Gesture highlights perceptually present information for speakers

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Why do speakers produce gestures? This study tests the hypothesis that gesture facilitates the conceptual planning of speaking, and in particular, gesture promotes thinking about perceptually present information. This view implies that, when gesture is prohibited, people should be less likely to speak about such information. We tested this prediction among children ($N = 50$) who solved and explained Piagetian conservation tasks. For one set of conservation tasks, all children were allowed to gesture. For a second set of tasks, some children were prohibited from gesturing by wearing a cloth muff. When children were prohibited from gesturing, they expressed more non-present information and less perceptually present information in their explanations than when allowed to gesture. Thus, gesture production appears to highlight or lend salience to perceptually present information. We argue that gesture helps speakers decide what to attend to and therefore what to say.

Keywords: gesture, conservation, perceptual-motor information, gesture prohibition

Why do speakers produce gestures? Many different answers to this puzzle have been proposed. Some investigators have focused on the effects of speakers' gestures on listeners' comprehension (e.g., Beattie & Shovelton, 1999; Kendon, 1994), whereas others have focused on how gestures function for speakers themselves (e.g., Kita, 2000; Krauss, 1998). A complete answer to this puzzle will likely require consideration of both listener-oriented and speaker-oriented functions.

In the present work, we focus on speaker-oriented functions of gesture, and we offer a new perspective on the puzzle of why speakers gesture. We build on three bodies of prior research, one that focuses on the role of gesture in packaging spatial information into speech (e.g., Kita, 2000), one that focuses on gestures as deriving from simulated actions (e.g., Hostetter & Alibali, 2008, in press), and one

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that focuses on the gestures people use in problem solving, particularly in situations in which important aspects of the problems are presented visuo-spatially (e.g., Church & Goldin-Meadow, 1986; Perry, Church, & Goldin-Meadow, 1988; Schwartz & Black, 1996). Taken together, these bodies of literature suggest a new hypothesis about a possible function of gestures for speakers, namely, that gestures highlight perceptual-motor information, making it more highly activated, and consequently more likely to be integrated into conceptualization for speaking and thinking.

Gesture in problem explanations

Many previous studies have investigated the gestures speakers produce when explaining their problem solutions (e.g., Goldin-Meadow, Alibali, & Church, 1993). There is evidence that such gestures reveal speakers' understanding of the tasks they are explaining (Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999; Garber, Alibali, & Goldin-Meadow, 1998). For example, in a mathematical problem-solving task, Alibali et al. (1999) found that speakers who depicted a particular problem feature in gesture when describing a problem were particularly likely to use a strategy that relied on that feature when solving the problem.

Other studies have suggested that gestures index transition periods in the development of problem solving. For example, Alibali and Goldin-Meadow (1993) found that children who gestured while explaining problems on a pretest learned more from a brief lesson than children who did not gesture. Other studies have shown that discrepancies between gesture and speech in children's task explanations are associated with readiness to learn. For example, Church and Goldin-Meadow (1986) found that children who frequently produced gestures that "mismatched" their speech were especially likely to learn from a brief lesson about Piagetian conservation. Similar findings have also been reported in several studies of children's understanding of equations (e.g., Perry et al., 1988; Singer & Goldin-Meadow, 2005).

A few recent studies have experimentally manipulated gesture and documented effects on learning outcomes. Cook, Mitchell and Goldin-Meadow (2007) found that children who were required to gesture as they learned a mathematical concept retained their new knowledge better than children who were not required to gesture. Along similar lines, Broaders and colleagues found that children who were required to gesture during explanations of math problems were later more receptive to instruction about the problems than children who were not required to gesture (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). Other research has examined the effects of preventing speakers from gesturing. Chu and Kita (2008) found that adults who were prohibited from gesturing in a mental rotation task were less likely to progress to a more efficient problem-solving strategy than those who were free to gesture.

Thus, there is extensive evidence, first, that the gestures speakers produce during problem explanations reflect aspects of their knowledge about the task being explained, and second, that gestures are implicated in knowledge change in important ways. Why might this be the case? Past research supports the view that gesture is an integral part of the process of thinking. However, the mechanisms by which gesture plays a role in thinking are largely unspecified. In this paper, we consider a possible mechanism. We propose that gesture serves to highlight a particular type of information, namely, perceptual-motor information, which is very likely to be expressed in gestures.

Gesture as simulated action

Any claims made about the role of gesture in problem solving or learning situations must be compatible with arguments about the cognitive processes that give rise to gestures. Mounting evidence suggests that language processing involves simulations of actions and perceptual states (e.g., Glenberg & Kaschak, 2002; Pulvermueller, 2005; Spivey, Richardson, & Gonzales-Marquez, 2005), and recent theoretical work suggests that gestures derive from these simulations (Hostetter & Alibali, 2008). According to Hostetter and Alibali (2008), speakers sometimes incompletely inhibit the motor activation that results from simulated actions, and when activation exceeds a set threshold, speakers produce gestures. As predicted by this framework, when speakers more strongly activate action simulations, they gesture at a higher rate (Hostetter & Alibali, 2010), Thus, this account of the cognitive underpinnings of gestures is gaining empirical support.

Building on this view, we suggest here that the action of producing gestures, in turn, can feed back to raise the level of activation of simulated actions and perceptual states. In this way, gestures could highlight the information they express for speakers themselves. Because speakers who produce gestures have more strongly activated action simulations, they may focus more on information derived from such simulations, so they may traverse a different path in learning or problem solving than do speakers who do not gesture. In this way, producing gestures could influence the course of learning and problem solving.

How gestures function for speakers

Claims made about the role of gesture in learning and problem solving must also be compatible with what is known about how gesture *functions* in the process of speaking. There is wide agreement that gesture plays a functional role in speaking (e.g., Kendon, 2004; McNeill, 1992); however, there is not agreement about precisely how or at what point in the process gesture plays a role. Various hypotheses have been put forward as to the exact locus of the link between speech and gesture production processes. One school of thought holds that gestures are involved in generating the surface forms of utterances, specifically, accessing items from the mental lexicon (e.g., Butterworth & Hadar, 1989; Krauss, Chen, & Chawla, 1996; Rauscher, Krauss, & Chen, 1996). Gestures are thought to serve as a "cross-modal prime" that activates lexical items.

An alternative view holds that gesture plays a role at an earlier point in the process of speech production, namely, in the conceptual planning of speaking. There are two variations of this view. Some investigators have proposed that gesture plays a role in activating or maintaining mental imagery (de Ruiter, 1998; Morsella & Krauss, 2004; Wesp, Hess, Keutmann, & Wheaton, 2001).[1] Others have proposed that gesture serves to facilitate the packaging of spatial-motor information into verbalizable units (e.g., Alibali, Kita, & Young, 2000; Hostetter, Alibali, & Kita, 2007; Kita, 2000; Kita & Davies, 2009; Melinger & Kita, 2007). This latter account rests on the fact that gestures often represent aspects of action simulations, such as information about the physical properties of objects, about how bodies interact with objects, and about how objects interact with one another. For example, when describing a cup, gestures may indicate or represent physical aspects of the cup (such as its size, shape, or height) or information about how the speaker's body could interact with the cup (such as by picking it up, holding it, or tilting it). According to Kita (2000), speakers use such gestures to explore alternative ways of organizing spatial-motor information. Gesture production helps speakers to arrive at a felicitous way of expressing such information in linear, verbal form. In this way, gesture is involved in the conceptual planning of utterances.

Effects of gesture prohibition

If gesture is involved in the conceptual planning of speaking, it seems possible that it may play a role in conceptualization more generally. As noted above, some recent experimental work supports this contention. In the present study, we use an experimental design to examine how gesture affects thinking and speaking in a problem explanation task. Specifically, we examined whether prohibiting speakers from gesturing influences the nature of the information they express. If, as we have suggested, gesture highlights perceptual-motor information by raising the level of activation of simulated actions and perceptual states, then speakers should express more perceptual-motor information when they are allowed to gesture, than when they are prohibited from gesturing.

Past studies in which speakers have been prohibited from gesturing have shown that gesture prohibition does indeed affect speech production. However, most previous studies of this issue have focused on the effects of gesture prohibition on the fluency of speech, rather than the content of speech. For example, Graham and Heywood (1976) found that speakers paused more when they were prohibited from gesturing while describing geometric shapes. Rauscher, Krauss, and Chen (1996) reported a similar phenomenon in participants who narrated an animated cartoon that they had just viewed. When gesture was prohibited, narrators spoke more slowly and produced more dysfluencies. However, this effect was found only in utterances that included spatial prepositions.

Two other studies investigated the effect of gesture prohibition on resolution of tip-of-the-tongue states, with mixed results (Beattie & Coughlan, 1999; Frick-Horbury & Guttentag, 1998). In these studies, participants were asked to retrieve a low frequency word on the basis of a verbal definition (Brown & McNeill, 1966). Frick-Horbury and Guttentag (1998) found that participants successfully retrieved more words when gesture was allowed than when gesture was prohibited; however, Beattie and Coughlan (1999) obtained a non-significant but reverse pattern of results.

One study has provided suggestive evidence that gesture prohibition can affect the content of speech (Rimè, Shiaratura, Hupet, & Ghysselinckx, 1984). Speakers were asked to converse freely on a set of given themes, and the imagery level of the speech was assessed using a "computer program of content analysis conceived to quantify the degree of speech imagery" (p. 317). When gestures were prohibited, speakers received lower imagery scores. At face value, this finding seems to support the view that gesture production promotes a focus on perceptual-motor information. However, Rimé and colleagues provided little information about the workings of their content analysis program, so it is difficult to evaluate their claim.

Two studies have investigated the effect of gesture prohibition on a memory task (Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Wagner, Nusbaum, & Goldin-Meadow, 2004). In both studies, participants first memorized a list of words or digits or a visual pattern, and then they solved and explained a math problem. After the explanation, they were asked to recall the words, digits or visual pattern. Their recall performance was better when they were allowed to gesture during the explanation then when they were prohibited from gesturing. These findings indicate that the effect of gesturing goes beyond speech production in a narrow sense, supporting the possibility that gesturing may affect conceptual processes associated with speaking.

In the present study, we sought to test whether prohibiting speakers from gesturing would cause them to shift their focus away from information that is likely to be expressed in gesture, namely, perceptual-motor information. To do so, we utilized a task in which speakers could choose to focus on either information that is perceptually present or information that is not perceptually present: Piagetian conservation. In conservation tasks, children are asked to judge whether or not two identical quantities (e.g., two rows of six checkers each) are the same or different following a transformation (e.g., one row is spread apart), and to explain that judgment. In explaining such tasks, children often focus on attributes of the task objects that are perceptually available (e.g., the length or density of the row of checkers). However, they also sometimes often focus on non-perceptual aspects of the task (e.g., the identity of the quantities prior to the transformation) or on aspects of the task that are not perceptually available at the time when the explanation is elicited (e.g., the transformation that was performed before the question was posed). Thus, conservation is an ideal task with which to examine whether gesture prohibition leads to a shift in the nature of the information that children focus on. Past work has shown that children's gestured responses to conservation tasks often express perceptually present information (Mainela-Arnold, Evans, & Alibali, 2006). Based on this prior work, we hypothesized that when allowed to gesture, children would be especially likely to focus on perceptually present information, which is a type of perceptual-motor information that they commonly express in gesture in conservation explanations.

We examined the effects of gesture prohibition using a within-subject design, in order to control for individual variation in gesture production. Children in the experimental group performed one set of conservation tasks with gesture allowed, and then performed a second set with gesture prohibited. Their performance was evaluated against that of children in a control group who performed both sets of conservation tasks with gesture allowed.

Method

Participants

Fifty students from two urban parochial schools participated in the study. The sample was predominantly Caucasian and middle class, and included 25 first-grade students (12 boys, 13 girls) and 25 second-grade students (13 boys, 12 girls). The children ranged in age from 5 years, 6 months to 7 years, 6 months (M = 6 years, 5 months).

Procedure

Each child was asked to solve six Piagetian conservation tasks, administered in two sets of three tasks each. Each set of three tasks included one liquid quantity task, one number task, and one length task. The liquid quantity tasks were conducted using containers of water, the number tasks using rows of plastic Duplo blocks or buttons, and the length tasks using Tinkertoy rods or wooden dowels. In each task, the objects were positioned such that one of them (i.e., one glass, row of blocks, or rod) was closer to the experimenter, and one was closer to the child.

In each task, children were first asked to verify that the two task objects (e.g., two glasses of water, two rows of blocks, or two rods) had the same quantity (amount, number or length). One object was then transformed (e.g., a glass of water poured into a short, wide dish, a row of blocks spread apart, or a rod moved to the right). Children were then asked to judge whether the quantities were the same or different, and to explain that judgment.

For the first set of three tasks, all children were allowed to gesture as they explained their judgments, and as expected, children gestured on a large majority of the trials (83%). For the second set of three tasks, children were randomly assigned to either a gesture-allowed or a gesture-prohibited condition. Children were prohibited from gesturing by placing their hands inside a furry cloth muff. This manipulation was effective at reducing gesture production. However, it did not eliminate gesture entirely. Some children occasionally used their muffed hands to indicate or characterize the objects, and some children occasionally tilted their heads or used their elbows to indicate the objects.

Coding children's verbal explanations

We identified two types of explanations in children's responses. The first focused on the present state of the task objects (e.g., "this one is tall and this one is short"), henceforth perceptually present explanations. Any response that included information about perceptual characteristics of the objects at the moment of explanation was classified as including a perceptually present explanation.[2]

The second type of explanation focused on information that was not perceptually present at the moment of explanation, henceforth non-present explanations. There were three subcategories of non-present explanations. Prior state explanations focused on the prior state of the objects, either directly ("they were the same length before") or indirectly ("it's still the same water"). Hypothetical explanations focused on possible states of affairs ("if you put these two together, then this will be longer than this") or on general rules ("when you have a fatter glass, the water gets lower"). Transformation explanations focused on the particular transformation that the experimenter had just performed (e.g., "you moved it over") or on a possible transformation that she did not perform (e.g., "you didn't add any"). Any response that was identified as including prior state, hypothetical, or transformation reasoning was classified as including a non-present explanation.

It is important to note that individual responses often included multiple explanations, so a single response could include both perceptually present and non-perceptual explanations. For example, in response to one of the length tasks, one child said, "Because, that one's shorter and that one's longer. Because you moved this over and this one stayed there." Also, some responses included neither perceptually present nor non-perceptual explanations. For example, children sometimes said "I don't know" or "I just looked at them" and they sometimes stated that they counted the objects on the number trials.

Coding children's gestured explanations

Gestures were defined as movements of the hands or arms that were produced in the act of speaking. Children's gestured explanations for the conservation tasks were segmented into individual gestures, transcribed, and assigned meanings using procedures described in prior work (Alibali et al., 2000; Church & Goldin-Meadow, 1986; Evans, Alibali, & McNeil, 2001), and summarized in the Appendix to this paper. The coding procedure involved describing the handshape, placement, and motion of the hands, and using these features to infer the meaning of the gesture.

Each individual gesture was then classified as to whether or not it incorporated deictic information. A gesture that incorporates deictic information can be either an iconic gesture that is performed towards one of the task objects (e.g., a flat hand, palm down, produced at the top edge of the tall glass) or a purely deictic gesture that simply indicates one of the task objects (e.g., an index finger point toward the tall glass).

Each individual gesture was further coded into one of four categories based on the meaning of the gesture: (a) gestures that express solely deictic information (i.e., they simply indicated the task objects, and did not convey perceptual or action information), (b) gestures that conveyed perceptual information (i.e., information about features of the task objects, such as height, width, density, and so forth), (c) gestures that conveyed information about action (i.e., actions that were or could be performed on the task objects, such as pouring water, moving a rod, taking blocks away), or (d) gestures that did not fall into one of the previous categories (i.e., beat gestures, which are small bi-phasic hand movements that are hypothesized to serve a discourse structuring function (McNeill, 1992)).

Reliability

To establish reliability, a second trained coder recoded a subset of 60 responses (20% of the total dataset). For verbal explanations, agreement between coders was

93% for identifying perceptually present explanations, 97% for identifying prior state explanations, 98% for identifying hypothetical explanations, and 96% for identifying transformation explanations. For gestured explanations, agreement between coders was 87% for identifying individual gestures from the stream of manual behavior, 95% for identifying whether or not gestures incorporated deictic information, and 81% for classifying gestures into the four meaning-based categories.

Results

The muff manipulation was effective at reducing gesture frequency, as seen in Table 1; however, participants continued to produce some gestures even while wearing the muff. As seen in the table, most gestures produced while wearing the muff conveyed exclusively deictic information (i.e., they simply indicated one of the task objects). Most gestures produced while not wearing the muff conveyed perceptual information about the task objects, and also incorporated deictic information (i.e.,

Table 1. Descriptive information about participants' gestures (mean values, with standard errors in parentheses)

Measure	Allowed-Allowed (Control)		Allowed-Prohibited (Experimental)	
	Set One	Set Two	Set One	Set Two
Total number of gestures	4.96 (0.71)	5.58 (0.57)	6.88 (0.94)	2.63 (0.61) **
Gestures that incorporate deictic information[a]	4.69 (0.67)	5.31 (0.55)	6.29 (0.91)	2.04 (0.57) **
Gesture that express *solely* deictic information	1.19 (0.27)	1.35 (0.28)	2.13 (0.35) *	1.75 (0.49)
Gestures that express perceptual information[b]	3.19 (0.60)	3.65 (0.54)	4.13 (0.67)	0.29 (0.11) **
Gestures that express information about actions[c]	0.50 (0.16)	0.46 (0.14)	0.38 (0.17)	0.33 (0.10)

[a] This category includes both gestures that express solely deictic information, and gestures that express both deictic and perceptual information.
[b] This category includes both gestures that express solely perceptual information (i.e., produced in neutral space), and gestures that express both deictic and perceptual information (i.e., produced on the task objects).
[c] This category includes both gestures that express solely action information (i.e., produced in neutral space), and gestures that express both deictic and action information (i.e., produced on or over the task objects).
** $p < .001$, comparing Experimental to Control
* $p < .05$, comparing Experimental to Control

gestures toward one of the task objects that also depicted a feature of the object, such as a flat palm held at the level of the water).

Participants' verbal explanations were analyzed using 2 (set: one vs. two) x 2 (condition: allowed-allowed vs. allowed-prohibited) repeated measures ANOVA, with set as a within-subjects factor and condition as a between-subjects factor. We used two different dependent measures: (1) number of responses that included perceptually present explanations, and (2) number of responses that included non-present explanations. Because there were 3 tasks in each set, participants' scores for each of these dependent measures for each set ranged from 0 to 3. Responses that included both types of explanations were counted in both categories. Because individual responses could include both types of explanations, the two measures are independent. Note that, because the experimental manipulation took place during the second set of tasks, an effect of gesture prohibition would be revealed in these analyses as an interaction of condition and set.

As seen in Figure 1, children produced more responses with perceptually present explanations when they were allowed to gesture, yielding the predicted significant interaction between condition and set, $F(1, 48) = 8.68$, $\eta^2 = .15$, $p = .005$. Focusing on set two, where the experimental manipulation occurred, a planned comparison indicated that children who were allowed to gesture produced significantly more responses with perceptually present explanations than did children who were prohibited from gesturing, $F(1, 48) = 9.17$, $\eta^2 = .16$, $p = .004$. Thus, when gesture was allowed, children were more likely to focus on the current perceptual state of the task objects. This general pattern held for each of the three quantities.

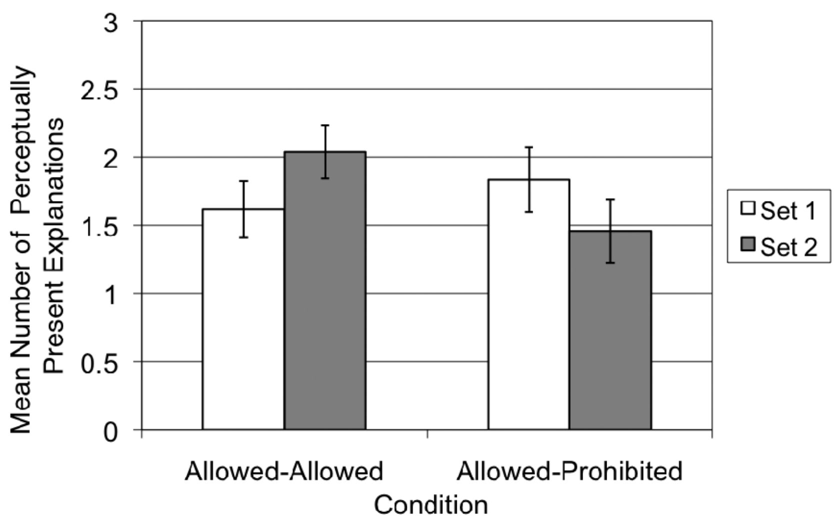

Figure 1. Mean number of perceptually present explanations produced in set one and set two for children in each condition. The error bars represent standard errors.

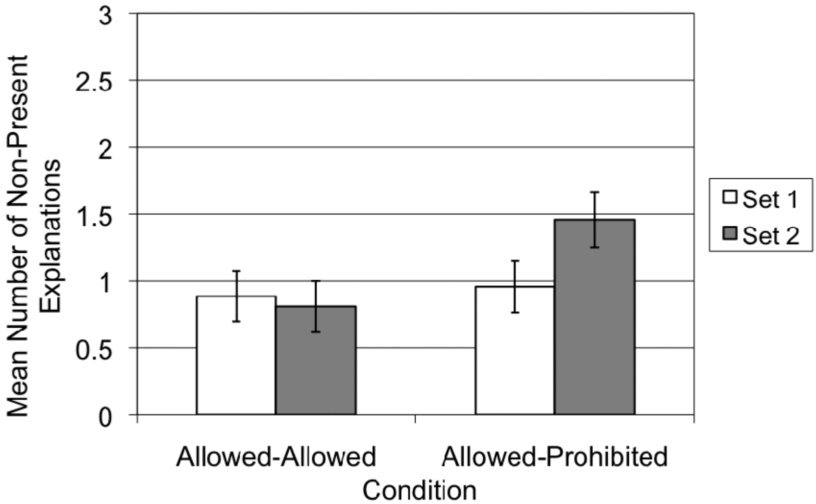

Figure 2. Mean number of non-present explanations produced in set one and set two for children in each condition. The error bars represent standard errors.

In set two, perceptually present explanations were given, for liquid quantity, by 92% of children in the gesture-allowed group and 73% of children in the gesture-prohibited group; for length, by 67% of children in the gesture-allowed group and 39% of children in the gesture-prohibited group; and for number, by 50% of children in the gesture-allowed group and 42% of children in the gesture-prohibited group.

As seen in Figure 2, children produced more responses with non-present explanations when they were prohibited from gesturing, yielding the predicted interaction between condition and set, $F(1, 48) = 6.26$, $\eta^2 = .11$, $p = .016$. Focusing on set two, where the experimental manipulation occurred, a planned comparison indicated that children who were prohibited from gesturing produced significantly more responses with non-present explanations than children who were allowed to gesture, $F(1, 48) = 15.93$, $\eta^2 = .28$, $p = .002$. Thus, when gesture was prohibited, children were more likely to refer to information that was not in front of them. This general pattern also held for each of the three quantities. In set two, non-present explanations were given, for liquid quantity, by 12% of children in the gesture-allowed group and 30% of children in the gesture-prohibited group; for length, by 23% of children in the gesture-allowed group and 68% of children in the gesture-prohibited group; and for number, 46% of children in the gesture-allowed group and 54% of children in the gesture-prohibited group.

We next examined whether this pattern held for each of the three subtypes of non-present explanations. A large majority of non-present explanations were of the transformation subtype. Limiting the analysis to transformation explanations only, we found that children produced more transformation explanations when they were prohibited from gesturing, yielding a marginally significant interaction between condition and set, $F(1, 48) = 3.27$, $\eta^2 = .06$, $p = .08$. A planned comparison at set two indicated that children who were prohibited from gesturing produced significantly more responses with transformation explanations than children who were allowed to gesture, $F(1, 48) = 13.38$, $\eta^2 = .25$, $p < .001$.

Prior state and hypothetical explanations were much less common in the dataset overall than were transformation explanations, and they were too few to analyze statistically. To evaluate changes in these types of explanations, we identified children who did not use such explanations on the first set of tasks, and then calculated the proportion of these children who used such explanations on the second set. For prior-state explanations, among children who did not use such explanations on set one, 20% of children in the gesture-prohibited group at set two generated prior-state explanations, whereas only 6% of children in the gesture-allowed group generated such explanations. For hypothetical explanations, among children who did not produce such explanations on set one, 14% of children in the gesture-prohibited group at set two generated hypothetical explanations, whereas 8% of children in the gesture-allowed group generated such explanations. Thus, more children who were prohibited from gesturing generated both prior-state and hypothetical explanations.

Potential issues and alternative explanations

One potential problem with the interpretation we have proposed is the fact that the muff manipulation did not eliminate gestures altogether. As noted above, children sometimes produced gestures with their hands in the muff. It is possible that the gestures that children produced while wearing the muff were somehow especially likely to activate or encourage non-present explanations. If this were the case, the results would require a substantially different interpretation from the one we have proposed. To address this possibility, we eliminated all of the trials in which children gestured with the muff from the dataset, and reanalyzed the data. Seven children who were prohibited from gesturing at set two were excluded from this analysis because they produced gestures on all three of the gesture-prohibited trials (e.g., by moving the muff or by moving their elbows).

The outcome was identical to that observed with the full dataset. Children produced more responses with perceptually present explanations when they were allowed to gesture ($M = .69$ vs. $M = .43$), yielding a significant interaction between condition and set, $F(1, 41) = 6.61$, $\eta^2 = .14$, $p = .01$. Focusing only on set two, where the experimental manipulation occurred, a planned comparison indicated that children who were allowed to gesture produced significantly more perceptually present explanations than children who were prohibited from gesturing, $F(1, 41) = 11.62$, $\eta^2 = .24$, $p = .002$. Further, children produced more responses with non-present explanations when they were prohibited from gesturing (and did not gesture) ($M = .48$ vs. $M = .28$), $F(1, 41) = 3.28$, $\eta^2 = .07$, $p = .08$. Focusing only on set two, children who were prohibited from gesturing produced significantly more responses with non-present explanations than children who were allowed to gesture, $F(1, 41) = 8.31$, $\eta^2 = .18$, $p = .006$. Thus, there was no evidence that the results depended on the types of gestures that children could produce while wearing the muff.

Another possible alternative explanation for our findings is that children chose the type of explanation that they found easier to express in each context. Non-present information may be easier to express without gesture than perceptually present information, so participants may have shifted to non-present explanations when gesture was prohibited. One way to assess this possibility is to examine how often children spontaneously gestured in responses that included only perceptually present explanations vs. only non-present explanations, when gesture was allowed (i.e., in set 1). If there were no differences in gesture frequency for the two types of explanations when gesture was allowed, this would undermine this explanation. Because there are large individual differences in gesture rates (Hostetter & Alibali, 2007), we limited this analysis to individuals who produced explanations in both categories in set 1 ($N = 12$). Indeed, the mean number of gestures per response did not differ significantly between perceptually present responses ($M = 2.21$, $SD = 1.33$) and non-present responses ($M = 2.28$, $SD = 1.99$), $t(11) = .41$, $d = .12$, $p = .69$. Thus, there was no evidence that the results were due to the two types of responses being differentially easy to express without gestures.

Another possible alternative explanation for our findings is that when gesture is prohibited, speakers may shift or "translate" information that they had previously expressed uniquely in gestures into speech. If this were the case, the results would also require a different interpretation from the one we have proposed. In addressing this issue, we focused on trials in which children expressed information about action uniquely in gesture, because children in the gesture-prohibited condition tended to express transformation information in speech when gesture was prohibited. Thus, we identified all trials in set one in which children expressed information about action uniquely in gesture ($N = 8$), and we examined whether children expressed transformation information in speech in the corresponding trials in set two in which gestures were prohibited. In not one of these eight cases did the children express transformation information in speech at set two. Thus, there was no evidence that the results were due to children expressing action information uniquely in gesture when gesture was allowed, and "translating" or shifting that information into speech when gesture was prohibited.

Relation to knowledge of conservation

Finally, we examined whether the pattern varied as a function of children's status as non-conservers, partial conservers, or full conservers at set one. Children were classified as non-conservers if they judged the quantities as different after the transformation for all three tasks in set one. Children were classified as full conservers if they judged the quantities as the same after the transformation for all three tasks in set one. Children were classified as partial conservers if they judged the quantities as the same after the transformation for one or two of the tasks at set one.

For all of the conservation knowledge subgroups, children who were prohibited from gesturing made greater decreases in perceptually present responses (Table 2) from set one to set two than did children who were allowed to gesture. This pattern was significant for the non-conservers, $F(1, 24) = 8.38$, $\eta^2 = .26$, $p = .008$, but did not reach significance for the partial conservers, $F(1, 15) = 2.13$, $\eta^2 = .12$, $p = .17$. There were very few full conservers (three who were allowed to gesture and four who were prohibited from gesturing), so the pattern could not be analyzed statistically.

In addition, for both non-conservers and partial conservers, children who were prohibited from gesturing made greater increases in non-present responses (Table 3) from set one to set two than did children who were allowed to gesture, $F(1, 24) = 9.95$, $\eta^2 = .21$, $p = .004$ for non-conservers, and $F(1, 15) = 4.64$, $\eta^2 = .23$, $p = .048$ for partial conservers. Among the full conservers, children in both conditions produced fewer such responses at set two.

Based on the foregoing analyses, it is apparent that gesture prohibition led to increased expression of non-present information. Given that many correct (conserving) explanations focus on non-present information (e.g., the initial

Table 2. Mean Number of Perceptually Present Explanations as a function of Pretest Knowledge Status (standard errors in parentheses)

Pretest Knowledge	Condition	N	Mean Number of Perceptually Present Explanations		
			Set 1	Set 2	Difference (Set 2 – Set 1)
Non-conservers	Allowed-Allowed	14	2.00 (0.28)	2.50 (0.23)	0.50 (0.23)
	Allowed-Prohibited	12	2.17 (0.35)	1.67 (0.28)	−0.50 (0.26)
Partial conservers	Allowed-Allowed	8	1.00 (0.27)	1.50 (0.27)	0.50 (0.38)
	Allowed-Prohibited	9	1.44 (0.34)	1.22 (0.43)	−0.22 (0.32)
Full conservers	Allowed-Allowed	4	1.50 (0.65)	1.50 (0.65)	0.00 (0.82)
	Allowed-Prohibited	3	1.67 (0.88)	1.33 (0.88)	−0.33 (0.33)

Note. The maximum number possible per set was 3.

Table 3. Mean Number of Non-Present Explanations as a function of Pretest Knowledge Status (standard errors in parentheses)

Pretest Knowledge	Condition	N	Mean Number of Non-Present Explanations		
			Set 1	Set 2	Difference (Set 2 – Set 1)
Non-conservers	Allowed-Allowed	14	0.50 (0.25)	0.57 (0.25)	0.07 (0.13)
	Allowed-Prohibited	12	0.75 (0.22)	1.50 (0.26)	0.75 (0.18)
Partial conservers	Allowed-Allowed	8	1.38 (0.26)	1.13 (0.30)	−0.25 (0.25)
	Allowed-Prohibited	9	1.00 (0.33)	1.67 (0.41)	0.67 (0.33)
Full conservers	Allowed-Allowed	4	1.25 (0.48)	1.00 (0.71)	−0.25 (0.48)
	Allowed-Prohibited	3	1.67 (0.88)	0.67 (0.33)	−1.00 (0.58)

Note. Non-present explanations include prior state, transformation, and hypothetical subtypes. The maximum number possible per set was 3.

equality of the quantities, the fact that nothing was added or taken away), it was natural to consider whether the increase in non-present explanations was accompanied by an increase in correct (same) judgements in the conservation tasks. Overall, children provided slightly more same judgements in set two ($M = 1.14$, $SE = 0.17$) than in set one ($M = 0.96$, $SE = 0.16$); however, this increase did not vary by condition. Thus, children who were prohibited from gesturing altered their verbal explanations in set two without substantially altering their conservation judgements. It should be noted, however, that the design of this study may not have been sensitive enough to reveal a change in judgements. If explanation under gesture prohibition influences conservation judgements, then this effect should appear only after the first trial with gesture prohibition. This leaves only two trials in the second set in which conservation judgements could potentially have been influenced by gesture prohibition.

Discussion

In explaining Piagetian conservation tasks, children were more likely to focus on information that was not perceptually present when gesture was prohibited, and more likely to focus on information that was perceptually present when gesture was allowed. These findings suggest that producing gestures makes perceptually present information more highly activated and more likely to be expressed in children's problem explanations. In this way, gesture is involved in the conceptual planning of speaking, and perhaps in conceptualization more generally.

Are the present findings compatible with the idea that gestures derive from simulated actions (Hostetter & Alibali, 2008)? At first glance, the findings seem more specific to perception than to action, because explanations that focused on the action the experimenter performed (e.g., pouring the water) were categorized as non-present responses in our coding scheme. In putting these pieces together, it is essential to consider the reciprocal relations between perception and action (e.g., Dewey, 1896; Gibson, 1979). We move our bodies (e.g., our eyes, heads, and hands) in order to perceive (e.g., Campos et al., 2000; O'Regan & Noë, 2001), and we perceive in order to guide our actions. For example, when we perceive objects, we automatically activate actions that we might use in manipulating or interacting with those objects (Ellis & Tucker, 2000; Tucker & Ellis, 1998). From this perspective, it is sensible that explanations that invoke perceptually present information involve simulated actions, which may evoke gesture production, and which may also become more highly activated as a result of gestural actions. Thus, the findings are indeed compatible with the idea that gestures derive from simulated actions.

Moreover, the current results suggest that gestures may actually influence the nature of people's simulations. In the present study, children were asked make inferences about objects that were physically present in front of them. Kita (2000) has argued that gestures are used to explore and highlight aspects of objects (simulated or real). In the present study, the "affordances" of the objects may have guided children's gestures, and these gestural actions in turn highlighted perceptual features of the objects in children's conceptualization, leading to a higher frequency of perceptually present explanations.

Indeed, gestures to perceptual features of the physically present task objects (e.g., deictic and iconic gestures that indicate their heights, water levels, endpoints, density, and so forth) may actually be an integral part of perceiving those features. If this is the case, such gestures should be especially likely to feed activation to those features, highlighting them for speakers' conceptualization of the task. From this perspective, it makes sense that, in this task involving physically present task objects, the availability of gesture promoted a focus on perceptually present information.

In contrast, when gestures were prohibited, the perceptually present situation was not highlighted by gesture, making other information about the task relatively more salient. When gesture was prohibited, children were less "bound" to the objects in front of them, and they were free to activate other sorts of information, such as information about how the objects looked before, how the objects were transformed by the experimenter, and how the objects could hypothetically be transformed. This led to a higher frequency of non-present explanations.[3]

An alternative, but related explanation can be given on the basis of the recent development of the Growth Point Theory of speech-gesture production, in which gesture is considered to be a "material carrier" of thinking (McNeill, 2005; McNeill & Duncan, 2000). According to this view, gestures do not merely encode prepackaged meaning, but producing a gesture can alter the status of the information encoded in the gesture: "[T]o make a gesture … is to bring thought into existence on a concrete plane, just as writing out a word can have a similar effect" (McNeill & Duncan, 2000, p. 156). When children gesture about perceptually present features of the task objects, these features become "concrete". This presumably means that the features become something more than physical parameters that guide motor control, namely, something accessible by other cognitive processes, such as verbal thought. Consequently, the features expressed in children's gestures are more likely to be incorporated into their verbal explanations. When gesture is prohibited, perceptually present features of the objects are highlighted less, and other types of information are more likely to be incorporated into the explanations.

Relation to other views about the function of gesture

Our account of the effects of gesture production differs from the one proposed by Goldin-Meadow, Nusbaum, Kelly and Wagner (2001) and Wagner, Nusbaum and Goldin-Meadow (2004), who also used a gesture-prohibition paradigm to investigate the function of gesture. However, these researchers did not focus on the *speech* that individuals produced under gesture prohibition. Instead, they focused on memory performance, and found that speakers performed better on various memory tasks when they were allowed to gesture. They interpreted these findings as showing that gesture off-loads working memory, freeing up capacity for a secondary task — as they put it, gesture "lightens the load" of explanation.

Although our approach was quite different from that of Goldin-Meadow and colleagues, our findings are not necessarily incompatible with theirs. We found that speakers expressed different information when they were prohibited from gesturing. It is possible that speakers produced more resource-intensive explanations when gesture was allowed and they could use gesture to help manage capacity demands. When gesture was prohibited, they shifted to more resource-lean explanations, which they could formulate and express even without gesture to assist them in managing memory demands. This explanation rests on the assumption that non-present explanations require fewer working memory resources than do explanations that focus on perceptually present information — a possibility that remains to be tested in future work.

Might our findings be explained by the idea that gestures facilitate accessing words, especially those with spatial content (e.g., Butterworth & Hadar, 1989; Krauss et al., 1996; Rauscher et al., 1996)? The explanation would be that gesture prohibition made it difficult to access spatial words necessary for perceptually present explanations, and thus the explanations shifted to ones with words that were readily accessible without gestures. We do not find this argument compelling, for two reasons. First, the spatial words used in perceptually present explanations were usually common words such as “big”, “small”, “tall”, “short”, “high”, “low”, which were presumably easy to access regardless of the availability of gestures. Second, most of non-present explanations included spatial words as well (e.g., “they were the same length before”, “you moved it over”, “when you have a fatter glass, the water gets lower”). Thus, it does not seem likely that gesture prohibition made it difficult to access the words needed for perceptually present explanations.

Our findings are most compatible with the idea that gestures facilitate conceptual planning for speaking, by helping speakers to package information into verbalizable units (Alibali et al., 2000; Kita, 2000). Gestures may help speakers to parse a complex array of information into small units (Hostetter et al., 2007) and to select units of information for verbalization (Kita & Davies, 2009; Melinger & Kita, 2007). Gestures highlight certain pieces of information — in the present study, perceptual features of the task objects. This information is then incorporated into conceptual planning for speaking, and eventually encoded in participants' verbal explanations.

Potential generalizability of the findings

Should we expect the present findings to generalize to other tasks or to other participant populations? At present, this remains an open question. It seems likely that the findings would be specific to tasks that draw on perceptual-motor thinking, such as conservation, or to tasks that elicit the types of gestures that are typically seen in conservation explanations — namely, deictic and iconic gestures that are directed toward relevant objects. Future studies will be needed to examine whether other types of gestures, in particular, those that are not directed toward objects, also serve to highlight perceptual information.

It is also an open question whether the findings would generalize to adult participants. Given that adults have better attentional control and greater working memory capacity than children, it is possible that they may be less reliant on gesture to represent object features or to help construct resource-demanding explanations. However, given the close ties between gesture, perception, and simulated action, we suspect that gesture serves to highlight perceptual-motor information for adults well as children. Therefore, we would expect a similar outcome on an adult-appropriate task with similar characteristics.

Implications for education

Do the present findings have implications for learning and instruction? The answer seems to be "it depends". Because gesture production promotes a focus on perceptual-motor information, then to the extent that perceptual-motor information is useful in completing a task at hand, producing gestures should be beneficial for thinking and learning. However, if perceptual-motor information is misleading, as it is in conservation tasks, producing gestures may actually be detrimental to thinking and learning. In the present study, we did not find beneficial effects of gesture prohibition on children's conservation judgements; however, it could be argued that non-present explanations, and in particular, prior state explanations, are more sophisticated than perceptually present explanations. Thus, the evidence about whether gesture is detrimental to conservation reasoning is mixed.

The present findings do not allow for a general statement about whether it would be valuable to elicit or encourage gestures in educational settings. A more nuanced consideration of the demands of each particular task, and of the pros and cons of activating perceptual vs. non-perceptual information for each task, will be required.

Conclusion

In sum, our main finding is clear — when speakers were prevented from gesturing, their explanations included perceptually present information less often and non-present information more often. These findings suggest that producing gestures highlights or lends salience to perceptual-motor information. We have argued that producing gestures feeds activation to simulated actions, and furthermore, producing gestures can influence the content of action simulation. As a result, gestures contribute to thinking by helping speakers decide what to attend to and what to say.

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Notes

1. Hadar, Burstein, Krauss, and Soroker (1998) propose a hybrid between the image-activation hypothesis and the lexical access hypothesis. They argue that gestures activate visuo-spatial representations, which in turn activate concepts that underlie the sought-after words. This extra activation of the underlying concepts facilitates access to the sought-after words.

2. Some responses described the present state of the task objects using a past participle construction. For example, on one of the number tasks, one child said, "Because these are all squished together." Such explanations include perceptually present information (i.e., information about the density of one row) but do so in terms of the transformation, which was not perceptually present (i.e., "squishing"). In the analyses presented in this paper, we counted these responses in the perceptually present category; however, the findings do not differ if they are excluded.

3. Note that activating non-present information likely involves motor or visual imagery (e.g., of the transformation or of the initial state of the objects), and there is evidence that imagery involves simulated actions (e.g., Jeannerod, 2001; Shepard & Metzler, 1971; Wohlschlaeger & Wohlschlaeger, 1998). However, it seems likely that mental imagery activates action simulations less strongly than direct perceptual experience of the objects.

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Appendix A. Coding gestures for conservation tasks

This coding system was based on the one developed by Church and Goldin-Meadow (1986) for coding gesture-speech matches and mismatches in conservation tasks.

Identifying individual gestures

A separate gesture is coded each time there is a change in the shape, placement, or motion of the hand(s). For example, if a child points to the top edge of the tall glass, and then makes a flat palm handshape at the top edge of the of the tall glass, this is coded as two separate gestures, due to change of handshape. If a child points to the top edge of the glass, and then to the base of the glass, this is coded as two separate gestures, due to change of placement. If a child makes a back-and-forth motion above the glass, and then makes an up-and-down motion above the glass, this is coded as two separate gestures, due to change of motion.

Transcribing gestures

Three aspects of each individual gesture are transcribed: the handshape, placement, and motion. In the examples that follow, the transformed object is abbreviated as *t* and the untransformed object as *u*. From the information in the transcript, someone reading the coding sheet should be able to essentially reproduce the child's gesture.

Handshape. The handshape code includes information about the hand(s) used, the shape of the hands, and the orientation of the hands. Hand codes are right, left, and both hands. Handshape codes are those from the manual alphabet, and also the following common handshapes that are not part of the manual alphabet: point, two finger point, spread fingers ("5"), fist, claw, grasp, and blob. Orientation codes include: toward down, toward up, toward body, toward center, and others as needed. Handshape codes include all of these types of information, for example, "right hand C facing down", "2 B hands facing toward center", "left hand point toward down".

Placement. The placement code includes information about the placement of the hand(s) with respect to the task objects or in neutral space in front of the body. The placement code should be as specific as possible, because variations in placement can affect interpretation of the gesture. For example, for the water tasks: "at level t", "at sides u", "into t"; for the stick tasks: "at left end-point u", "along t, endpoint to endpoint"; for the checker tasks: "over checker 3, t" or "at center of u row".

Motion. The motion code includes information about the motion of the hand(s), including direction and extent. The motion code should be as specific as possible, because variations in motion can affect interpretation of the gesture. For example, for the water tasks: "from base t to level t", "pouring motion from t to u"; for the stick tasks: "L to R", "sweeps back and forth 2x", "slides leftward"; for the checker tasks: "pull apart slightly", "squish 2x". Very frequently there is no motion in a gesture.

Assigning meanings to gestures: The lexicon

Based on the transcribed features, each individual gesture is assigned a meaning, as described below.

Water tasks
1. *Height*. Any indicating gesture at the top edge of a container is interpreted as "height". Any gesture that traces vertically along the side of a container to the top or from the top down is also interpreted as "height".
2. *Water level*. Any indicating gesture at the water level of a container is interpreted as "level". Any gesture that traces vertically along the side of a container to the level or from the level down is also interpreted as "level".
3. *Width*. Any gesture that indicates both sides of a container is interpreted as "width". Any gesture that traces horizontally the width of a container is also interpreted as "width". A C-shaped gesture around a container is also interpreted as "width". A width gesture may also include information about height or level, depending on its placement.
4. *Shape*. A gesture that traces or mimics the round or cylindrical shape of a container is interpreted as "shape". A shape gesture may also include information about height, depending on its placement.
5. *Area*. A gesture that delineates the cross-sectional area of a container is interpreted as "area". An area gesture may also include information about height, depending on its placement.
6. *Into*. Any indicating gesture into one of the containers is interpreted as "into".
7. *Indication*. Any indicating gesture toward one of the containers that is not meaningfully placed is interpreted as an indication of that container. A gesture that indicates toward the original glass (usually off screen but sometimes visible) is interpreted as an indication of the original glass.
8. *Transform and reversibility*. Any gesture that makes a pouring or arcing motion from u to t or into t is interpreted as "transform". Any gesture that makes a pouring or arcing motion from t to u or into u is interpreted as "reversibility". These gestures occur most frequently with a "C" handshape.

Stick tasks
1. *Length*. Any gesture that marks both endpoints of a stick is interpreted as "length". Any gesture along a stick that does not mark both endpoints is NOT interpreted as "length" but as indication; see below.
2. *Placement*. Any gesture indicating one endpoint of a stick is interpreted as "placement".
3. *Width/diameter*. Any gesture indicating the width/diameter of a stick is interpreted as "width/diameter".
4. *Extension*. On the move left/right task, the overlap of the sticks, or the extension of one stick, can be indicated or traced. Each of these is interpreted as an indication of that particular portion of the sticks.

5. *Indication*. Any indicating gesture toward one of the sticks that is not meaningfully placed is interpreted as an indication of that stick. Also, any gesture that moves along a stick that does not mark endpoints is also interpreted as indication.
6. *Transform and reversibility*. Any gesture that mimes the moving of a stick to the transformed position is interpreted as "transform". Any gesture that mimes pushing the transformed stick back to its original position is interpreted as "reversibility". These gestures are typically produced with a "C" or grasping handshape. Note that whether a gesture is interpreted as transform or reversibility depends on which direction the stick was actually transformed.

Number tasks
1. *Length*. Any gesture that marks both endpoints of a row of checkers is interpreted as "length".
2. *Density*. Any gesture with a (tensed) handshape that shows "spread out" (for example, with a 5 handshape) or "close together" (for example, with a "claw" handshape) is interpreted as "density". Also, any gesture that indicates the size of the spaces between the checkers is interpreted as density.
3. *Placement*. Any gesture that indicates one endpoint of a row of checkers is interpreted as "placement".
4. *Indication*. Any indicating gesture toward one of the rows of checkers (or to one of the checkers or spaces in a row) that is not meaningfully placed is interpreted as an indication of that row (or that checker or space). Any gesture along the row of checkers that does not mark the endpoints is also interpreted as indication.
5. *Number*. A set of indications of checkers 1 through 6 for a single row is interpreted as "number".
6. *Transform and reversibility*. Any gesture that mimes spreading or squishing the checkers is interpreted as "transform" or "reversibility", depending on whether it mimes the transformation or undoing the transformation. These gestures usually occur with a grasp or "C" handshape.
7. *Take away*. Any gesture that mimes taking a checker away from a row is interpreted as "take away".

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