Preschoolers’ Spontaneous Gesture Production Predicts Analogical Transfer

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Abstract

We explore the link between children’s gesture production and analogical reasoning. Specifically, we ask whether children who spontaneously gesture when completing a retelling task are more likely to engage in analogical transfer, compared to those who do not gesture. To test this, 85 5-7-year-olds listened to three superficially distinct stories that shared a common abstract problem and solution. After each of the first two exemplar stories, participants were asked to retell the story events to a naïve listener and their speech and spontaneous gesture(s) were coded. For the third story, participants were asked to generate the analogous solution themselves. Results indicate a significant relationship between children’s analogical transfer and gesture production. This preliminary study suggests that children’s spontaneous gestures may provide a window into their analogical processing. We discuss future directions aimed at further examining the mechanism underlying this relationship.

Keywords: cognitive development; gesture; analogical transfer; abstract reasoning

Learning requires more than acquiring new knowledge; it depends on the application of that knowledge to new contexts. Analogical reasoning—the ability to go beyond perceptual cues to identify abstract structural similarity between events—is therefore of particular significance for learning, since it enables knowledge transfer. For example, if a Windows user switches to a Mac, the ability to map functions from one system to the other will facilitate learning how to use the new computer. For instance, recognizing that the function of the *Command* key on a Mac is analogous to that of the *control (CTRL)* key on a PC will allow a novice Mac user to apply their prior knowledge of their PC to execute specific tasks.

In order to successfully draw this analogy, the learner must ignore salient surface differences (e.g., between the words, symbols, and placement of the keys) and recognize the abstract similarities between their functions (e.g. Brown et al., 1986; Richert et al., 2011). This type of task often poses a challenge for children, who tend to privilege perceptual over structural similarity (e.g., Gentner & Toupin, 1986; Gentner, 1988; Gentner & Rattermann, 1991; Holyoak et al., 1984).

A variety of minimal scaffolds have been used to support children’s recognition of abstract structure, including prompts to compare or explain (e.g., Christie & Gentner, 2010; Walker & Lombrozo, 2017) and providing relational language (e.g., Christie & Gentner, 2014). In one classic study by Brown and colleagues (1986), 3- to 5-year-olds were told a story in which a protagonist solves a problem (i.e., transferring objects across a barrier) by repurposing a flat object to create a hollow tube and passing the objects through (Brown et al., 1986). Four- and 5-year-olds successfully applied this abstract solution to a new story that was structurally similar, but superficially distinct. Critically, however, children’s success in this task was mediated by their ability to recall the “goal structure” (i.e., the protagonist, the goal, the obstacle, and the solution) of the problem in the original story. The authors concluded that the key factor predicting transfer was whether children represented the underlying abstract structure.

Here we consider whether children’s *gestures* may be linked to their success in a similar analogical reasoning task.

Several recent proposals suggest that representational gestures (i.e., gestures that reference information related to the content of concurrent speech or thought; McNeil, 1992) facilitate knowledge transfer by selectively schematizing some features over others (e.g., Kita et al., 2017). Indeed, prior work shows that observing co-speech gestures (Guarino & Wakefield, 2020; Guarino et al., 2021) and receiving training to produce gestures (Novack et al., 2014) supports abstraction during early learning. However, there are few studies exploring whether children’s *spontaneous* gesture production plays a similar role (e.g., Church & Goldin-meadow, 1986). Below, we review existing theoretical and empirical work that provides support for this hypothesis and describe our novel approach.

Gesture Production Facilitates Abstract Reasoning

According to the *gesture-for-conceptualization hypothesis* (Kita et al., 2017), gestures serve to schematize information for both communication and thinking by stripping away superficial details. This, in turn, shapes the various functions of gesture:

First, gestures *activate* relevant knowledge that supports reasoning and facilitates problem-solving (Church & Goldin-Meadow, 1986). For example, when children are asked to explain a Piagetian conservation task, those who are allowed to use their hands tend to activate spatial features (e.g. height, width), which scaffolds their understanding (Goldin-Meadow & Wagner, 2005).

Second, gestures *manipulate* abstract concepts, often independently from the particular context in which they appear. For example, 4- to 6-year-old children who were taught to use gestures as a strategy for solving mental rotation tasks performed better than those who were trained to physically move objects (i.e., Wakefield et al., 2019). These findings suggest that isolating structural information from the visual and physical details of the problem fosters abstract reasoning.

Third, gestures help learners to *package* relevant information into units that can be flexibly recruited and combined across different contexts. For instance, when children were trained to use gestures as a strategy for solving problems using the equality principle (e.g. a+b+c = ___ + c), they were more likely to transfer this concept to novel contexts than those trained to manipulate sets of magnetic number tiles representing each value (Novack et al., 2014). This provides additional evidence that gesture production may support knowledge transfer.

Finally, gestures allow learners to *explore* various potential solutions for a problem before they have identified the correct one. In fact, children often produce relevant information in their gestures before it appears in their speech. These gesture-speech incongruities have been interpreted to indicate that the learner is in a transitional period of conceptual change (Alibali, Kita & Young, 2000; Church & Goldin-meadow, 1986; Pine et al., 2004).

Here, we build on this prior work to examine whether children's spontaneous gesture production may provide a window into their analogical transfer. As noted above, the majority of prior work examining the relationship between children's gestures and learning has relied on training or explicitly prompting children to use gestures. Far fewer studies have observed children's spontaneous co-speech gestures during reasoning tasks (e.g., Church & Goldin-Meadow, 1986; Iverson & Goldin-Meadow, 1997), and, to our knowledge, no previous studies have observed children's spontaneous gestures during analogical transfer. Findings with adults provide support for the hypothesis that spontaneous gesture production may be related to analogical reasoning. Specifically, Cooperrider and colleagues (2016) demonstrate that adults often spontaneously recruit gestures to represent abstract relationships while explaining causal events (e.g., stock values rising and falling). Indeed, over 70% of the total number of gestures adults produced referenced structural information. In fact, evidence suggests that spontaneous gesture may be a *more effective* scaffold for abstraction than prompts to use co-speech gestures. In one study, adults who received explicit instructions to produce gestures while providing verbal explanations were *less* likely to engage in analogical transfer than those who gestured spontaneously (Hostetter et al., 2016).

The Current Study

This initial study explores the relationship between children's analogical transfer and their spontaneous gesture production. We consider two questions: First, do children who spontaneously produce gestures perform better on analogical transfer tasks, compared to those who do not? Given that successful analogical transfer hinges on children's recognition of common abstract structure (e.g., Brown et al., 1986), and that spontaneous gestures have been shown to promote abstraction (e.g., Church & Goldin-Meadow, 1986; Cooperrider et al., 2016; Kita et al., 2017; Pine et al., 2004), we predict greater rates of analogical transfer in children who spontaneously gesture when retelling exemplar stories.

Second, does the *type* of spontaneous gestures produced (i.e., solution-relevant vs. solution-irrelevant) correspond to children's success on analogical transfer? Given that spontaneous gestures tend to reflect abstract relationships over superficial details (e.g. Cooperrider et al., 2016), we predict a higher rate of success among children who produce solution-relevant gestures.

Following Brown and colleagues (1986), we presented children with three superficially distinct stories in which the protagonists each shared a common goal and discovered a common solution. The first two exemplar stories were each followed by a retelling task. We included *two* exemplar stories to promote comparison and facilitate abstraction (e.g., Gentner & Hoyos, 2017). The third story presented an analogous problem, and children were asked to provide the solution themselves. We included children aged 5- to 7-, since they are capable of succeeding in similar narrative-based analogical transfer tasks with minimal scaffolding (e.g. Richert et al., 2011; Holyoak et al., 1984).

Method

Participants

Eighty-five 5- to 7-year-olds participated in the study (M = 6.51 years, SD = 0.83, range = 5.0-7.92 years), with half of these children tested in person (n = 43, M = 6.56 years, SD = 0.89, range: 5.0-7.92 years) and the other half tested remotely (n = 42, M = 6.45 years, SD = 0.78, range: 5.17-7.67 years). An additional 9 participants were excluded (2 in person and 7 remote) due to stimuli malfunction (1), experimenter error (2), technological issues (5) or interruption by a sibling (1). Children who participated in-person were recruited and tested at a local museum, an aquarium, or at local preschools, and received small gifts. Children who participated remotely were recruited through the lab database, and received a $5 Amazon gift card.

Materials

Three stories, including two exemplar stories (presented in counterbalanced order), and an analogical transfer task, were presented as PowerPoint slides on a 13-inch laptop screen (in-

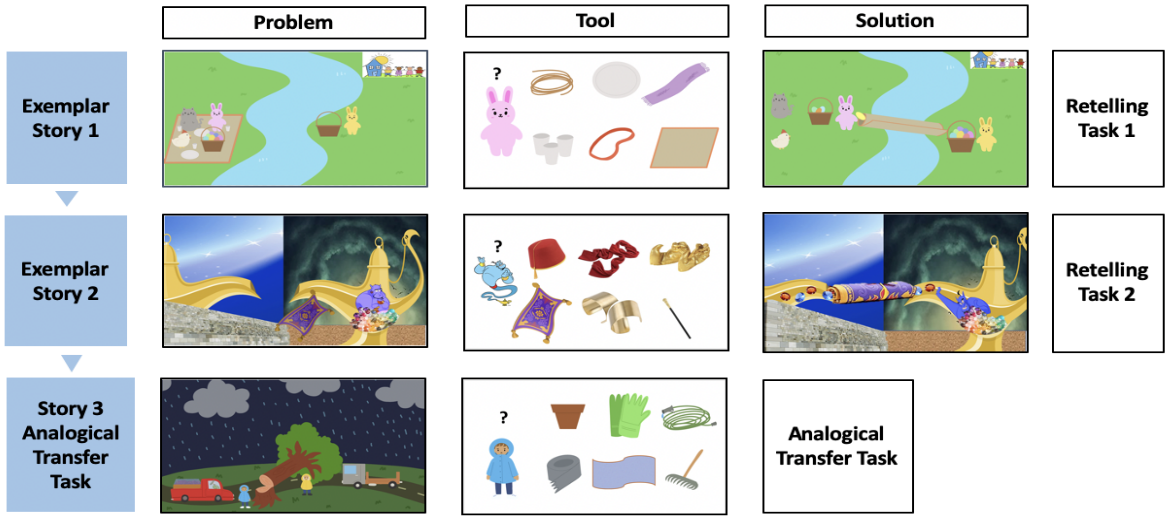

Figure 1. Stimuli. Three stories with a common abstract problem and solution were used. In Exemplar Story 1, a bunny wanted to deliver eggs to the other side of the river. The bunny rolled a picnic mat into a hollow tube, and passed the eggs through it. In Exemplar story 2, a genie wanted to move his jewels to a new lamp across a wall. The genie rolled his magic carpet into a hollow tube, and passed the jewels through it. Exemplar Stories 1 and 2 were each followed by a retelling task. In the Analogical Transfer Task story, a farmer wanted to deliver the cherries across a fallen tree in the road. Children were presented with tools (including the target tool, a flat truck cover), and asked to solve the problem themselves.

person) or via an online presentation platform (slides.com) during a Zoom session. Each story included static images of a protagonist, a set of tools, and a barrier. Stories were modified versions of those used in Brown et al. (1986) (see Fig. 1).

The first few slides of the exemplar stories presented the protagonist's goal (i.e., a bunny wants to deliver painted eggs to children on the other side of a river; a genie wants to move his jewels to a new lamp across a wall), followed by a description of the barrier (i.e., a river; a wall). The next slide displayed six tools that the protagonist could use to solve the problem, including the target object (i.e., a picnic mat; a magic carpet). The exemplar stories also included solution slides demonstrating how the protagonist solved the problem. On the first slide, the protagonist rolled a flat material (the target object) into a hollow tube. Then, on the second slide, the protagonist passed the objects (i.e. the painted eggs; the jewels) through the tube to the other side of the barrier.

The third story was used for the analogical transfer task. The first few story slides presented a new character with an analogous goal (a farmer wants to transfer the cherries in his truck across the road, which is blocked by a fallen tree). The next slide displayed six tools, including the target object (a flat truck cover). Since children were prompted to generate the solution themselves, no solution slides were provided.

Other materials included a photograph of a child, which was used for the retelling tasks after the exemplar stories.

Procedure

In-person version. Children were tested, one-on-one, in a quiet area of a museum or preschool classroom. All materials were presented on a laptop screen. Participants were told that they would be listening to three stories, and that they would be asked to answer some questions about the stories.

The experimenter read the first exemplar story, which introduced a protagonist and his goal, followed by a description of the barrier (see Fig. 1). After describing the problem, the experimenter proceeded to the *tools slide*, and labeled each of the six tools available, while pointing to the objects on the screen. The experimenter briefly prompted the participant to consider what the protagonist could do to solve his problem, but did not give them sufficient time to answer. Instead, the experimenter proceeded to the solution slides and completed the story.

In the *retelling task* for the first exemplar story, the participant was asked to look at a picture of a gender-matched child attached to the video camera, and were told that the child would be watching this video later on. With the laptop screen closed, the participant was prompted to tell the child what happened in the story and how the protagonist solved the problem. The experimenter said: "This is a picture of another child named Alex. Alex won't get to hear this story. Instead, he/she will be watching your video! Can you tell Alex what happened in the story and how [character] solved the problem?" Participants were not prompted to gesture, but the study session videos were coded offline to record children's speech and spontaneous gestures.

Afterwards, the experimenter began the second exemplar story, which presented an analogous problem and solution (see Fig. 1). Again, children were prompted to look at the camera and retell the story events for another child to watch.

The third story was used to assess analogical transfer. After presenting the analogous problem, the experimenter told the child that they will be solving the problem themselves this time. The experimenter labeled the available tools that the protagonist could use. Then, the experimenter asked the child how the protagonist could solve his problem using one of the tools (e.g. “Can you tell me, how can Farmer Jones move his cherries across the big fallen tree?”). Here, we coded whether children used a similar solution from the previous stories.

Modification for the online version. The online version of the experiment was conducted on Zoom. Stories were presented using Slides.com. Before beginning the session, parents were instructed to set up their webcam at an angle that could capture both the child’s face and hands. Although the procedure for the online version was identical to the in-person version, the narration for each story was pre-recorded. In place of pointing, an animated arrow indicated each object as it was introduced.

Coding. Children’s spontaneous gestures were coded from the video by a naive researcher. Children who produced spontaneous gestures while retelling either of the exemplar stories were coded as 1, and those who did not gesture at all were coded as 0. This variable was used to form post-hoc groups (*gesture*, *no-gesture*) for analysis, which served as a binary predictor variable in logistic regressions.

Among the participants who produced gestures, we also coded whether those gestures were relevant to the analogical solution. Gestures that were spontaneously produced while describing the solution (e.g., rolling, passing through) were given a score of 1 (solution-relevant), and all other gestures were given a score of 0 (solution-irrelevant). Solution-relevant gestures included, for example, rotating both hands or placing both fists next to each other and tilting the wrists forwards and back (for rolling), and then moving one hand to the other (for passing objects through). Solution-irrelevant gestures included non-referential gestures (e.g. finger tapping for particular words), or gesturing superficial content that was not central to the abstract solution (e.g. using both hands to simulate lowering the picnic mat down to the ground). Children who produced solution-relevant gestures at least once during either of the retelling tasks were categorized into the solution-relevant gesture group. Children who only produced solution-irrelevant gestures were categorized into the solution-irrelevant gesture group.

Children’s performance on the analogical transfer task was coded based on whether they described the abstract solution (i.e., rolling a flat material into a tube and passing the objects through). A minority of children who only mentioned the first part of the solution (i.e., rolling the flat material into a tube) in their descriptions were also coded as correct. The participant videos were coded independently by two researchers, and the overall inter-coder reliability on children’s gesture production and analogical transfer ratings was 84.1%. Any discrepancies were resolved in discussion with a third researcher.

Results

Chi-square tests indicated that the testing medium (in person vs. online) was not related to children’s spontaneous gesture production, $\chi^2(1) = 0$, $p = 1$), or children’s analogical transfer performance, $\chi^2(1) = 0.10$, $p = 0.75$. We therefore combined the two participant samples for all analyses.

As noted above, children were categorized into two groups: those who produced spontaneous gestures during at least one of the two retelling tasks (*gesture* group, $n = 48$ out of 85, 56.5%) and those who did not (*no-gesture* group, $n = 37$ out of 85, 43.5%).

The overall analogical transfer rate in our sample (23%) was low, but consistent with findings from prior work in this age group when no additional hints or scaffolding are provided (e.g., Brown et al., 1986; Holyoak et al., 1984; Kim & Choi, 2003). Among children in the *gesture* group, 16 of 48 succeeded at the analogical transfer task (33.3%), whereas in the *no-gesture* group, only 4 of 37 participants succeeded

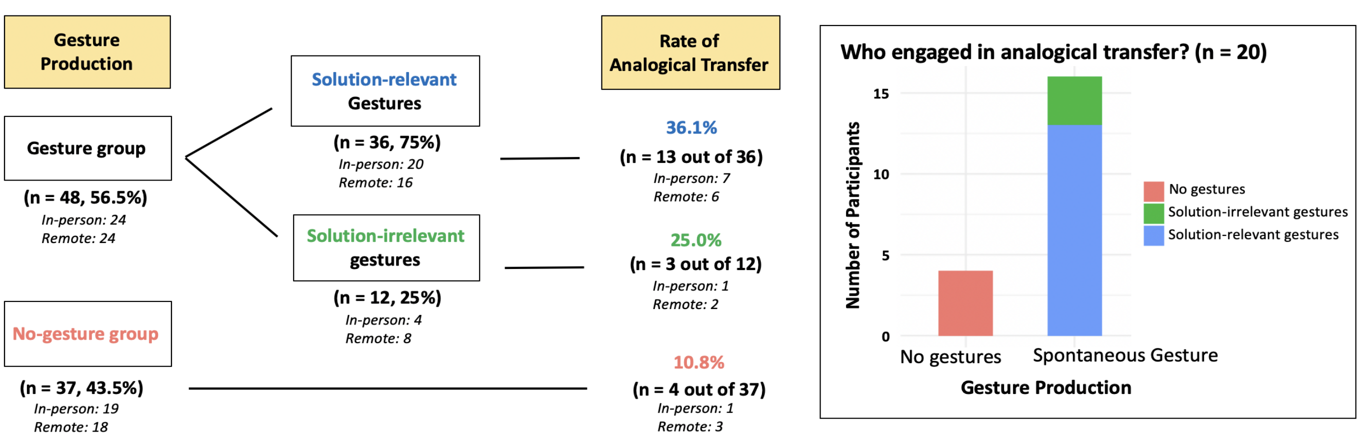

Figure 2. Results. The diagram on the left shows the proportion of participants who gestured during the retelling tasks, the proportion of participants who produced solution-relevant and solution-irrelevant gestures, and the rates of transfer for each group. The chart on the right shows the number of participants in each group who engaged in analogical transfer.

(10.8%). A chi-square test of independence indicated a significant relationship between children's spontaneous gesture production and their tendency to engage in analogical transfer, $\chi^2(1) = 4.71$, $p = 0.03$. This finding was confirmed using logistic regression, Wald-Z-test; $\chi^2(1) = 5.4$, $p = 0.02$. These results support our main hypothesis that children who produced spontaneous gestures would perform better on the subsequent analogical transfer task, compared to children who did not produce gestures.

Age did not significantly predict gesture production, Wald Z-test; $\chi^2(1) = 0.27$, $p = 0.60$ or analogical transfer $\chi^2(1) = 0.01$, $p = 0.92$. Adding age as an additional variable to our main model did not perform better than the model alone; $\chi^2(1) = 0.32$, $p = 0.57$ (nested model comparison).

Relevance of Gesture to the Goal-structure

Thirty-six of the 48 participants in the gesture group produced solution-relevant gestures (75.0%), and 13 of these 36 participants also engaged in analogical transfer (36.1%). In contrast, 12 out of 48 participants produced only solution-irrelevant gestures (25.0%), and only 3 out of these 12 participants engaged in analogical transfer (3/12, 25.0%, see Fig. 2). Despite this numerical difference in the rate of analogical transfer between groups, this was not statistically significant, $\chi^2(1) = 0.13$, $p = 0.72$.

Individual Differences in Speech

As a proxy for individual differences in engagement, we analyzed the total number of words produced during both retelling tasks, excluding any verbal disfluencies ($M = 49.08$). Although we found a significant correlation between word count and children's spontaneous gesture ($M_{gesture} = 58.30$, $M_{no\ gesture} = 37.10$; $r = 0.31$, $p = 0.004$), word count was not correlated with participants' success on analogical transfer ($r = 0.14$, $p = 0.20$) or their tendency to produce relevant gestures during retelling ($r = 0.08$, $p = 0.43$). Finally, adding word count as an additional predictor to our main model did not increase the explanatory power of the model; $\chi^2(1) = 0.31$, $p = 0.57$ (nested model comparison).

Discussion

In the current paper, we aimed to establish a relationship between children's spontaneous gestures and their subsequent analogical transfer. Our results provide preliminary evidence for this: Children who produced gestures when retelling one or both of the exemplar stories were significantly more likely to abstract a common solution to a superficially distinct target story. We also sought to determine whether the type of gestures produced mattered for transfer. Although we observed a numerical difference in the rates of analogical transfer, with a higher rate of success in children who produced solution-relevant gestures, this difference was not statistically significant. Since this null result may have been due to the small sample size of the *gesture* group, future work will replicate this study with a larger sample.

Also, given that we used relatively inclusive criteria for coding gesture content, ongoing work will apply a more fine-grained approach, coding the type and semantic content of gestures, as well as the co-occurrence between spontaneous gestures and speech. Future work will also examine any differences in the occurrence or type of gestures produced during the first and second retelling tasks. This will allow us to explore specific effects of spontaneous gesture production before and after children had the opportunity to compare solutions between structurally-similar stories (see Cooperrider & Goldin-Meadow, 2014 for related findings in adults).

Critically, although we find evidence for a relationship between children's spontaneous gesture production and analogical transfer, the correlational design of this study cannot establish causality. Indeed, several other variables may have plausibly contributed to this relationship. Specifically, children who were more attentive or engaged during storytelling may have been more likely to produce gestures during retelling and also more likely to succeed on the analogical transfer task. As a proxy for engagement, we analyzed the total number of words produced by each child during the retelling tasks. Although word count was correlated with gesture production, it was *unrelated* to success on analogical transfer. It is therefore unlikely that increased transfer in the gesture group can be explained by differences in verbal production. Future studies will further explore the relationship between engagement, speech and gesture production, and analogical transfer by including additional measures to capture potential differences in attentiveness (e.g., memory questions).

Additional work is also necessary to determine whether spontaneous gestures *facilitated* analogical reasoning or were a by-product of this process. In future studies, we plan to manipulate children's gesture, by either restricting it (e.g., by asking children to sit on their hands) or by increasing gesture production by explicitly prompting them to use their hands during retelling. These interventions will not only help to establish whether gesture *supports* relational transfer in our task, but will also shed light on the potential differences between spontaneous and prompted gesture in children (see Hostetter et al., 2016 for related work in adults).

In addition to further examining the relationship between gesture and abstraction, these studies may have important implications for research on the development of analogical reasoning. As noted in the introduction, children's gestures have been shown to reveal latent concepts that are not yet manifest in speech (Church & Goldin-Meadow, 1986; Goldin-Meadow & Wagner, 2005; Pine et al., 2003). For example, Church and Goldin-Meadow (1986) report that some children who provided incorrect verbal explanations in a Piagetian conservation of liquid task (i.e., emphasizing differences in the height of the glass), produced gestures that referenced the *width* of the glass, indicating their nascent understanding of the relevant variable. Children who produced these speech-inconsistent gestures were more responsive to later instruction than children who produced speech-consistent gestures or no gestures at all. The authors argued that children's spontaneous gestures can sometimes reveal the "thoughts at their fingertips" (Goldin-Meadow & Wagner, 2005), signaling a transitional state during learning and conceptual change. Given that gestures have been proposed to function as a *comfortable middle ground* between concrete and abstract concepts (Novack et al., 2014), spontaneous gestures may provide a novel tool for assessing the emergence of analogical reasoning.

In sum, this study provides initial evidence for the relationship between children's spontaneous gestures and their analogical transfer, suggesting that gesture may provide a window into early abstract reasoning.

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