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Effects of Learning With Gesture on Children's Understanding of a New Language Concept

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Asking children to gesture while being taught a concept facilitates their learning. Here, we investigated whether children benefitted equally from producing gestures that reflected speech (speech-gesture matches) versus gestures that complemented speech (speech-gesture mismatches), when learning the concept of palindromes. As in previous studies, we compared the utility of each gesture strategy to a speech alone strategy. Because our task was heavily based on language ability, we also considered children's phonological competency as a predictor of success at posttest. Across conditions, children who had low phonological competence were equally likely to perform well at posttest. However, gesture use was predictive of learning for children with high phonological competence: Those who produced either gesture strategy during training were more likely to learn than children who used a speech alone strategy. These results suggest that educators should be encouraged to use either speech-gesture match or mismatch strategies to aid learners, but that gesture may be especially beneficial to children who possess basic skills related to the new concept, in this case, phonological competency. Results also suggest that there are differences between the cognitive effects of naturally produced speech-gesture matches and mismatches, and those that are scripted and taught to children.

Keywords: gesture, word learning, phonological competency

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Gestures are spontaneous hand movements individuals produce while speaking. These movements have the power to shape our cognitive system across the life span and can facilitate learning in many domains such as mathematics (e.g., Cook & Goldin-Meadow, 2006; Cook, Mitchell, & Goldin-Meadow, 2008; Goldin-Meadow, Cook, & Mitchell, 2009; Perry, Church, & Goldin-Meadow, 1988), spatial understanding (e.g., Beilock & Goldin-Meadow, 2010; Church & Goldin-Meadow, 1986; Ping & Goldin-Meadow, 2008), and vocabulary learning (Kelly, McDevitt, & Esch, 2009). Given the power of gesture as a tool for facilitating cognitive change, and the prevalence of natural gesture use in educational settings (Flevares & Perry, 2001), it is important to understand what aspects of gesture make it most beneficial to a learner so that gesture can be used effectively as teaching tool.

One obvious aspect of cospeech gesture is that it accompanies speech. In an educational context, this means that children can be taught to express one strategy for learning a concept in speech and can either express the same strategy in gesture (termed a *speech-gesture match*) or a different strategy in gesture (termed a *speech-gesture mismatch*). Training children to produce either type of speech-gesture strategy while learning a concept facilitates learning above and beyond asking them to produce a speech strategy alone (Cook et al., 2008; Goldin-Meadow et al., 2009). But whether there is a *greater* benefit for teaching children to produce a speech-gesture match versus a speech-gesture mismatch strategy while learning is unknown. We addressed this question in the present study.

Definition of Speech-Gesture Matches and Mismatches

The difference between a speech-gesture match and a speech-gesture mismatch lies in the relation between the meaning instantiated in the gesture and the spoken message. Illustrating this based on previous work (e.g., Cook et al., 2008; Goldin-Meadow et al., 2009), when learning to solve a problem like 3 4 5 __ 5, a child might be taught to say, "I want to make one side equal to the other side," illustrating an *equalizer* strategy in speech. She might also be taught to produce gestures that instantiate the equalizer strategy; moving her hand under the left side of the problem while saying "one side" and under the right side of the problem while saying "the other side." When produced together, these strategies combine to form a speech-gesture match, because the gesture instantiates the same strategy used in speech. Alternatively, a child could be taught to say the equalizer strategy while producing a different strategy in gesture: She could point to the first two addends on the left side of the problem (3 and 4) with her middle and index fingers while saying "one side," and then point to the blank on the right side of the problem while saying "the

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other side." In this case, her gestures instantiate a *grouping* strategy—if the child adds the first two numbers, she will arrive at the correct answer. Because this strategy is different than the strategy produced in speech, these strategies combine to form a speech-gesture mismatch. Importantly, the speech and gesture strategies in a mismatch can both be correct; they are simply different ways to solve the same problem.

In the present study, our main goal was to directly compare the effectiveness of speech-gesture match and mismatch strategies to determine whether one was more beneficial to a learner than the other. As a secondary goal, we sought to extend the generalizability of gesture as a teaching tool. Whereas previous researchers have asked about the effects of cospeech gesture while children are learning mathematical or spatial concepts, we ask how the use of gesture affects learning in a language-based task: instructing children on the concept of a palindrome (i.e., a word that is spelled the same forward and backward). We discuss this new learning task, followed by our hypotheses.

A New Test Bed: Palindromes

To extend the generalizability of gesture as a teaching tool, we created a paradigm that retained important components of the mathematical equivalence paradigm; one of the most widely used in the gesture-for-learning literature, but was based in a new learning domain. We asked children to learn the concept of palindromes: words that are spelled the same forward and backward, using pseudo-word palindrome problems presented with a missing letter (BEW_B). In both the palindrome and mathematical equivalence paradigms, children can arrive at correct solutions to problems through multiple strategies. Importantly, these strategies can be expressed in both speech and gesture; allowing for the creation of speech-gesture match and mismatch strategies. When solving an equal addends mathematical equivalence problem, children can correctly answer problems by making the sides equal each other, or by grouping two of the addends on the left side of the problem. In our task, children must understand that the correct letter will make a word that reads the same left to right and right to left. However, children can alternatively see that words are symmetrical, and fill in problem blanks accordingly. The palindromes task was primarily developed as a new test-bed for the effects of gesture on learning, and teaches a much simpler concept than mathematical equivalence, but it is also a task that could be used in classrooms to bolster children's phonemic awareness. Our task provides a fun way to practice reading, and a unique way for children to understand how sounds fit together. Building phonological competence is an important skill, as it is a predictor of more advanced skills, such as second language acquisition (Durgunoğlu, Nagy, & Hancin-Bhatt, 1993).

Hypotheses

Next, we outline the potential effects of our training conditions (i.e., speech, speech-gesture match, speech-gesture mismatch). We begin with our main hypothesis; that mismatching gesture may be more facilitative of learning than matching gesture, and then present two alternative hypotheses that are also motivated by previous literature.

Mismatching Gestures May Facilitate Learning More Than Matching Gestures

There is ample evidence that children should learn better from producing speech-gesture mismatches than from producing speech-gesture matches. First, producing a speech-gesture mismatch provides children two different strategies through which to understand a new concept. Early research on the relation between children's spontaneous gestures and their ability to learn showed that children who naturally produced speech-gesture mismatches while explaining their incorrect solutions to related problems, prior to instruction, were more likely to benefit from instruction than children who produced speech-gesture matches. This was true whether gestures were completely spontaneous (Church & Goldin-Meadow, 1986; Perry et al., 1988), or whether children were required to gesture during their explanations (Broaders, Cook, Mitchell, & Goldin-Meadow, 2007). It has been argued that the act of producing two strategies simultaneously helps children integrate the individual strategies, which results in a better understanding of the concept being learned (Church, 1999; Church & Goldin-Meadow, 1986; Goldin-Meadow, Alibali, & Church, 1993). Second, a study of the effect of gesture observation on learning showed that children learned more from seeing a teacher instruct through a speech-gesture mismatch strategy, compared to a speech-gesture match strategy (Singer & Goldin-Meadow, 2005). Based on these pieces of evidence, we hypothesized that having children produce speech-gesture mismatches would facilitate learning more than having them produce speech-gesture matches.

There are caveats to this hypothesis, however: Children may learn differently through naturally produced mismatches (like those discussed in preceding text) versus scripted mismatches they are taught to produce, and children may also learn differently through observing versus producing speech-gesture strategies.

Natural versus scripted gestures. Children who produce speech-gesture mismatches naturally when discussing a concept they do not fully understand are thought to be in a more advanced cognitive state (i.e., a transitional knowledge state, see Goldin-Meadow et al., 1993), than their peers who produce speech-gesture matches. Thus, if it is the presence of two strategies simultaneously produced through speech and gesture that contributed to better learning in previous studies, children who are instructed to produce mismatches in the present study should benefit more than children instructed to produce matches. However, if it is the cognitive state of children who naturally produce mismatches that ultimately caused better learning for these children in previous studies, then we may not find support for this hypothesis.

Observed versus produced gestures. Previous work on learning through transitive action (i.e., actions used to manipulate objects) has shown that there are very different effects of learning through self-produced versus observed transitive actions (e.g., James & Swain, 2011; Kersey & James, 2013). Thus, as gesture is a special type of action, we may also expect children to learn differently through self-produced versus observed gestures, and may not see the same pattern as found by Singer and Goldin-Meadow (2005).

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Matching Gestures May Facilitate Learning More Than Mismatching Gestures

Because of the caveats above, we also review support for the opposite prediction, that asking children to produce speech-gesture matches will facilitate learning more than asking them to produce mismatches. Support for this alternative hypothesis comes from studies of the effect of gesture on cognitive load (i.e., the amount of working memory capacity an individual has that can be allocated to a task). One reason gesture is thought to help a learner is that it reduces cognitive load; that is, the act of gesturing increases the amount of working memory that a learner can dedicate to processing to-be-learned information. This may occur because gesturing allows an individual to access a rich visuospatial representation of the idea he is expressing verbally, which facilitates the process of communicating his ideas. In previous literature, the ability of gesture to decrease cognitive load has been explored through dual-task paradigms, in which an individual is given a set of information to remember, asked to perform another task during which he is or is not allowed to gesture, and is then tested on his memory for the original information (e.g., Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001). When an individual is allowed to gesture during the intermediate task, he performs better on the memory task. However, Goldin-Meadow and colleagues (1993) found that this benefit of gesture depended on the relation of gesture and speech: Participants who produced speech-gesture mismatches performed worse on a cognitive load task than those who produced speech-gesture matches. Therefore, if part of the reason gesture facilitates learning is because it decreases cognitive load for the learner, children may benefit more from producing speech-gesture matches, which will be less cognitively taxing, than from producing speech-gesture mismatches.

Again, however, this hypothesis is based on naturally produced gesture, not scripted gesture. It could be that being asked to produce speech-gesture matches and mismatches will have the same effect on a learner's cognitive load, because they involve the same basic task (i.e., the learner must recall the words she was taught and the gestures she was taught, and produce these on cue). In this case, we would not expect to find support for this hypothesis, as both types of gesture would have the same effect on cognitive load.

Matching and Mismatching Gestures May Be Equally Facilitative of Learning

Finally, a third possibility is that speech-gesture matches and mismatches will have a comparable facilitative effect on children's ability to learn a new concept. Support for this hypothesis is related to gesture being a type of action. Like gesture, learning through transitive action can be facilitative: In the case of producing action to learn about novel objects, action use leads to faster object recognition, faster learning, and better memory for learned information (Butler & James, 2013; Harman, Humphrey, & Goodale, 1999; James et al., 2002), and this seems to be caused by the establishment of sensory-motor representations of learned information in the brain that occurs when children learn through transitive action (James, 2010; James & Engelhardt, 2012; James & Swain, 2011). Further, Novack and colleagues (2014) recently showed that children who produced a strategy in transitive action or gesture while learning the concept of mathematical equivalence were equally successful when asked to solve problems of the same form as those on which they were trained. This suggests that gesture may have its facilitative effects, in part, through the same mechanism as transitive action. If this is the case, there should be an equal benefit from learning through speech-gesture matches and mismatches, because both strategies incorporate the use of the motor system during learning.

A Final Factor to Consider: Phonological Competence

Along with our prediction that the strategy used during learning will affect learning outcomes, we also consider the impact of children's phonological competency—a skill closely related to our task. In previous work, researchers have taken into account basic skills children possess that may affect their ability to learn from instruction (Goldin-Meadow et al., 2009), and recently, Post and colleagues (2013) found that general language skills significantly affected whether a gesture strategy helped children learn grammar rules. In the present study, we expect that children with high phonological competency will expend less cognitive effort during our task than their less phonologically competent peers, because of their ability to sound out words. This will increase the cognitive resources they can devote to understanding the palindromes concept, which in turn will lead to better learning outcomes. We also expect that the strategy children produce while learning may interact with phonological competency to predict successful learning: Children with high phonological competency should have an advantage during the task in general, but those learning through gesture strategies may have an extra advantage compared to those who learn from speech alone because they have two routes through which to benefit.

In summary, the purpose of the present study was to determine the relative facilitative effect of asking children to produce a speech-gesture match strategy, speech-gesture mismatch strategy, or speech alone strategy during palindrome learning. We expected to show that both gesture strategies would facilitate learning more than a speech alone strategy (Cook et al., 2008; Goldin-Meadow et al., 2009), and that children would learn better from producing a speech-gesture mismatch strategy than a speech-gesture match strategy (Church, 1999; Church & Goldin-Meadow, 1986; Goldin-Meadow et al., 2009; Perry et al., 1988), although there were reasons to consider alternative hypotheses. In addition, we also considered children's phonological competency as potentially impacting children's learning outcomes, given its close relation to our task.

Method

Participants

Data from 90 children between the ages of 6.0 and 8.5 years were analyzed in the present study (M 6.8 years, 43 girls), out of an initial sample of 128 children. This age group was selected after unpublished pilot data from a wider age-range (4 to 11 years) suggested that 6- to 8-year-old children typically fail to understand what a palindrome is without instruction. Children were recruited through a database maintained by the Indiana University Psychological and Brain Sciences Department. Children came from

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working- and middle-class families, from both urban and rural areas, and were predominately Caucasian. Informed consent was obtained from a parent or guardian of the children, and assent was obtained from children over the age of 7. Children were excluded from analysis if they demonstrated an understanding of what a palindrome was during a pretest (*n* 20), failed to complete the experimental session or follow an experimenter's directions (*n* 15), had been diagnosed with a psychological disorder (*n* 1), or if an equipment malfunction occurred and the session was not recorded properly (*n* 2).[1] Of the remaining children, each was randomly assigned to one of three experimental conditions: speech alone (speech, *n* 30), speech-gesture match (SGmatch, *n* 30), or speech-gesture mismatch (SGmis, *n* 30).[2] All children received compensation in the form of a small toy.

Stimuli and Phonological Competency Assessment Materials

For the present study, pseudo-word palindromes (i.e., words that are spelled the same forward and backward) were created. Pseudo-word palindromes were pronounceable pseudo-words (e.g., BEWEB, FROTORF).[3] Palindromes were displayed with a missing letter (e.g., B_WEB,_OGOL, ANIMI_A), which was either completed by the experimenter or child. The location of the missing letter was not consistent across trials, and was never the letter in the center of the word. Palindromes created for the pretest and posttest were seven, nine, or 11 letters in length; palindromes created for the training session were five or seven letters in length. Shorter palindromes were used during training to decrease the amount of effort needed to sound out the words, and therefore increase children's likelihood of understanding the relation of their training strategy to the problems. At posttest, the length of the words was increased as a more general test of the understanding of the palindrome concept, and to decrease the likelihood that children would randomly guess the correct letter from those included in the word.

To assess participants' phonological competency (i.e., ability to sound out nonsense words), the Structural Analysis assessment from the BADER Reading and Language Inventory (5th ed.; Bader, 2005) was administered. Children were asked to read a list of pseudowords composed of English prefixes and suffixes (e.g., SUBMAN, COUNTERHID). The experimenter recorded whether each item was attempted, and if so, whether it was pronounced correctly. Children were separated into two groups for subsequent data analyses, based on responses. (1) Children in the high phonology group could correctly pronounce 50%–100% of the pseudo-words; (2) children in the low phonology group could correctly pronounce 0%–50% of the pseudo-words.

Learning Strategies (Training Conditions)

To determine the best instructional strategies to use when teaching the concept of palindromes, we turned to the classroom. Elementary school teachers were videotaped teaching the concept, and their explanations were used to create speech and gesture strategies for the present experiment (for details, see the Appendix). Strategies taught to children, speech, SGmatch, and SGmis, are displayed in Figure 1. It is important to note that in the creation of our matching strategy, we chose speech and gesture strategies

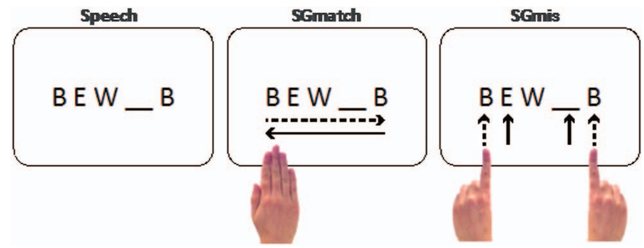

Figure 1. Training strategies. Speech: Child says, "A palindrome reads forwards and backwards." Speech-gesture match (SGmatch): Child says, "A palindrome reads forwards and backwards"; when saying "forward," she sweeps her right hand under the palindrome from left to right; when saying "backward," she sweeps her left hand under the palindrome from right to left. Speech-gesture mismatch (SGmis): Child says, "A palindrome reads forwards and backwards"; when saying "forward," she simultaneously points to the outer most letters on each side with her left and right index finger; when saying "backward," she simultaneously points to the second-outer most letters on each side with her left and right index finger. Movements made on the word "forwards" are shown in a dotted line; movements made on the word "backwards" are shown in a solid line. See the online article for the color version of this figure.

that not only seemed to express the same information, but were naturally produced together by teachers. Previous literature indicates that individuals are more likely to produce gestures and speech that express the same idea, than to provide different information in two modalities when they understand a concept (Church & Goldin-Meadow, 1986). Thus, we are confident that we created a speech-gesture match strategy. In contrast, our mismatching gesture was most often produced with a different speech strategy that expressed the idea of the symmetry inherent in a palindrome. Paired with our speech strategy, this creates a speech-gesture mismatch, as defined in previous literature.

Finally, to further validate our strategies, we turned to a sample of 20 children who could correctly solve our palindromes problems without instruction. When children produced a strategy in gesture similar to the one used in our speech-gesture mismatch condition, it was never paired with the speech strategy we developed. In contrast, in the instances that children used a similar speech strategy to ours, emphasizing the fact that the palindrome

[1] Children who correctly answered three or more problems on a pretest of six problems (e.g., BEW_B) were automatically excluded from data analysis. Children who correctly answered one or two problems were included if they demonstrated a lack of knowledge about palindromes when explaining their letter choice. For example, a child might fill in an "M" for the problem TRI_UMIRT, but explain that she made this choice because her name begins with "M." To ensure that these children were not at an advantage to those who answered zero questions correctly, we used a mixed-effects binomial regression model to determine if pretest score predicted performance on posttest. Pretest performance was not predictive of posttest performance (0.55, *z* 1.29, *SE* 0.42, *p* .20).

[2] Groups were evenly matched by sex (speech: 14 girls; SGmatch: 16 girls; SGmis: 13 girls), age (a one-way analysis of variance showed no significant difference between groups, *F*(2, 87) 0.67, *ns*, and phonological competency (speech: 13 high; SGmatch: 11 high; SGmis: 12 high; no significant difference between groups, ^{2}(2, *N* 90) 0.28, *ns*.

[3] Each palindrome consisted of five, seven, nine, or 11 letters. Odd numbers were chosen so that when asked to fill in a missing letter of a palindrome, a child could not determine the correct answer by identifying the letter that only appeared once in the word.

read the same way forward and backward, it was always accompanied by sweeping gestures similar to those used in our speech-gesture match strategy. Based on work by Alibali and Goldin-Meadow (1993) who documented the use of speech-gesture matches and mismatches as children developed understanding of a concept, we suggest that our children should be predominately producing speech-gesture matches, as they understand the palindrome concept. This further establishes that we created true speech-gesture match and speech-gesture mismatch strategies.

Procedure

Children participated individually in a session modeled on previous studies of learning with gesture (Cook et al., 2008; Goldin-Meadow et al., 2009). Children completed a pretest, pretraining instruction period, training, posttest, and phonological competency assessment.

Pretest. Children were asked if they had ever heard of a palindrome, and were read a set of instructions at the top of a worksheet, "A palindrome reads the same, forwards and backwards. 'GUG' is a palindrome, but 'GUH' is not." When saying "gug" and "guh," the experimenter simultaneously pointed to the words to highlight them for the children. Next the experimenter said, "Below are funny words with missing letters. Can you think of the letter that would make each of these examples into palindromes?" These instructions were used to ensure that children who were included in the study did not understand the concept of a palindrome, rather than simply lacking the proper lexical label for the concept. Children then completed a worksheet, which consisted of six palindromes with one missing letter in each. After the worksheet was completed, children explained their answers at a whiteboard, and responses were recorded. The session was discontinued for children who correctly answered all of the pretest questions.

Pretraining instruction period. After completing the pretest, children were taught one of three strategies to help them think about how to solve palindrome problems. In the speech condition, children learned the phrase "A palindrome reads the same forwards and backwards." Children in the SGmatch condition learned to say the same phrase while simultaneously producing an analogous strategy in gesture (see Figure 1). Finally, children in the SGmis condition learned the same phrase as children in the other conditions, but learned to produce a mismatching strategy in gesture (see Figure 1). Children learned to produce these strategies on a wall-mounted whiteboard, with the example palindrome TTT_T, and were told that they would "say their words (and make their movements)" before and after solving each palindrome in the next game (i.e., Training). When children were able to successfully produce their strategy without help from the experimenter, the Training session began. There was no significant difference in the amount of time children took to learn their strategy across the conditions, $F(2, 84)$ 1.21, *ns*.

Training. During Training, the experimenter and child alternated filling in the blank to complete palindromes problems (ex. BEW_B). The child and the experimenter each completed 6 problems. When it was the experimenter's turn, she said, "A palindrome reads the same forwards and backwards." Then she said "If I put a [correct letter] in the blank . . ." while writing the letter that correctly completed the palindrome ". . . this is a palindrome, because it says [Palindrome] forwards and [Palindrome] backwards, so it's a palindrome." The experimenter was consistent in her explanation across the three conditions, only producing her explanations in speech. On their problems, children were asked to produce the strategy they learned during the Pretraining instruction period, fill in the blank with the letter that would complete the palindrome, and produce the strategy again. Children did not receive feedback on their answers.

Posttest and phonological competency assessment. After Training, children completed a posttest, which was comparable to the initial pretest, but with different palindromes problems. Children then explained their answers. Finally, the structural analysis assessment from the BADER Reading and Language Inventory (Bader, 2005) was administered to measure children's ability to sound-out pseudowords (i.e., phonological competency).

Results

Before conducting analyses, we considered the distribution of our data. A Shapiro-Wilk test confirmed that the distribution of performance on palindromes problems at Posttest (i.e., how many problems children correctly answered) was nonnormative (W 0.86, p .001). Based on the analyses conducted by Novack and colleagues (2014) and Goldin-Meadow et al. (2012), who used a similar training task and whose results were also nonnormative, we separated children into categorical groups for our analyses. As the distribution of our data was bimodal in character, and the median score across participants was three correct responses out of six problems, we separated our participants into two groups: learners—children who correctly answered at least half of the questions at posttest (3 or more out of 6), and nonlearners—children who answered less than half the questions correctly at posttest. This resulted in 17 learners and 13 nonlearners in both the SGmatch and SGmis conditions, and 13 learners and 17 nonlearners in the speech condition.

We hypothesized that the training condition children were in would affect their performance at Posttest, and that this may interact with their level of phonological competency. To test this, we ran a fixed-effects binomial logit model predicting learner status (learner, nonlearner) by an interaction of condition (speech, SGmatch, SGmis) and phonological competency (high, low), controlling for age.[4] We found that condition significantly predicted learner status: Children who learned through the SGmatch strategy were more likely to learn than those in the speech condition (2.67, SE 1.22, z 2.19, p .05), as were those who learned through the SGmis strategy (2.06, SE 1.00, z 2.06, p .05). Releveling the model with SGmis as baseline showed no difference between the two gesture conditions (0.61, SE 1.32, z 0.46, p .64). However, we also found an interaction between condition and phonological competency (SGmatch: 2.74, SE 1.41, z 1.94, p .05; SGmis: 2.13, SE 1.23, z 1.73, p .08).

To explore the moderately significant interaction between condition and phonological competency, we separated children into two groups based on phonological competence (high, low; see Figure 2). We then ran binomial logistic regressions on each of

[4] Model was a significantly better fit than a model lacking in the interaction term, ^{2} 10.38, p .05.

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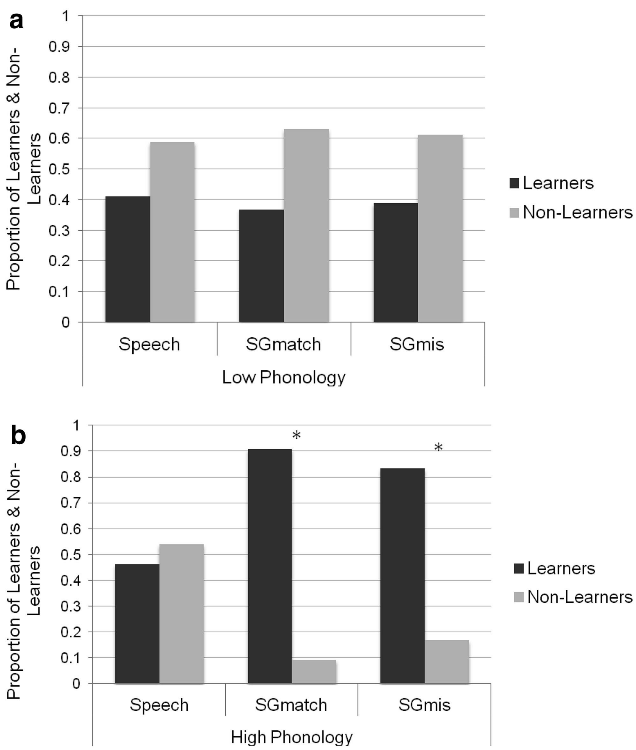

Figure 2. Proportion of children classified as learners versus nonlearners at posttest, separated by condition and (a) low phonological competency versus (b) high phonological competency, *p* .05.

these groups separately, predicting learner status by condition, with speech as the baseline. With respect to children in the low phonology group, condition was not a significant predictor (SG-match: 0.11, *SE* 0.70, *z* 0.15, *p* .88; SGmis: 0.08, *SE* 0.70, *z* 0.91, *p* .91). Therefore, children were equally likely to be classified as learners, regardless of whether they had produced a speech strategy alone, or a speech strategy paired with a matching or mismatching gesture strategy during training. Whereas condition was not a significant predictor of learning for children in our low phonology model, the opposite was true when we tested whether condition predicted learning in our high phonology group. We found that children were more likely to be classified as learners if they were in either the SG-match condition compared with speech (2.82, *SE* 1.27, *z* 2.22, *p* .05), or the SGmis condition compared with speech (2.33, *SE* 1.11, *z* 2.10, *p* .05). To determine whether one type of gesture was more beneficial than the other, we releveled our data with SGmis as the baseline. We found no significant difference between SGmatch and SGmis (0.49, *SE* 1.35, *z* 0.36, *ns*). Taken together, children were more likely to learn if they were in either gesture condition, compared with the speech alone condition, but only if they could readily sound-out new words.

Discussion

The results of the present work demonstrate that when learning the concept of palindromes, asking children to produce certain speech-gesture match and mismatch strategies facilitated learning more than speech alone for children with higher phonological skills relative to their peers, but that for children with lower phonological ability, gesture production did not benefit learning more than production of a strategy in speech alone. In addition, we did not find differences in learning outcomes for children who learned through a speech-gesture match versus a speech-gesture mismatch strategy.

On the basis of our results, the hypothesis that children would learn more effectively through the use of a speech-gesture mismatch strategy, compared to a speech-gesture match strategy was not supported. We proposed two alternative hypotheses: (1) Speech-gesture matches could lead to better learning than speech-gesture mismatches because they might cause more of a reduction in cognitive load during training, or (2) speech-gesture mismatches and matches could be equally beneficial to children learning a new concept, because both gesture strategies engage the motor system in the learning process—this hypothesis was supported by our results. Below, we put forth a potential mechanism for our finding that match and mismatch strategies were equally beneficial to learners and explore our effect of phonological competency.

Gesture Strategies May Benefit Learners Through the Same Mechanism as Transitive Action

Our alternative hypothesis; that children would benefit equally from matching and mismatching gesture, was based on the idea that both types of gesture would involve the motor system in the learning process, presumably leading to a rich sensory-motor representation of the concept being taught. This hypothesis was driven by the similarities between the effects of gesture and transitive action strategies on learning (Novack et al., 2014) and literature that suggests that producing transitive action during learning causes sensory-motor representations of learned information to be stored in the brain, which can be activated subsequently when a learner is faced with a similar problem (e.g., James, 2010; James & Swain, 2011). Potentially, children who incorporated a sensory-motor representation of the concept of palindromes through gesture use during training were better able to remember how to solve a palindrome problem than those who had stored a representation through speech alone.

Although we cannot speak directly to the neural changes that we believe drove our behavioral effects, previous literature on gesture production during a task suggests that gesture use focuses learners on the sensory-motor aspects of a problem, which could lead to the proposed neural changes. For example, Alibali and colleagues (2011) either allowed or prohibited the use of gesture when individuals solved a spatial gear-task and found that people who gestured used a perceptual-motor based strategy for solving problems, whereas those who could not gesture adopted an abstract strategy. Similarly, individuals alter their representations of a puzzle problem based on the gestures they produce while explaining the actions taken to solve it (Beilock & Goldin-Meadow, 2010; Goldin-Meadow & Beilock, 2010). Finally, there is a small body of neuroimaging evidence that confirms that producing symbolic or iconic gestures while learning information, in this case learning melodies or new vocabulary, respectively, does lead to subsequent activation in motor areas when these stimuli are subsequently encountered (Macedonia, Muller, & Friederici, 2011; Wakefield &

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James, 2011). Together, this evidence lends support to the idea that gestures help learners by engaging the motor system.

A novel and interesting result from the current work was that our findings were affected by phonological competency, suggesting that the capacity to learn from gesture may actually interact with individual differences. We suggest that the ability to sound-out words allowed children to make sense of the spoken strategy, and incorporate the gesture into their representation of this strategy, leading to our pattern of results. That is, our instructions; that explicitly referred to reading the word, were interpretable for children with high phonological skill, but may have been confusing to their peers with low phonological competency. Whereas transitive actions are used to manipulate concrete objects, and thus, they can lead to sensory-motor representations of these objects simply by necessitating the coordination of visual and motor systems, gestures are more abstract, instantiating a strategy for understanding a concept and naturally occurring with a spoken message. Because of this abstraction, the way gesture affects cognitive processing may be dependent on its connection with spoken language. In the present study, this connection hinged on children's phonological competency; gesture could only be effective, above-and-beyond speech, if children could interpret the spoken message. Our findings support previous work showing that gesture is most beneficial for children at a certain level of ability in a related skill (Post et al., 2013).

Whereas our proposed mechanism for the facilitative effects of gesture must be tested empirically in future research, we believe that our current results still inform a general understanding of how gesture affects cognitive function: It is not necessarily important whether children are instructed to produce a speech-gesture match or mismatch while learning a concept, what is most important is that they are using their hands to help them learn. Importantly, we also show that gesture may be more beneficial for children that are at a certain skill level in relation to the task being learned, in the present case, phonological understanding. We chose to explore the question of how different types of gesture (match vs. mismatch) affected children's ability to profit from gesture use during learning outside of the domain of mathematics—the domain in which many effects of gesture on learning have been established. In doing so, we highlight the importance of clarifying the constraints and generalizability of gesture's learning effects across domains. Our results should be replicated not only in the mathematical equivalence paradigms, but other novel paradigms that represent various learning domains.

Our results also highlight a potential difference between the cognitive effects of naturally produced versus scripted gestures. In the current study, children produced scripted gestures, those that were taught to them. In contrast, the prediction that asking children to produce speech-gesture mismatches would be more or less facilitative of learning than speech-gesture matches—predictions that were not supported by our findings—were based on literature in which gestures were naturally produced. Previous research suggests that when children produce a speech-gesture mismatch that contains two strategies related to a new concept, these strategies can be integrated, and lead to a better understanding of the concept than if they express the same strategy in speech and gesture (i.e., a speech-gesture match; e.g., Church, 1999; Goldin-Meadow, 2010). This led to the hypothesis that mismatches would help children more than matches. However, our results suggest that this ease of integration may only occur when children internally generate the two strategies in speech and gesture; not when gesture strategies are scripted. In other words, when gestures are scripted for children, the presence of two strategies is not detrimental (otherwise children would have performed better in our SGmatch condition), but the strategies do not have the same cognitive benefit as if they were produced spontaneously.

Research on the effects of naturally produced gesture on cognitive load supported the opposite prediction: that a speech-gesture match strategy should have benefited children more than a mismatching strategy. When speech-gesture matches are internally generated and naturally produced, one strategy for solving a problem has been activated and expressed through two modalities. Gesture provides a visuospatial, holistic representation of the strategy that complements the linear description of the same strategy in speech, thereby reducing cognitive load (Goldin-Meadow et al., 2001). In comparison, when naturally produced speech-gesture mismatches occur, a speaker activates two strategies, expressing one in each modality, and this does not free up the same amount of cognitive resources as a matching gesture. We believe that again, a crucial difference between the present study and previous work is that here, speech-gesture strategies were scripted, not spontaneous. In both speech-gesture conditions, children learned to perform two separate activities during the experiment: a set of words, and a set of movements. Eventually, these strategies may have been processed as either having the same (speech-gesture matches) or different (speech-gesture mismatches) meanings, and if these strategies were naturally produced, at a later time, we might see the same effects on cognitive load as in previous literature. However, it is likely that for much of the training period, children in both gesture groups treated speech and gesture strategies as two separate strategies, leading to similar cognitive effort across conditions. Future research should be conducted to further understand the differences between the cognitive effects of naturally produced versus scripted gesture.

Alternative Explanations

Attentional mechanism. It could be argued that speech-gesture match and mismatch strategies were equally beneficial to learners in the current study because of an attentional mechanism, rather than our proposed sensory-motor mechanism. In other words, gesture could help merely by drawing visual attention to the problems during the Training session. We believe this is an unlikely explanation. First, if gesture benefited children by drawing attention to the problems, we would expect to see gesture facilitating learning in all children. Instead, our results show that gesture benefited children with high phonological competency, but not low phonological competency—there is no reason to predict that only children high phonological competency would be affected by attention. Second, previous work suggests that the power of gesture does not come simply from gesture's ability to capture attention, but from the meaning that is instantiated in the gesture itself through handshape and movement pattern (Goldin-Meadow et al., 2009). Thus, based on previous research and the lack of performance differences across conditions in our Low Phonology group, it is unlikely our results are due to an attentional mechanism.

Palindromes versus other learning tasks. A second alternative explanation for our results is that they were driven by our

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learning paradigm and the specific strategies we taught children to produce. We chose to compare the effects of speech-gesture matches and mismatches in a task that had not been used before. In doing so, we demonstrated that the benefits of gesture use extend to a new domain: learning a concept that involves both reading ability and an understanding of patterning. However, by asking our question within a new framework, a potential concern is whether our results would be replicable in other paradigms, like mathematical equivalence or Piagetian conservation. Although future work should directly compare the effects of speech-gesture matches and mismatches in these tasks, we believe that our paradigm shares many of the characteristics of past studies, and thus suggest that our results would generalize to other domains. To elaborate, we can consider the similarities between our current task and previously studied paradigms.

One of the hallmarks of past studies on the effects of gesture was that children and teachers naturally used gesture when explaining problems based on a particular concept. In creating our strategies, we documented natural gesture use by both teachers and students when talking about palindromes. Further, adults and children who already understood the concept predominantly displayed speech-gesture matches when explaining their solutions to problems, as would be expected from previous literature (e.g., Church & Goldin-Meadow, 1986; Goldin-Meadow et al., 1993). Finally, we created a task in which children could solve problems based on an underlying principle, or alternative algorithms. This is very similar to the types of strategies that are used in the mathematical equivalence task. We therefore think it unlikely that our findings were task-specific.

Within our task, there is also the potential issue that the specific strategies we chose affected our results. Because we were interested in whether speech-gesture match or mismatch strategies were differentially effective learning tools for children, we were not concerned with the specific speech strategy or gesture strategies used. Future work should expand on our current work: A fuller design would include a comparison of the symmetry strategy in speech (i.e., a spoken version of our mismatch gesture strategy), paired with each gesture strategy. By asking children to use the forward-backward strategy in speech in the present study, we may have inadvertently caused children to recruit phonological processing skills, leading to our interaction effect. In contrast if children had produced the symmetry strategy in speech, this may have only required children to pick up on the pattern of the individual letters to understand the concept of a palindrome, rather than having to process the sound of the nonsense words backward and forward. That being said, although we may not find an interaction with phonological processing if the alternative speech strategy was used in future work, there is no reason to suspect that we would not see a significant main effects of gesture strategies, compared to speech alone.

Future Directions

In the present study, we asked whether teaching children to produce speech-gesture match or mismatch strategies differentially impacted learning. Based on our results, we suggest that in designing curricula that incorporate scripted gesture as a learning tool, teachers can be encouraged to use either speech-gesture match or mismatch strategies—both facilitated learning equally well in the present study. However, this should be substantiated through the direct comparison of match and mismatch strategies in other paradigms, especially as the concept of palindromes is a much simpler concept than those previously used to study gesture for learning. Further, the effect of speech-gesture matches and mismatches should be studied in the classroom, so that the way these types of gestures are used naturally can be taken into account. Additionally, gesture may be particularly beneficial for children from low socioeconomic backgrounds who tend to produce fewer spontaneous gestures (Rowe & Goldin-Meadow, 2009), and it has been shown to benefit children who have been diagnosed with learning disabilities (Daniels, 2001; Evans, Alibali, & McNeil, 2001). Therefore, extending our results to these populations would also be beneficial.

In conclusion, our study represents the first comparison of the benefits of teaching children to produce matching and mismatching speech-gesture strategies to help them learn a concept. Our results suggest that gesture is facilitative of learning when children are in a cognitive state to benefit from instruction (in this case, if children are able to sound-out novel words), regardless of whether the gesture reflects the same meaning as the speech it accompanies in the case of a speech-gesture match, or provides additional information, in the case of a speech-gesture mismatch. Given the lack of difference between the effects of speech-gesture matches and mismatches, we suggest that scripted gestures may affect the cognitive system differently than naturally produced gestures, a topic that should be studied more in the future. We suggest that based on the action-learning literature, our scripted gestures were equally beneficial because in both cases, gesture could be causing to the development of strong sensory-motor representations for the concept being learned, a hypothesis that should be tested in the future.

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(*Appendix follows*)

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Appendix

Speech and Gesture Strategy Creation

In previous studies in which children were taught speech and gesture learning strategies to help them understand mathematical equivalence, researchers modeled the taught strategies after those that were naturally produced by teachers and learners in prior observations. To create speech and gesture strategies that were as naturalistic as possible, we videotaped two elementary school teachers explaining the concept of palindromes to a child. Teachers were given a list of palindromes, and were told they could use other additional palindromes, as long as they used at least two words and two phrases that were palindromes to teach the concept to a child.

Speech and gesture were transcribed separately in ELAN Linguistic Annotator. So as to avoid the influence of either source of information biasing the coding of the other, the video was removed for speech coding, and the audio was removed for gesture coding. Speech was segmented by phrases such that each contained one explanation for what a palindrome is (e.g., "This word is a palindrome, do you know why? Because you can read it forward and backwards and it says the same thing"). Gestures were segmented using guidelines established in the literature (e.g., McNeill, 1992) in which a gesture is defined as a preparation, stroke, and return. Gestures were then grouped into gesture phrases based on overlap with the spoken phrases.

Using a ground-based coding system, it became clear that the spoken strategies used by the teachers could be separated into two general categories. Either, an explanation emphasized the idea that a palindrome reads the same way forward and backward, or an explanation emphasized the symmetry inherent in a palindrome. Phrases were coded as *forward-backward* if words describing directionality were used (e.g., "this way," "that way," "forward," "backward"). Phrases were coded as *symmetry* if the teacher made comparisons between matching letters on the two sides of the palindrome, or stated that both halves of the palindrome were the same, often highlighting what letter was in the middle of the palindrome (e.g., "Look, here's an M and here's an M," "Look, if we cut this word in half at the T, both sides are the same").

Collapsing across the teachers, 21 spoken explanations were produced. Eight explanations were coded as forward-backward speech strategies, and the remaining 13 spoken explanations were coded as expressing the symmetry strategy. Next, the gestures used during the speech strategies were assessed. Of the eight forward-backward strategies, seven were accompanied by a gesture in which the finger or hand was swept under the entire palindrome (left-to-right and/or right-to-left), and one was accompanied by a gesture in which the finger was swept under each half of the palindrome separately. Of the 13 symmetry strategies, seven were accompanied by a gesture in which individual matching letters were pointed to consecutively or simultaneously, three were accompanied by a gesture in which the two sides of the palindrome were highlighted separately through a single point to both sides with a finger or hand, one was accompanied by a folding motion, in which the hands were opened palms forward near the ends of the palindrome and brought together, palms touching, in the middle, one was accompanied by a gesture in which the finger was swept under each half of the palindrome separately, and a final spoken explanation was not accompanied by gesture.

On the basis of the gestures accompanying speech, we determined that a sweeping motion outlining a palindrome in either direction is most often used when the forward-backward nature of a palindrome is being described, and a gesture highlighting the two sides, or matching letters in a palindrome is most often used when the symmetry nature of a palindrome is being described. In both cases, the gestures seem to express the same information as the speech being used. This is not surprising as in a previous set of studies in which the meaning expressed through speech and gesture were coded, it was shown that individuals who understood a concept were more likely to produce gesture and speech that expressed the same idea, than to provide different information in the two modalities (Church & Goldin-Meadow, 1986).

Our final step was to create our speech and gesture strategies for our experiment. We chose to use the speech strategy "A palindrome reads the same forwards and backwards." When palindromes were taught, the teachers often said that the word "reads" the same forward and backward instead of "is spelled" the same forward and backward; thus, we used this terminology accordingly. We chose this speech strategy because it was the strategy that was most consistently paired with one type of gesture, and therefore we could create a speech-gesture match strategy by pairing it with a gesture in which the child places right hand under the left side of the palindrome and moves it to the right end of the palindrome while saying "A palindromes reads the same forwards," pauses, then places the left hand under the right side of the palindrome and moves it to the left while saying "and backwards." To create a speech-gesture mismatch strategy, we used the same speech phrase but paired it with a gesture that was never paired with the forward-backward strategy by teachers, and was the predominant gesture strategy used when teachers expressed a symmetry strategy in speech (i.e., child points to the outside letters of the word with index fingers while saying "A palindrome reads the same forwards," then simultaneously moves fingers to the second-to-outside letter while saying "and backwards").

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