their attention on the object whose label they are learning (Shimpi & Huttenlocher, 2007). *Conventional* gestures, or socially constructed gestures (often called *emblems*, Ekman & Friesen, 1969), such as head nods, can also be used by children as young

* Corresponding author at: 5848 S. University Avenue, Chicago, IL 60637, United States.

E-mail address: mnovack1@gmail.com (M.A. Novack).

http://dx.doi.org/10.1016/j.cognition.2015.05.018
0010-0277/© 2015 Elsevier B.V. All rights reserved.

as 2 years to infer whether a statement is correct or incorrect (Fusaro & Harris, 2013). Both deictic and conventional gestures have frozen, unchanging forms with established referential meanings. As a result, once children learn what a point is, or that you wave "good bye" when leaving a room, they know enough to be able to interpret the gesture.

In contrast, iconic gestures are created on the spot to represent ideas, objects, or actions, and are therefore unique representations. Given that there is no "right" way to produce an iconic gesture, iconic gestures must be *interpreted* by the learner every time they are encountered. This property makes it more challenging to glean information from iconic gestures and subsequently learn from them. However, it also makes iconic gestures a rich source of information, particularly in pedagogical contexts. Previous work suggests that incorporating iconic gestures into instruction helps school-aged children make inferences by highlighting the relational structure underlying a problem. For example, an instructor teaching about Piagetian conservation can use her hands iconically to represent the relative heights and widths of the containers, or to represent pouring liquid from one container to another, which helps 5- to 7-year-olds figure out how to solve conservation problems (Church & Goldin-Meadow, 1986; Ping & Goldin-Meadow, 2008). Similarly, 9- and 10-year-old children can figure out novel strategies for solving math problems after seeing a teacher produce iconic gestures that represent those strategies, even if the teacher's gestures do not match her words (Congdon et al., 2015; Singer & Goldin-Meadow, 2005). Although there is substantial evidence that school-aged children benefit from instruction containing iconic gesture (e.g., Church, Ayman-Nolley, & Mahootian, 2004; Cook, Duffy, & Fenn, 2013; Valenzeno, Alibali, & Klatzky, 2003), we do not yet know whether this ability is in place during the pre-school years.

Children's ability to learn from iconic gesture is likely to be constrained by their ability to interpret iconicity. Previous research suggests that, before age 3, children struggle in interpreting iconicity in drawings (Simcock & DeLoache, 2006), toy replicas (Tomasello, Striano, & Rochat, 1999), sign language (Tolar, Lederberg, Gokhale, & Tomasello, 2008), and scale model tasks (Blades & Cooke, 1994; Deloache, 1987). These studies raise the possibility that iconicity in gesture may be equally challenging for children under 3 years.

However, children as young as 26 months have been found to display at least some sensitivity to iconicity in gesture. For example, the iconicity in a gesture makes it easier for infants and young children to associate the gesture with an object (Namy, 2008; Namy, Campbell, & Tomasello, 2004) or an action (Marentette & Nicoladis, 2011), or even to use the gesture as support for learning a novel word for an object (Capone & McGregor, 2005) or action (Goodrich & Hudson Kam, 2009). In each of these studies, young children detected the iconicity of a gesture in relation to a referent that was present in the situation.

Thus, we know that children as young as 3 can appreciate iconicity in gesture. But can they use that iconicity to gain insights beyond the information present in the physical context? In all of the previous work with 2- to 4-year olds, children were shown an action performed on or by an object, along with a gesture for that action or object. For example, Namy and colleagues (Namy, 2008; Namy et al., 2004) presented children with a moving object (e.g., a toy bunny hopping); they then asked whether children learned an iconic gesture (a hopping gesture) as a label for the object more easily than an arbitrary gesture (a dropping gesture). In other words, children were asked to *associate* an object or action with an iconic gesture. They were never asked to *infer* novel information from the iconic gesture. Using an iconic representation to infer novel information (i.e., "arrive at a new insight") commands a greater level of computation than recognizing the iconic relation between a gesture and its referent. We know that presenting adults with iconic movements can lead to success on insight problems (Thomas & Lleras, 2009), and that presenting 9-year-old children with gestures can lead to novel strategies for solving math problems (Goldin-Meadow, Cook, & Mitchell, 2009). Here we test whether 2- and 3-year-old children can gain new insights from an iconic gesture, a critical first step in being able to use iconic gesture to learn about complex conceptual ideas.

Not only must children be able to see the iconicity in gesture in order to learn from it, but they must also be able to see gesture as an intentional communicative act. For example, a twisting gesture performed in the air could be interpreted as an instruction to perform a twisting movement on the object in hand. Alternatively, it could be interpreted as a movement made for its own sake, as part of a dance or an exercise. Schachner and Carey (2013) have found that when an agent produces so-called irrational movements (e.g., moving toward a goal and then away from it), adults typically interpret those movements as movement performed for the sake of movement. If children view gestures as irrational movements, they may think of gesture as movement for its own sake. If so, after watching an adult produce a gesture for an action intended to be performed on an object, a young child might respond by reproducing the gesture itself (i.e., making a movement in the air), rather than by acting on the object.

Our goal was to discover the point in development when children are able to interpret iconic gestures as representations of goal-directed actions. To do so, we presented 2- and 3-year-old children with gestures that demonstrated in an iconic, representational format how to operate a novel toy to achieve a goal. Enacting the movement represented in the gestures to achieve the target action (a goal they had never seen before) would provide evidence that children can use iconic gesture to infer a novel action, particularly if the children produced this movement to achieve the goal more often than children who received no demonstration.

Gesture demonstrations are challenging not only because they present content in a representational format, but also because they require the child to infer an action based on incomplete information—the child never sees the full action produced. For example, the child sees the experimenter move her hands as though opening the handles on a lemon press but, of course, the handles do not open. To control for the fact that the child is working with incomplete information, we included a control condition in which the instructor tried to act on the toy (and thus touched the toy) but failed to carry out the target action (incomplete-action trials). For example, the experimenter attempted to open the handles of the lemon press but never managed to get the handles open. Incomplete-actions are similar to gestures in that they require the learner to infer an action without having seen it carried out on the object, yet they differ from gesture in that the relevant information is conveyed through a direct act on the object. In other words, gestures, as we define them here, are movements produced in the air, whereas incomplete-actions are movements (albeit incomplete) produced directly on the objects. Previous work shows that children as young as 1.5 years are able to infer an actor's goal from watching an incomplete-action demonstration (e.g., Meltzoff, 1995). As a result, incomplete-actions serve as a useful comparison condition since both 2- and 3-year-old children should be able to successfully interpret them. If children in our study are able to learn which action to perform on an object from watching an incomplete-action demonstration (e.g., watching someone try, but fail, to put a ring on a peg), but not from watching a comparable gesture (e.g., watching someone gesture the movement that would result in the ring being put on the peg), we will have evidence that gleaning substantive information from gesture requires skills that go beyond making an inference from an action that is not completed.

2. Study 1

2.1. Method

2.1.1. Participants

Sixty-four full term 2- and 3-year-olds were recruited from a database of families managed by a large university in an urban Midwest region in the United States. Participants were 54% Caucasian, 24% African American, 2% Asian, 5% Hispanic, and 15% multiracial. Sixteen 2-year-olds (*range* = 22–26 months; *mean* age = 23.35 months, 8 female) and sixteen 3-year-olds (*range* = 34–38 months; *mean age* = 35.68 months, 8 female) were assigned to the experimental group. An additional sixteen 2-year-olds (*range* = 22–26 months; *mean age* = 23.97, 9 female) and sixteen 3-year-olds (*range* = 34–38 months; *mean age* = 35.40, 6 female) were assigned to the baseline control group. Another five 2-year-olds and seven 3-year-olds failed to complete the procedure due to uncooperativeness ($n = 6$), stimulus malfunction ($n = 3$) or experimenter error ($n = 3$) and thus were excluded from the study. Families received either a small prize or ten dollars for participating.

2.1.2. Materials

Materials consisted of two practice toys and two sets of four experimental toys. Each experimental toy was designed to have a specific target action that could be demonstrated to the child via either a gesture or an incomplete-action (see Fig. 1).

2.1.3. Procedure

Children sat on their parent's lap at a table across from a female experimenter. The experimenter first showed the child two practice toys in order to familiarize the child with the experimenter and set up, and also to create the expectation that all toys should "do something". In each trial, the experimenter placed a toy in front her on a foam board, and examined it. Looking between the child and the toy, she said, "Hmm, what does this thing do?" The experimenter then looked at the child and said, "I think I know how to make it work. I think you do this!" She then demonstrated the target action (e.g., opening the box, taking out the ball and shaking it), returned the toy to its initial state, said, "now it's your turn to make it work," and passed it to the child. If the child was shy or unwilling to approach the toy, the experimenter helped the child open the box and achieve the goal. She followed the same procedure for the second practice toy.

Following the two practice toys, the child saw each of the eight experimental toys, one at a time. For children in the baseline control condition, the experimenter placed the object in front of her, examined it, and said, "hmm, what does this thing do?" She then passed the toy to the child for 15 s to explore. For children in the experimental condition, the experimenter said the same words that she said for the practice toys, but then showed the child how to operate the toy using either a gesture demonstration (gesture trials), or an incomplete-action demonstration (incomplete-action trials). In gesture demonstration trials, the experimenter produced a gesture that represented how to act on the toy to achieve the goal, but she did not directly act on the toy (e.g., making a flat handed, up-and-down gesture in the space over a push-light). In incomplete-action trials, the experimenter acted on the toy directly, but failed to achieve the goal (e.g., making a flat-handed up-and-down motion that makes contact with the light, but fails to turn it on). In all experimental trials, after the demonstration, the experimenter said, "now it's your turn to make it work," and then gave the toy to the child for 15 s.

Experimental toys were blocked by set and randomized within set. Children in the experimental condition saw one set of toys demonstrated with gestures and one set demonstrated with incomplete-actions; the order of demonstration types was counterbalanced. Children in the baseline control condition saw both sets of toys without a demonstration. For both conditions, the order of toy sets was counterbalanced.

2.1.4. Coding

All sessions were video recorded and independently coded by two individuals blind to condition and type of trial (i.e., demonstration type). For each trial in the experimental condition, coders determined whether the child produced the target action on the object, and/or an imitation of the demonstration (either the incomplete-action or the gesture). For example, if the child picked up a ring and placed it over the peg, this response was coded as successful completion of the target action. If the child picked up the ring and ran it down the side of the peg (without putting it over), this response was coded as an imitation of the incomplete-action demonstration. If the child swept her hand from the ring to the peg, without touching the ring, this response was coded as an imitation of the gesture. Coders agreed on 93% of trials for determining when children produced the target action ($K = 0.85$) and on 95% of trials for determining when children imitated the demonstration ($K = 0.81$).

2.2. Results

Our first question was whether toddlers could interpret the iconic gesture demonstrations to discover a novel procedure for acting on an object. Fig. 2 displays the average number of toys per set (out of 4) on which 3-year-old children (left graph) and 2-year-old children (right graph) produced the target action in incomplete-action (dark gray bar) and gesture (light gray bar) trials; baseline performance is shown in both graphs in the third (black) bar and is also indicated by the horizontal dotted line across the other two bars. All data were analyzed using mixed-effects logistic regression models, which predicted the log-odds of success (i.e., producing the target action) on a given trial with subject and stimulus as random factors. Initial analyses found no effect of gender, demonstration order, or stimulus set; these factors were therefore removed from subsequent models.

A first model using age group (2-year-olds, 3-year-olds), demonstration type (baseline, incomplete-action, gesture), and an interaction of the two reveled a main effect of age such that 3-year-olds were more likely to produce the target action than 2-year-olds ($\beta = 1.61$, $z = 4.42$, $p < .001$). There were also significant effects for both incomplete-action trials ($\beta = 2.02$, $z = 4.99$, $p < .001$) and gesture trials ($\beta = 1.18$, $z = 2.82$, $p < .004$) relative to baseline, demonstrating that children in both age groups can use incomplete-action and iconic gestures to learn about how to act on an object above and beyond what they might discover themselves from the affordances of the object. Further analysis re-leveling the model with gesture trials as the baseline revealed that children performed significantly better on incomplete-action trials ($\beta = 0.83$, $z = 2.29$, $p = .02$) than gesture trials. The interaction of age and demonstration did not reach significance ($\chi^2(2) = 3.15$, $p = 0.20$).

Note that there was a large, and significant, difference between the two age groups in baseline rates of target-goal discovery ($\beta = 1.72$, $z = 4.68$, $p < .001$). On average, 2-year-olds spontaneously discovered the target action on 0.47 ($SE = 0.09$) out of 4 toys, whereas 3-year-olds did so on 1.59 ($SE = 0.22$) out of 4 toys. This significant difference in baseline performance indicates that the toys were not equally challenging for the two age groups—the toys were appropriate for the 2-year-olds, but likely too simple for the 3-year-olds. The baseline rate is thus meaningful within each age range—it provides a starting point against which to judge

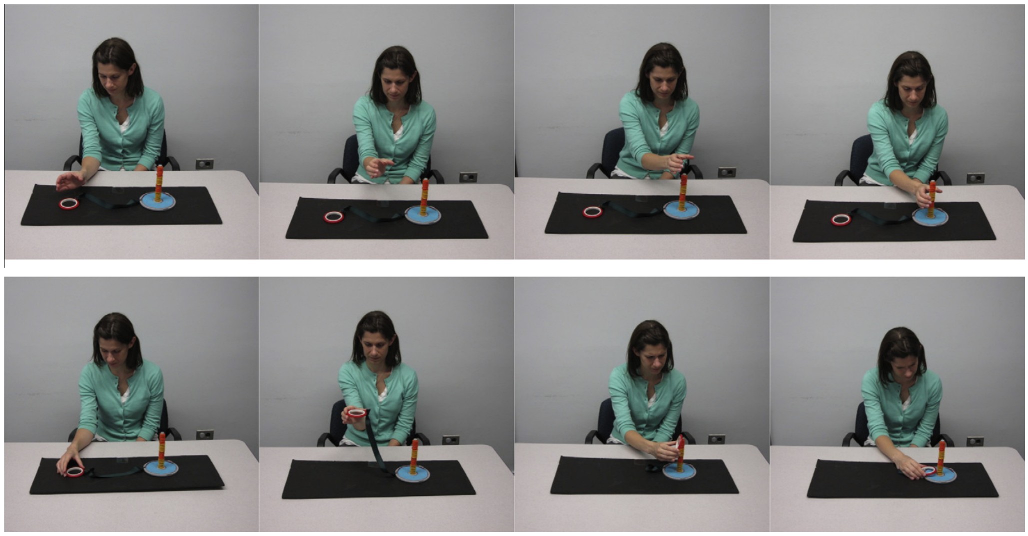

Fig. 1. Example of gesture demonstration (top) and incomplete-action demonstration (bottom). The target action (placing the ring over the peg) is not demonstrated in either type of trial.

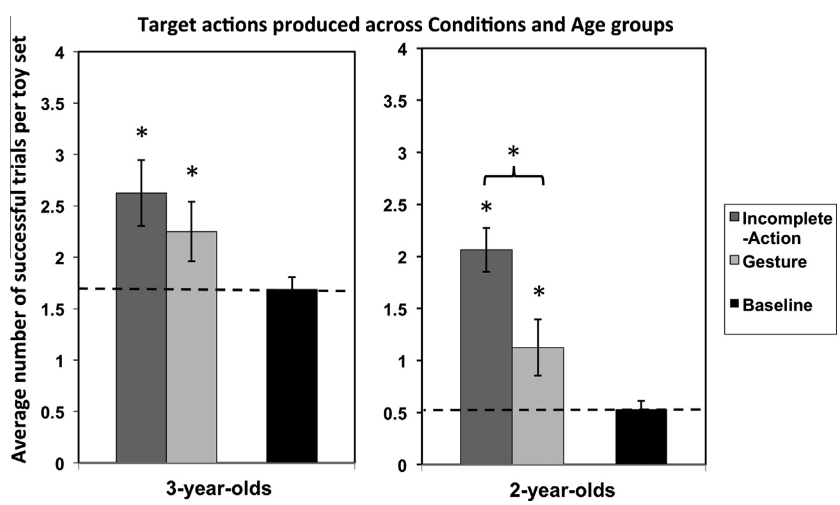

Fig. 2. Average number of target actions completed per toy set for incomplete-action (dark gray bar) and gesture (light gray bar) demonstrations in the experimental condition for 3-year-olds (left graph) and 2-year-olds (right graph). The black bar and dotted line indicates average performance on baseline trials in the control condition for each age. Asterisks indicate a significant difference ($p < .05$) from baseline, or between children's performance in incomplete-action and gesture.

improvement. However, the difference in baselines means that the relative changes in performance are not likely to be equitable across age groups. For this reason, we also analyzed performance separately for each age group.

2.2.1. Three-year-old performance

We evaluated rates of target action completion in the experimental condition (following either the incomplete-action or gesture demonstrations) in relation to the control condition (baseline) to determine whether the 3-year-old children were able to use the experimenter's demonstrations to figure out more target actions than they would have discovered on their own (see Fig. 2, left graph). The results indicated that, for 3-year-olds, both incomplete-action demonstrations ($\beta = 1.19$, $z = 2.96$, $p = .003$) and gesture demonstrations ($\beta = 0.87$, $z = 2.18$, $p = .03$) had a significant, and positive, effect on the likelihood of producing a target action, relative to baseline. That is, 3-year-olds were more likely to produce the target action on incomplete-action trials ($M = 2.56$, $SE = 0.30$) than on baseline trials ($M = 1.59$, $SE = 0.21$), and were also more likely to produce the target action on gesture trials ($M = 2.25$, $SE = 0.28$) than baseline trials ($M = 1.59$, $SE = 0.21$).

To evaluate the relative effect of incomplete-action and gesture demonstrations, we re-ran the analysis with incomplete-actions as the comparison. Relative to incomplete actions, 3-year-olds were no less likely to produce a target action on gesture trials ($\beta = -0.33$, $z = -0.847$ $p = 0.40$). Thus, 3-year-olds were able to learn about the function of a novel toy equally well from both an incomplete-action demonstration and an iconic gesture demonstration.

2.2.2. Two-year-old performance

We performed the same analysis to predict the success of completing a target action in the 2-year-old sample (see Fig. 2, right graph). We found that both incomplete-action demonstrations ($\beta = 2.27$, $z = 5.24$, $p < .001$) and gesture demonstrations ($\beta = 1.31$, $z = 2.97$, $p = .002$) were significant predictors of action completion, relative to baseline production. In other words, 2-year-olds were more likely to produce a target action following an incomplete-action demonstration ($M = 2.0$, $SE = 0.24$) and following a gesture demonstration ($M = 1.19$, $SE = 0.28$), compared to baseline performance ($M = 0.47$, $SE = 0.09$).

Again, to evaluate the relative effect of the two types of demonstrations, the model was re-run with incomplete-actions as the comparison. Unlike the 3-year-old children, 2-year-olds were significantly less likely to produce the target action following a gesture demonstration than following an incomplete-action demonstration ($\beta = -0.95$, $z = -2.40$ $p = 0.02$). Thus, although 2-year-olds were able to reliably learn how to produce the target action from an iconic gesture demonstration, their performance was significantly better if they saw object-based actions (i.e., incomplete-actions) than representational actions (i.e., gestures).

2.2.3. Action responses vs. movement responses

Next, to consider whether children view gestures as movements for their own sake, we compared how often children produced an action (the target action or an irrelevant action) on the toy, compared to how often they reproduced the gesture that the experimenter demonstrated (producing it in the air off the toy, as demonstrated) for all gesture trials. For this analysis, we removed any trial in which children produced both responses (i.e., a gesture imitation plus an action on the toy within a single trial, 23 out of 256 trials). Across both ages, children were more likely to produce an action on the object (76% of trials) than to imitate the experimenter's gesture (24% of trials) ($t(30) = 6.59$, $p < .001$). Thus, even though children (particularly the 2-year-olds) did not always infer the correct action from the gesture, they also did not resort to focusing on the hand movement as an end in itself. In other words, they did not seem to think that the experimenter's goal in gesturing was to wave her hands around.

We conducted the same analysis on the incomplete-action trials. We classified responses as actions (the target action or an irrelevant action) or imitations (producing the failed attempt on the object, as demonstrated). Again, children were more likely to produce actions (81% of trials) than imitations (19% of trials) $t(30) = 10.28$, $p < .001$. Imitations were thus rare following both incomplete-action and gesture demonstrations.

Finally, we noticed that when children imitated the gesture, they sometimes went on to complete the target action as well. In fact, a large proportion of the trials in which 2-year-olds were successful in discovering the target action were trials in which they had first imitated the gesture (42% of successful gesture trials). This was not the case for 3-year-olds, who only imitated the gesture in 19% of successful gesture trials. Nor was this the case for the incomplete-action trials. Two-year-olds imitated the incomplete-action on 6% of successful incomplete-action trials, and 3-year-olds did so on 14% of successful incomplete-action trials. We evaluate the reliability of this effect in Study 2.

2.3. Study 1 discussion

The results from Study 1 provide evidence that, by the second year of life, children are able to glean novel insights from watching an iconic gesture demonstration. However, iconic gestures can support learning in a variety of ways. Iconic gestures can convey content through their form; for example, a twist gesture produced near a toy can give children information about the twisting action that they should produce on the toy. Iconic gestures can also guide children's visual attention to the part of the toy that affords a particular action; for example, the twist gesture near the part of the toy that twists could simply focus children's attention on a part of the toy and that part (rather than the gesture) might then facilitate the twisting action. As a result, one possible explanation for the fact that children in Study 1 discovered more target actions following iconic gesture trials, relative to baseline, was that the gesture simply focused their attention on the critical part of the toy, which then allowed them to figure out the target action. In other words, children did not glean meaning from the iconic properties of the gesture, but merely from its ability to direct attention.

In Study 2, we test this hypothesis by comparing children's ability to achieve a target action following a point gesture vs. an iconic gesture demonstration. If the iconic gestures in Study 1 did nothing more than guide children's attention to a critical piece of the toy (which then led them to discover what to do with the toy), then we should expect equal performance on iconic gesture and point gesture trials. If, however, the iconic gestures in Study 1 provided essential information about how to act on the toy, then we should expect better performance on iconic gesture than point gesture trials. Because we were primarily interested in the youngest age at which children are able to learn from an iconic gesture demonstration, we tested this alternative hypothesis only on 2-year-olds.

Study 2 also allowed us to conduct a post hoc investigation of the effect that spontaneous imitation has on success in this task. We did not ask children in Study 1 to imitate the demonstrations they saw; nevertheless, some children did spontaneously imitate. We noticed that after some of these imitations, children went on to produce the target action (successful trials); after others, they stopped when they imitated and did not go on to produce the target action. Imitating gesture may indicate that the young child does not understand the communicative value of the gesture, but there is a way in which imitating gesture could be useful for learning. When 9- to 10-year-old children are exposed to gesture in an instructional setting, they are likely to gesture themselves and, in turn, are likely to learn from the instruction—more likely than children who do not spontaneously reproduce the gesture (Cook & Goldin-Meadow, 2006). Moreover, when explicitly told to gesture with no instruction about which gestures to produce (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007), or when told to reproduce gestures explicitly taught to them by an experimenter (Goldin-Meadow et al., 2009), children are more likely to profit from instruction in a math task than when they are not given instructions to gesture. We were curious if a similar phenomenon might have taken place with the children in our study. We therefore conducted a post hoc investigation across Studies 1 and 2 (both studies were needed in order to have enough participants who spontaneously imitated the experimenter's gestures) to determine whether spontaneous imitations led children to complete the target action.

3. Study 2

3.1. Method

3.1.1. Participants

Sixteen full term 2-year-olds (*range* = 22–26 months; *mean* age = 24.35 months, 9 female) were recruited from the same database as Study 1. As in Study 1, participants in Study 2 were racially and ethnically diverse (68% Caucasian, 25% African American, 6% Hispanic, and 6% multiracial). No participants were excluded from the study. Families received either a small prize or ten dollars for participating.

3.1.2. Materials

Materials consisted of the same 8 toys (divided into 2 sets) from Study 1.[1] Toys had the same target actions associated with them, and the same iconic gestures were used to describe those actions.

3.1.3. Procedure

All children saw one set of toys with an iconic gesture demonstration and the other set of toys with a point gesture

[1] One toy from Study 1, the push light, was broken and therefore was replaced by a similar push light.

demonstration. The order of demonstration conditions (iconic gesture first or point gesture first), and toy set, were both counterbalanced across participants. The order of toys was randomized within set.

As in Study 1, children sat on their parents' laps at a table across from a female experimenter. After a brief warm up period (identical to Study 1), they saw each of the experimental toys one at a time. For iconic gesture trials, the experimenter put the toy in front of her, examined it, and then said, "Hmm, what does this thing do? I think I know how to make it work. I think you do this!" She then demonstrated the target action with an iconic gesture (e.g., sliding her hand back and forth in the space above a roller), said, "now it's your turn to make it work," and passed it over to the child for 15 s to explore (see Fig. 3).

For point gesture trials, the procedure was almost identical. The experimenter placed the toy in front of her, examined it, and then said "Hmm, what does this thing do? I think I know how to make it work. I think you use this!" She then pointed to the critical part of the toy necessary to achieve the goal (e.g., pointing to the roller) (see Fig. 3). Again, she then pushed the toy toward the child as said, "now it's your turn to make it work". In contrast to the baseline condition from Study 1, the point gesture condition provided verbal scaffolding and a point gesture directing the children's attention to a critical part of the toy.

3.1.4. Coding

Children's actions and gestures were coded according to the same criteria used in Study 1. Two individuals, blind to the presentation, coded each trial. Coders agreed on 98% of trials for determining when children produced the target action ($K = 0.80$) and on 91% of trials for determining when children imitated the gesture ($K = 0.94$).

3.1.5. Results

Initial analyses found no effect of gender, demonstration order, or stimulus set; these factors were therefore removed from subsequent models. We predicted log-odds of success on each trial using a mixed-effects logistic regression that included trial type (iconic gesture or point gesture) as a fixed factor and subject and stimulus as random factors. The model revealed that the 2-year-olds discovered more target actions during iconic gesture demonstrations ($M = 1.18$, $SD = 0.91$) than point gesture demonstrations ($M = 0.50$, $SD = 0.51$) ($\beta = 1.09$, $z = 2.32$, $p = .02$). In addition, performance in iconic gesture trials was significantly better than baseline performance from Study 1 ($\beta = 1.15$, $z = 2.99$, $p < .002$), replicating the gesture effect from Study 1, whereas point gesture trials were no different from Study 1 baseline performance ($\beta = 0.07$, $z = 0.47$, $p = 0.87$). Thus, despite the verbal scaffolding and the point gesture guiding attention to the critical part of the toy, 2-year-olds were unlikely to discover the target action of the toys without an iconic gesture demonstrating the target action. Finally, within the iconic gesture trials, we found that 2-year-olds were more likely to produce an action (83% of trials) than to imitate the gesture (17% of trials) ($t(15) = 10.54$, $p < .001$), replicating the finding that 2-year-olds tend not to interpret gesture as movement for its own sake (see Fig. 4).

3.1.6. Does imitating the demonstrated gesture lead to success?

The final analyses examined whether spontaneously imitating the experimenter's gesture made it more likely that a child would produce the target action. We combined data from Studies 1 and 2 in order to maximize the number of participants who spontaneously imitated the experimenter's gesture. Fig. 5 presents the data on all trials, classified according to whether the child spontaneously imitated the experimenter's iconic gesture or not. The figure presents the proportion of trials with imitation on which the child achieved the target action (successful trials) in the black bars, and the proportion of trials without imitation on which the child was successful in the white bars; data for the for the 3-year-olds (from Study 1) are on the left, and from the 2-year-olds (Studies 1 and 2) are on the right. The 3-year-olds were more likely to be successful when they did *not* imitate the experimenter's iconic gesture than when they did. In contrast, the 2-year-olds were more likely to be successful when they *did* imitate the gesture than when they did not.

We predicted the log-odds of successfully producing the target action, using age group (2-year-olds, 3-year-olds), whether or not the child imitated the iconic gesture in the trial (binary), and study (Study 1, Study 2) as fixed-effects, as well as a random effect of subject. The model showed no effect of study ($\beta = 0.05$, $z = 1.39$, $p =$ ns), but a significant effect of age group ($\beta = 2.20$, $z = 4.59$, $p < 0.001$), demonstrating again that 3-year-olds were more likely to achieve the target action than 2-year-olds. There was also an overall effect of imitating the demonstrated iconic gesture ($\beta = 1.04$, $z = 2.32$, $p = 0.02$), as well an interaction between imitating the gesture and age group ($\beta = -3.05$, $z = -4.17$, $p < .001$). To explore this interaction, we ran the same model separately on the 2-year-olds and on the 3-year-olds. The model with the 2-year-olds revealed that imitating the gesture was a positive predictor of success (i.e., achieving the target action, $\beta = 1.04$, $z = 2.31$, $p = 0.02$), whereas the model for the 3-year-olds revealed that imitating the gesture was a negative predictor of success ($\beta = -2.01$, $z = -3.48$, $p < .001$).

For comparison, we examined whether spontaneously imitating the experimenter's incomplete-action led both 2- and 3-year-olds to achieve the target action in Study 1. We found a significant effect of age group ($\beta = 2.20$, $z = 4.59$, $p < 0.001$), demonstrating again that the 3-year-olds were more likely to produce the target action on the incomplete-action trials than the 2-year-olds. There was also an overall negative effect of imitating the demonstrated incomplete-action ($\beta = -2.12$, $z = -4.130$, $p < .001$), but no interaction between imitating the incomplete-action and age group. For both 2- and 3-year-olds, imitating the incomplete-action demonstration was a negative predictor of success; that is, both age groups were less likely to produce the target action (i.e., to be successful) if they first imitated the demonstrated incomplete-action than if they had not imitated it (28% of trials with imitation vs. 76% of trials without imitation were successful for 3-year-olds; 27% vs. 53% for 2-year olds).

4. General discussion

Our goal was to determine whether 2- and 3-year-olds are able to gain new insights from watching an iconic gesture. Previous research has shown that school-age children can use the information conveyed in iconic gesture to acquire novel problem-solving strategies (e.g., Goldin-Meadow et al., 2009; Ping & Goldin-Meadow, 2008). To date, this ability has not been assessed in preschool children. Here, we created a problem-solving task suitable for a very young child—inferring an action to achieve an unknown goal. Across two studies, our results indicate that that both 2- and 3-year-olds can learn how to act on a novel toy from watching a gesture demonstration. Importantly, iconic gestures do more than just focus children's attention. The 2-year-olds' performance following the experimenter's pointing gesture was almost identical to their performance following no demonstration (the baseline condition), suggesting that it was the representational content of the experimenter's iconic gesture that helped 2-year-olds figure out what to do with the toys.

It is also important that in Study 1, 2-year-olds produced significantly fewer target actions after watching the experimenter

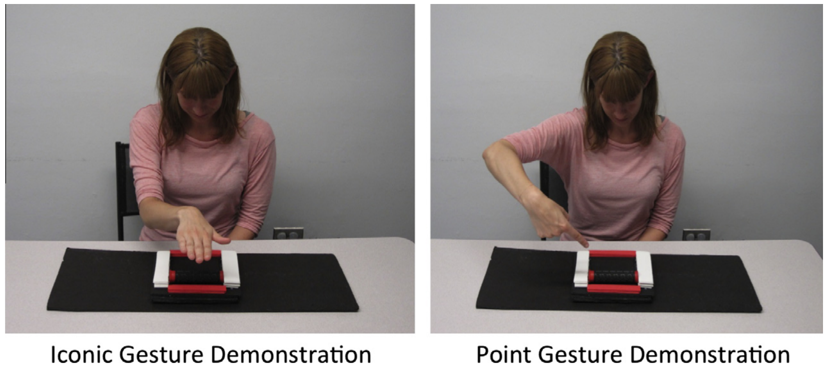

Fig. 3. Examples of the iconic gesture and point gesture demonstration trials from Study 2.

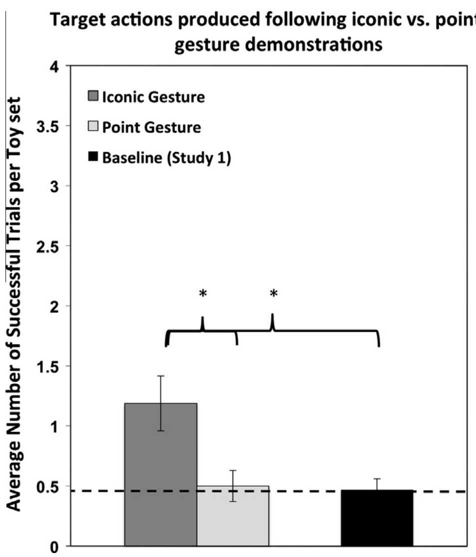

Fig. 4. Average number of target actions completed per toy set following an iconic gesture (dark gray bar) vs. point gesture (light gray bar) demonstration for 2-year-olds. Average number of target actions completed by 2-year-olds in baseline from Study 1 (black bar) shown for comparison. Asterisks indicate a significant difference ($p < .05$) from baseline, or between children's performance in point and iconic gesture conditions.

produce an iconic gesture (gesture trials) than after watching the experimenter act directly, although unsuccessfully, on the object (incomplete-action trials). Given that 2-year-old children are already largely familiar with gesture as a communicative device, displaying an understanding of both deictic gestures (Behne, Liszkowski, Carpenter, & Tomasello, 2012) and familiar conventional gestures (Crais, Douglas, & Campbell, 2004; Fenson et al., 1994), it is likely that what the 2-year-olds found challenging in our study was the representational aspect of the iconic gestures in the task. Since both iconic gestures and incomplete-actions require one to infer information beyond what is shown, this raises questions about what specific features of the gesture made it more difficult than the incomplete-action for the 2-year-olds. For incomplete-action demonstrations, the experimenter made direct contact with the object. For gesture demonstrations, her hands moved in the space above the object. This difference is, in part, definitional—gestures do not have a direct impact on the physical world, but affect the world indirectly through their representational properties. It is possible that the physical contact on the demonstration object in the incomplete-action trials provided a scaffold necessary for the child to understand the intended action. Learning to abstract a movement away from an object and to interpret the movement as a representation may be just the skill that the 2-year-olds in our study are in the process of developing. Overall, our findings suggest that 2-year-olds find cues displayed in object-based actions to be more comprehensible than cues displayed in representational actions. By age 3, this bias is no longer evident. A question for future research is whether the bias actually reverses later in development, that is, whether gestures provide advantages over and above object-based actions in learning situations for older children (see, for example, Novack, Congdon, Hemani-Lopez, & Goldin-Meadow, 2014).

A similar open question relates to how these findings fit into research on comprehension of pretend play. Pretend play, like iconic gesture and incomplete-action, requires deciphering another's non-literal actions (Harris & Kavanaugh, 1993). For example, one may use a block as a telephone or a stick as a toothbrush. In contrast to gesture, these pretend actions typically involve physically manipulating the objects (you actually *pick up* the block and hold it to your ear to pretend it's a telephone). As a result, pretend actions may actually be more similar to incomplete-actions and may therefore be *easier* for young children to interpret, compared to iconic gestures. In fact, Onishi, Baillargeon, and Leslie (2007) found that even 15-month-olds detect inconsistency in an event that involves pretense. Infants who saw an experimenter pretend to pour water into one glass expected her to drink from that same glass, not a different one. What is unknown is how the

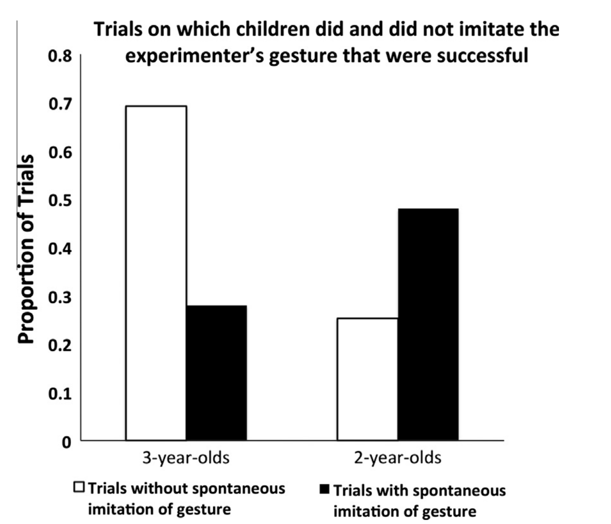

Fig. 5. The proportion of trials on which children did (black bars) or did not (white bars) spontaneously imitate the experimenter's iconic gesture that were successful (i.e., the child achieved the target action). Data for the 3-year-olds (from Study 1) are presented on the left; data from the 2-year-olds (from Studies 1 and 2) are presented on the right.

development of iconic gesture understanding relates to the development of pretense understanding, given that both are types of non-literal actions. Piaget's classic observations (1951) suggest that iconic gesture production may grow out of pretend play actions. For example, Piaget described his daughter (age 1; 7) first imitating drinking from a glass of water, then pretending to drink out of an empty glass, and finally imitating drinking without a glass in hand (Piaget, 1951). Whether this same transition is found in the development of how non-literal actions are seen and understood is an open question worthy of additional empirical investigation.

A second issue that our study can speak to is whether young children see iconic gesture as movement for the sake of movement. Schachner and Carey (2013) argue that some movements are easily interpreted as goal-directed actions (movements that are produced on objects), whereas others are seen as movement for its own sake (movements that are produced with no objects present). We suggest that there is a third category of movement—movement that is intended to represent goal-directed action—in other words, gesture. When a movement is produced in the presence of objects, but does not involve touching or moving the objects (e.g., a hand makes an arc motion from a ball to a box), adults tend to interpret that movement as a representation of goal-directed action (in this case, how the ball should be moved to the box) (Novack, Wakefield, & Goldin-Meadow, 2015).

Schachner and Carey (2013) proposed that the phenomenon of over-imitation (i.e., children imitating the exact movements of a demonstration rather than carrying out the act the demonstration was intended to illustrate) comes about when a child views another's movements as movement for its own sake (rather than as movement for the sake of an external goal). If a child responds to the gesture demonstration in our study by imitating the experimenter's movement (that is, by producing the gestural movement in the air and not on the object), following Schachner and Carey (2013), we would have evidence that the child sees gesture as movement for its own sake.

We found that the children in our study rarely imitated the experimenter's gestural movements exactly (i.e., they rarely produced the movements in the air over the object). However, it is important to point out that our practice trials encouraged children to view the task as one in which something needs to be done *to* an object; not imitating the experimenter's gestural movements exactly might therefore be viewed as an appropriate response to the demands of our task. Despite these task demands, a few children in our study did imitate the experimenter's iconic gestures exactly, suggesting that they may have seen the experimenter's gestures as movement for the sake of movement. Interestingly, these gestural imitations may have served a function, particularly for the youngest children in our sample. Recall that 2-year-olds were more likely to succeed in producing the target action on the object after imitating the experimenter's iconic gesture than after not imitating the gesture. Thus, although responding to gesture as though it were movement for its own sake may be a relatively infrequent response even in 2-year-olds, when children do imitate the form of a gesture, doing so might help them glean meaning from that gesture (see, for example, Goldin-Meadow et al., 2009, who find that, in the context of a math lesson, 9- and 10-year-old children told to reproduce a gestural movement that is initially meaningless to them eventually glean meaning from the gesture that they apply to the math problem).

Although 2-year-olds were more likely to succeed in producing the target action after imitating the experimenter's demonstrated movements than after not imitating the movements on gesture trials, they displayed the opposite pattern on incomplete-action trials, and 3-year-olds displayed the opposite pattern on both gesture and incomplete-action trials. Why? Two-year-olds may have benefited from the increased attention they paid to the movements of the demonstration (as evidenced by the fact that they imitated them) when it occurred in a challenging and unfamiliar format (i.e., gesture, in which they were novices), but were distracted and hindered by this overt attention when it occurred in a presentation that they could easily understand (i.e., action, in which they were experts). This pattern is analogous to findings in motor learning in adults. For example, expert golfers exhibit flawed swings when they over-attend to the details of their movements, but novices benefit from increased attention to procedural detail (Beilock, Wierenga, & Carr, 2002). In a similar way, for children who are novices in learning from iconic gesture (2-year-olds), imitating the movements of a gesture may provide a necessary scaffold that supports the initial learning of representational information. In contrast, imitating the presentation among 3-year-olds, who were "experts" at interpreting both types of demonstrations (and 2-year olds who were experts at action), may have stemmed from their tendency to over-attend to the perceptual features of the task, and thus may have made it more difficult for them to abstract the important information from the movement. That said, because we did not manipulate whether the children imitated gesture, we are unable to draw any causal claims about the role of gesture production in learning. Follow-up work that specifically encourages children to gesture before acting on the toy is needed to determine whether the gesture imitation that we saw in our study only reflected children's understanding of the task, or also played a role in improving that understanding.

Our findings also add to our understanding of when young children gain access to the different types of iconicity displayed in gesture. Previous research has found that 2-year-old children recognize the iconicity in gestures whose forms trace movement (Goodrich & Hudson Kam, 2009), but it is not until age 3 or 4 that children can interpret gestures whose forms display shape properties of objects (Hodges, Özçalışkan, & Williamson, in press; Magid & Pyers, 2015; Tolar et al., 2008). In our study, even 2-year-olds were successful at learning from iconic action gestures, suggesting that it may be relatively easy to map gestural movement onto action and, as the literature suggests, harder to map gestural shape onto objects. The children in our study were asked to use an iconic gesture displaying hand movements that could be made on an object to figure out how to make those hand movements on the object. This relatively straightforward mapping from body to body may be an easy analogy to interpret, easier than interpreting the mapping from body to object. It is an open question as to whether the similarity between a gesture and the action it is meant to represent affects how children process the gestures. Adult listeners have been found to be affected by how closely the gestures they see map onto the body; for example, adults watching a speaker explain a tower of Hanoi task solve the task differently depending on whether the speaker used a grasping handshape mimicking how the disks were held and moved vs. a pointing handshape tracing the trajectory of the disks (Cook & Tanenhaus, 2009). Future research is needed to compare how these differences in gesture form affect a young child's ability to interpret gesture, and whether the differences have differential implications for learning, generalization, and retention.

Finally, the current findings open up a number of questions for future research about iconic gesture input. For example, how do parents' iconic gestures influence children's ability to see relational structure in the world or reason about novel problems? We know that parents who produce many gestures (primarily pointing and conventional gestures) when their children are 14-months-old have children who also gesture a great deal at 14 months, which, in turn, predicts language outcomes several years later (Rowe & Goldin-Meadow, 2009). Future research is needed to document the types of iconic gestures parents spontaneously produce in problem solving tasks, and whether these gestures have an impact on learning outcomes or the capacity to learn from gesture in formal settings later in life.

These open questions aside, our findings suggest that the ability to derive new insights from iconic gesture is in place in the early years of life, as soon as children are able to produce iconic gestures themselves (Behne, Carpenter, & Tomasello, 2014; Ozcaliskan & Goldin-Meadow, 2011; Ozcaliskan et al., 2014). Thus, learning from representational gesture—a phenomenon that we see in older children and adults—may not be specific to formal educational settings, nor to learners of a certain age. Rather, this spatial, movement-based tool is a useful source of information for learners of all ages. Even before children can reliably understand iconic toys, maps or images, they can interpret the iconic form of an instructor's hands and use that information to achieve novel insights.

Acknowledgements

This work was supported by NIH grant number R01-HD047450 and NSF grant number B6S-0925595 to Goldin-Meadow, NSF grant number SBE-0541957 (Spatial Intelligence and Learning Center, Goldin-Meadow is a co-PI), NIH grant number P01-HD064653 to Woodward and a grant from the Institute of Education Sciences (R305-B090025) to S. Raudenbush in support of Novack. We would like to thank Sheila Krogh-Jespersen, Amanda Favata, Madeline Garza, and Anna Pfautz, as well as the rest of the members of the University of Chicago Center for Early Childhood Research. Finally, we would like to thank the families who participated, without whom this research would not be possible.

References

Behne, T., Carpenter, M., & Tomasello, M. (2014). Young children create iconic gestures to inform others. *Developmental Psychology, 50*(8), 2049–2060. http://dx.doi.org/10.1037/a0037224.

Behne, T., Liszkowski, U., Carpenter, M., & Tomasello, M. (2012). Twelve-month-olds' comprehension and production of pointing. *British Journal of Developmental Psychology*. http://dx.doi.org/10.1111/j.2044-835X.2011.02043.x.

Beilock, S. L., Wierenga, S. A., & Carr, T. H. (2002). Expertise, attention, and memory in sensorimotor skill execution: Impact of novel task constraints on dual-task performance and episodic memory. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 55A*, 1211–1240. http://dx.doi.org/10.1080/02724980244000170.

Blades, M., & Cooke, Z. (1994). Young children's ability to understand a model as a spatial representation. *Journal of Genetic Psychology, 155*, 201–218. http://dx.doi.org/10.1080/00221325.1994.9914772.

Broaders, S., Cook, S. W., Mitchell, Z., & Goldin-Meadow, S. (2007). Making children gesture brings out implicit knowledge and leads to learning. *Journal of Experimental Psychology: General, 136*(4), 539–550. http://dx.doi.org/10.1111/j.1467-9280.2009.02297.x.

Capone, N. C., & McGregor, K. K. (2005). The effect of semantic representation on toddlers' word retrieval. *Journal of Speech, Language, and Hearing Research, 48*, 1468–1480. http://dx.doi.org/10.1044/1092-4388(2005/102).

Church, R. B., Ayman-Nolley, S., & Mahootian, S. (2004). The role of gesture in bilingual education: Does gesture enhance learning? *Bilingual Education and Bilingualism, 7*, 303–319. http://dx.doi.org/10.1080/13670050408667815.

Church, R. B., & Goldin-Meadow, S. (1986). The mismatch between gesture and speech as an index of transitional knowledge. *Cognition, 23*(1), 43–71. http://dx.doi.org/10.1016/0010-0277(86)90053-3.

Congdon, E. L., Novack, M. A., Brooks, N., Hemani-Lopez, N., O'Keefe, L., & Goldin-Meadow, S. (2015). Better together: Simultaneous presentation of speech and gesture in math instruction supports generalization and retention (submitted for publication).

Cook, S. W., Duffy, R. G., & Fenn, K. M. (2013). Consolidation and transfer of learning after observing hand gesture. *Child Development, 84*(6), 1863–1871.

Cook, S. W., & Goldin-Meadow, S. (2006). The role of gesture in learning: Do children use their hands to change their minds? *Journal of Cognition and Development, 7*(2), 211. http://dx.doi.org/10.1207/s15327647jcd0702_4.

Cook, S. W., & Tanenhaus, M. K. (2009). Embodied communication: Speakers' gestures affect listeners' actions. *Cognition, 113*, 98–104. http://dx.doi.org/10.1016/j.cognition.2009.06.006.

Crais, E., Douglas, D., & Campbell, C. C. (2004). The intersection of the development of gestures and intentionality. *Journal of Speech, Language, and Hearing Research, 47*, 678–694. http://dx.doi.org/10.1044/1092-4388(2004/052).

Deloache, J. S. (1987). Rapid change in the symbolic functioning of very young children. *Science, 238*, 1556–1557. http://dx.doi.org/10.1126/science.2446392.

Ekman, P., & Friesen, W. (1969). The repertoire of nonverbal behavior: Categories, origins, usage, and coding. *Semiotica, 1*, 49–98.

Fenson, L., Dale, P. S., Reznick, J. S., Bates, E., Thai, D., & Pethick, S. (1994). Variability in early communicative development. *Monographs of the Society for Research in Child Development, 59*(5). http://dx.doi.org/10.2307/1166093.

Fusaro, M., & Harris, P. L. (2013). Dax gets the nod: Toddlers detect and use social cues to evaluate testimony. *Developmental Psychology, 49*(3), 514–522. http://dx.doi.org/10.1037/a0030580.

Goldin-Meadow, S. (2003). *Hearing gesture: How our hands help us think*. Cambridge, MA: Belknap Press of Harvard University Press.

Goldin-Meadow, S., & Beilock, S. L. (2010). Action's influence on thought: The case of gesture. *Perspectives on Psychological Science, 5*, 664–674. http://dx.doi.org/10.1177/1745691610388764.

Goldin-Meadow, S., Cook, S. W., & Mitchell, Z. A. (2009). Gesturing gives children new ideas about math. *Psychological Science, 20*(3), 267–272. http://dx.doi.org/10.1111/j.1467-9280.2009.02297.x.

Goodrich, W., & Hudson Kam, C. L. (2009). Co-speech gesture as input in verb learning. *Developmental Science, 12*(1), 81–87. http://dx.doi.org/10.1111/j.1467-7687.2008.00735.x.

Harris, P. L., & Kavanaugh, R. D. (1993). Young children's understanding of pretense. *Society for Research in Child Development Monographs*. Serial No. 231.

Hodges, L., Özçalışkan, Ş., & Williamson, R. (in press). How early do children understand different types of iconicity in gesture? In *Proceedings of the 39th Boston University conference on language development*. Somerville, MA: Cascadilla Press.

Kendon, A. (1980). Gesture and speech: Two aspects of the process of utterance. In M. R. Key (Ed.), *Nonverbal communication and language* (pp. 207–227). The Hague: Mouton.

Magid, R., & Pyers, J. (2015). Iconicity lends a hand in language learning only after children know its there (submitted for publication).

Marentette, P., & Nicoladis, E. (2011). Preschoolers' interpretation of gesture: Label or action associate? *Cognition, 121*, 386–399. http://dx.doi.org/10.1016/j.cognition.2011.08.012.

McNeill, D. (1992). *Hand and mind: What gestures reveal about thought*. Chicago: University of Chicago Press.

Meltzoff, A. N. (1995). Understanding the intentions of others: Re-enactment of intended acts by 18-month-old children. *Developmental Psychology, 31*, 838–850. http://dx.doi.org/10.1037/0012-1649.31.5.838.

Namy, L. L. (2008). Recognition of iconicity doesn't come for free. *Developmental Science, 11*, 841–846. http://dx.doi.org/10.1111/j.1467-7687.2008.00732.x.

Namy, L. L., Campbell, A. L., & Tomasello, M. (2004). The changing role of iconicity in non-verbal symbol learning: A U-shaped trajectory in the acquisition of arbitrary gestures. *Journal of Cognition and Development, 5*, 37–57. http://dx.doi.org/10.1207/s15327647jcd0501_3.

Novack, M. A., Congdon, E. L., Hemani-Lopez, N., & Goldin-Meadow, S. (2014). From action to abstraction: Using the hands to learn math. *Psychological Science, 25*, 903–910. http://dx.doi.org/10.1177/0956797613518351.

Novack, M. A., Wakefield, E., & Goldin-Meadow, S. (2015). What makes a movement a gesture? (submitted for publication).

Onishi, K. H., Baillargeon, R., & Leslie, A. M. (2007). 15-month-old infants detect violations in pretend scenarios. *Acta Psychologica, 124*(1), 106–128. http://dx.doi.org/10.1016/j.actpsy.2006.09.009.

Ozcaliskan, S., Gentner, D., & Goldin-Meadow, S. (2014). Do iconic gestures pave the way for children's early verbs? *Applied Psycholinguistics, 25*(6). http://dx.doi.org/10.1017/S0142716412000720.

Ozcaliskan, S., & Goldin-Meadow, S. (2011). Is there an iconic gesture spurt at 26 months? In G. Stam & M. Ishino (Eds.), *Integrated gestures: The interdisciplinary nature of gesture*. Amsterdam, NL: John Benjamins.

Piaget, J. (1951). *Play, dreams, and imitation in childhood*. New York: Norton.

Ping, R. M., & Goldin-Meadow, S. (2008). Hands in the air: Using ungrounded iconic gestures to teach children conservation of quantity. *Developmental Psychology, 44*(5), 1277–1287. http://dx.doi.org/10.1037/0012-1649.44.5.1277.

Rowe, M. L., & Goldin-Meadow, S. (2009). Differences in early gesture explain SES disparities in early child vocabulary size at school entry. *Science, 323*(5916), 951–953. http://dx.doi.org/10.1126/science.1167025.

Schachner, A., & Carey, S. (2013). Reasoning about 'irrational' actions: When intentional movements cannot be explained, the movements themselves are seen as the goal. *Cognition, 129*, 309–327. http://dx.doi.org/10.1016/j.cognition.2013.07.006.

Shimpi, P. M., & Huttenlocher, J. (2007). Redirective labels and early vocabulary development. *Journal of Child Language, 34*(4), 845–859. http://dx.doi.org/10.1017/S0305000907008112.

Simcock, G., & DeLoache, J. S. (2006). The effects of iconicity on re-enactment from picture books by 18- to 30-month-old children. *Developmental Psychology, 42*(6), 1352–1357. http://dx.doi.org/10.1037/0012-1649.42.6.1352.

Singer, M. A., & Goldin-Meadow, S. (2005). Children learn when their teacher's gestures and speech differ. *Psychological Science, 16*, 85–89. http://dx.doi.org/10.1111/j.0956-7976.2005.00786.x.

Thomas, L. E., & Lleras, A. (2009). Swinging Into Thought: Directed Movement Guides Insight in Problem Solving. *Psychonomic Bulletin & Review, 16*(4), 719–723.

Tolar, T. D., Lederberg, A. R., Gokhale, S., & Tomasello, M. (2008). The development of the ability to recognize the meaning of iconic signs. *Journal of Deaf Studies and Deaf Education, 13*(2), 225–240. http://dx.doi.org/10.1093/deafed/enm045.

Tomasello, M., Striano, T., & Rochat, P. (1999). Do young children use objects as symbols? *British Journal of Developmental Psychology, 17*, 563–584. http://dx.doi.org/10.1348/026151099165483.

Valenzeno, L., Alibali, M. W., & Klatzky, R. L. (2003). Teachers' gestures facilitate students' learning: A lesson in symmetry. *Contemporary Educational Psychology, 28*, 187–204. http://dx.doi.org/10.1016/S0361-476X(02)00007-3.