Research Report

EXPLAINING MATH: Gesturing Lightens the Load

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Abstract—*Why is it that people cannot keep their hands still when they talk? One reason may be that gesturing actually lightens cognitive load while a person is thinking of what to say. We asked adults and children to remember a list of letters or words while explaining how they solved a math problem. Both groups remembered significantly more items when they gestured during their math explanations than when they did not gesture. Gesturing appeared to save the speakers' cognitive resources on the explanation task, permitting the speakers to allocate more resources to the memory task. It is widely accepted that gesturing reflects a speaker's cognitive state, but our observations suggest that, by reducing cognitive load, gesturing may also play a role in shaping that state.*

Gesturing occurs across ages, tasks, and cultures (Feyereisen & de Lannoy, 1991). Although in theory gesture could be nothing more than meaningless hand waving, recent research has found that gesturing conveys meaningful information (Clark, 1996; Goldin-Meadow, McNeill, & Singleton, 1996; Kendon, 1980; McNeill, 1992), information that is not always found in the speech it accompanies (Goldin-Meadow, Alibali, & Church, 1993). For example, a speaker might say, "I ran all the way upstairs" while moving her index finger upward in a spiral. It is through the speaker's gestures, and only her gestures, that the listener knows the staircase is a spiral. Moreover, gesture is noticed. The information that gesture conveys frequently has an impact on the message listeners take from the communication (Alibali, Flevares, & Goldin-Meadow, 1997; Goldin-Meadow, Kim, & Singer, 1999; Goldin-Meadow & Sandhofer, 1999; Goldin-Meadow, Wein, & Chang; 1992; Kelly & Church, 1997; McNeill, Cassell, & McCullough, 1994; Povinelli, Reaux, Bierschwale, Allain, & Simon, 1997; Thompson & Massaro, 1994).

However, speakers use gesture even when they know it cannot possibly be seen by their listeners (Cohen & Harrison, 1973; Rime, 1982). For example, congenitally blind speakers gesture when talking to blind listeners (Iverson & Goldin-Meadow, 1998). Why? Might gesturing serve a function for speakers beyond the obvious communicative function it serves for listeners?

Consider a young speaker explaining how she solved the problem $3 + 6 + 7 = \_\_ + 7$. She says, "I added the 3 and 6 and put 9 in the blank," while at the same time pointing at the 3 and 6 with her middle and index fingers forming a V-shape, and then pointing at the blank (Perry, Church, & Goldin-Meadow, 1988). What relation do those gestures have to the accompanying speech? Gesturing while speaking (as opposed to speaking without gesturing) is likely to require motor planning, execution, and coordination of two separate cognitive and motor systems (Andersen, 1995; Petersen, Fox, Posner, Mintun, & Raichle, 1988). If so, gesturing might be expected to increase speakers' cognitive load (Norman & Bobrow, 1975; O'Reilly, Braver, & Cohen, 1999; Wickens, 1984). Alternatively, gesture and speech might form a single, integrated system in which the two modalities work together to convey meaning (Goldin-Meadow et al., 1993; McNeill, 1992). In this view, gesturing reduces demands on the speaker's cognitive resources, and frees cognitive capacity to perform other tasks.

In order to distinguish these alternatives and to determine the impact of gesturing on a speaker's cognitive load, we explored how gesturing on one task (explaining a math problem) affected performance on a second task (remembering a list of words or letters) carried out at the same time. If gesturing increases cognitive load, gesturing while explaining a math problem should take away from the resources available for remembering (Baddeley, 1986). Memory should then be worse when speakers gesture than when they do not gesture. Alternatively, if gesturing reduces cognitive load, gesturing while explaining a math problem should free up resources available for remembering. Memory should then be better when speakers gesture than when they do not.

METHOD

Participants

Forty children were tested individually on 20 addition problems of the form $4 + 5 + 3 = \_\_ + 3$, and 36 adults were tested individually on 24 factoring problems of the form $x^2 - 5x + 6 = (\quad)(\quad)$.[1] We included only those participants who gestured when permitted, which left 26 children (mean age = 9 years 11 months; 7 boys, 19 girls) and 32 adults (college age; 15 males, 17 females). Participants were asked to solve the math problem at the blackboard. Seventeen children solved at least 18 of 20 problems correctly ($M = 98\%$, $SD = 4\%$); the remaining 9 solved only 5% ($SD = 15\%$) correctly. All 32 adults solved at least 19 of 24 problems correctly ($M = 96\%$, $SD = 5\%$).

Procedure

After solving each problem, participants were given a list of items (words for children, letters for adults) to remember. The experimenter read the words to the children, and displayed a card containing the letters to the adults. Adults were allowed to look at the card for approximately 5 s. Participants were then asked to explain how they arrived at their solutions to the math problem. Note that participants had to keep the word or letter list in memory throughout the math explanation. After completing the explanation, participants were asked to recall the list as a measure of

1. The tasks differed for the adults and children because of basic differences in their mathematical and memorial skills. The children were challenged by the addition problems, whereas the adults needed the more difficult factoring problems to be engaged. In addition, the adults were able to solve and explain more math problems before tiring than the children (24 vs. 20 problems). Finally, the adults needed a more difficult task than the children did in order to have their memories taxed (remembering unrelated letters vs. words).

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Table 1. *Examples of children's explanations in speech and gesture for the problem 3 + 4 + 5 = __ + 5*

Type of procedure	Speech	Gesture
Incorrect procedures		
Add all the numbers	"I added the 3 plus 4 plus 5 plus 5 equals 17"	Point at 3, point at 4, point at left 5, point at right 5, point at solution
Add to the equal sign	"I added the 3 plus 4 plus 5 and got 12"	Point at 3, point at 4, point at left 5, point at solution
Carry	"They don't have another 4 like that so I put the 4 over there"	Point at 4, point at solution
Correct procedures		
Equalizer	"3 plus 4 plus 5 equals 12, so to make the other side equal 12 you need 7 more"	Sweep across 3, 4, and 5 on left side of the equation, point at equal sign, sweep across solution and 5 on right side of the equation
Grouping	"I added the 3 and the 4"	V-hand under 3 and 4, pause, point at solution
Equivalent addends plus grouping	"Since there was a 5 here and a 5 here, I added the 3 and the 4 and got 7"	Point at right 5, point at left 5, drop hand; V-hand under 3 and 4, pause, point at solution
Add-subtract	"I added 3 plus 4 plus 5 and that equals 12 so then I had to subtract the 5 over here and I got 7 for the answer"	Point at 3, point at 4, point at left 5, pause, pull hand down under right 5, point at solution

Note. The children either put the correct solution (7, in this example) in the blank or gave one of a number of incorrect solutions generated by different procedures, such as 17 (add all the numbers), 12 (add to the equal sign), or 4 (carry).

the cognitive load imposed by the explanation (Logan, 1979; Shiffrin & Schneider, 1984). Participants took approximately 5 s to recall the items.

Participants gave explanations under two conditions: (a) gesture permitted, in which their hands were unconstrained, and (b) gesture not permitted, in which they were instructed to keep their hands still on the tabletop. Within each condition, lists were of two difficulty levels (three- vs. one-word lists for children; six- vs. two-letter lists for adults), a manipulation that allowed us to examine the effect of gesturing on memory when it is more versus less taxed. Words on the lists were monosyllabic, concrete nouns selected from the list of words with the highest frequency according to Wepman and Hass (1969); the letters were capitalized consonants presented in groups of two (e.g., "XR QP BN").

Data Analysis

Movement of the hand during the explanation task was counted as a gesture if there was no obvious alternative purpose to this movement (such as fiddling with hair or folding the hands together). Speech and gesture were coded according to a previously developed system for the children (Perry et al., 1988) and an analogous system developed for this study for the adults. Gestures were described in terms of three parameters: hand shape, motion, and location in space. Tables 1 and 2 display examples of the most common explanations given by the children and adults in speech and gesture. Children's explanations were coded in terms of procedures used to arrive at a solution to the problem. Adults' explanations were coded in terms of properties of the problem involved in arriving at a solution.

Proportion correct on the memory task was subjected to an arcsine transformation before analysis. Data were entered into an analysis of variance (ANOVA) with two within-subjects factors (gesturing, list length). Because some children knew how to solve the math problems correctly and others did not, a between-subjects factor (math knowledge) was also included in the ANOVA for the children.

Table 2. *Examples of adults' explanations in speech and gesture for the problem* $x^2 + 5x + 6 = (\quad)(\quad)$ *[solution = (x + 3)(x + 2)]*

Type of property	Speech	Gesture
Multiplying	"3 times 2 is 6"	Point at 3, point at 2, point at 6
Combining terms	"3*x* plus 2*x* is 5*x*"	Point at 3, point at right *x*, pause, point at 2, point at left *x*, point at 5*x*
Combining addends	"3 plus 2 is 5"	Point at 3, point at 2, point at 5
Factoring	"I wanted factors of 6 that added up to 5"	Point at 6, point at 5
x^2	"The *x* squared needs to be broken into *x* and *x*"	Point at *x* squared, point at left *x*, point at right *x*
Signs	"If the 2 signs over here are both plusses, then they both have to be plusses in the parentheses"	Point at first plus, point at second plus, point at first plus in parentheses, point at second plus in parentheses
Multiplying signs	"The 6 has a plus in front of it, so these signs are plus and plus, which multiply out to another plus"	Point at second plus, point at first plus in parentheses, point at second plus in parentheses
Adding signs	"The 5 has a plus in front of it, so these signs are plus and plus, which add to another plus"	Point at first plus, point at first plus in parentheses, point at second plus in parentheses

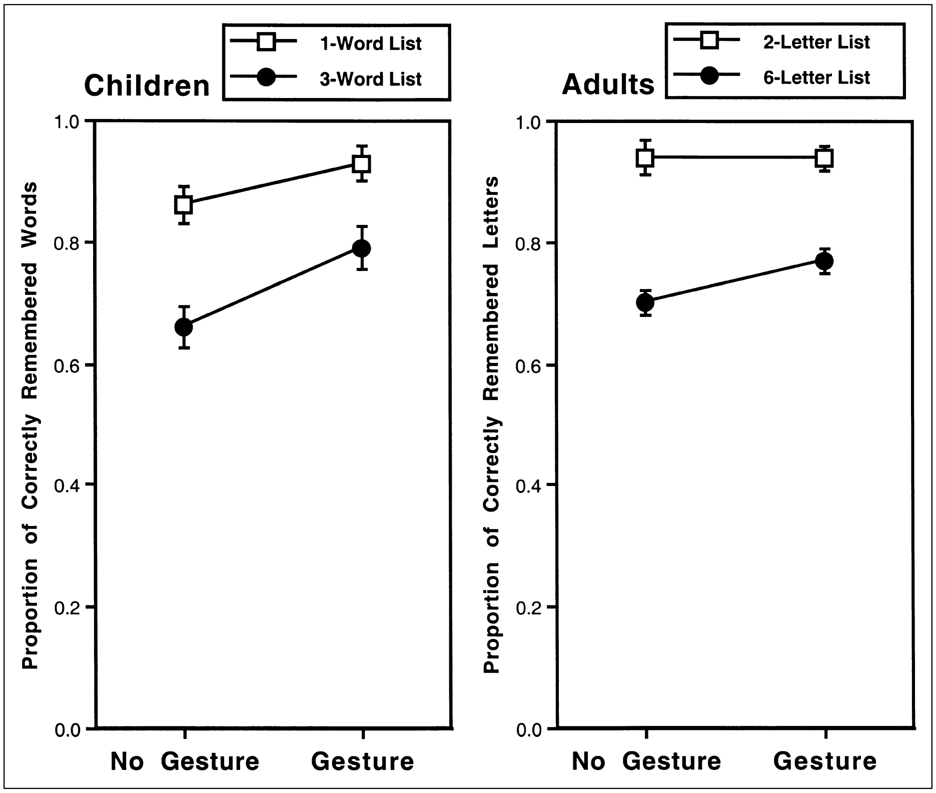

Fig. 1. Proportion of correctly remembered items on short and long lists for children (left) and adults (right). Error bars indicate standard errors.

RESULTS

Gesturing Improved Recall on the Memory Task

Does gesturing on math explanations affect memory? Both children and adults remembered a significantly larger proportion of items when gesturing than when not gesturing (Fig. 1), $F(1, 24) = 11.32$, $p = .003$, for children; $F(1, 31) = 4.47$, $p = .04$, for adults. Not surprisingly, children and adults also remembered more on short than long lists, $F(1, 24) = 22.24$, $p = .0001$, for children; $F(1, 31) = 137.74$, $p < .0001$, for adults. Although list length did not interact with gesturing in either children, $F(1, 24) = 0.55$, n.s., or adults, $F(1, 31) = 0.94$, n.s., planned comparisons revealed that, in both groups, gesturing was particularly beneficial when memory was taxed (Fig. 1). Participants remembered a significantly larger proportion of items on long lists when gesturing than when not gesturing, $F(1, 24) = 15.40$, $p = .001$, for children; $F(1, 31) = 5.03$, $p = .03$, for adults. In contrast, the difference between the two gesture conditions was not significant for short lists, $F(1, 24) = 3.17$, n.s., for children; $F(1, 31) = 0.43$, n.s., for adults.

All the adults knew how to solve and explain the math problems correctly. Not all the children, however, did. It is possible that expertise might affect the role gesture can play in recall. Interestingly, however, gesturing benefited memory independently of math knowledge. Children who solved the math problems correctly remembered the same proportion of words as children who solved them incorrectly ($M = .85$, $SD = .11$ vs. $M = .87$, $SD = .15$), $F(1, 24) = 0.08$, n.s. Moreover, gesturing improved memory to the same extent in the two groups (i.e., there was no interaction between gesturing and knowledge of math solutions), $F(1, 24) = 0.63$, n.s. (see Fig. 2).[2] Thus, superior performance on the memory task was not a consequence of producing the correct answers on the math task—what mattered was whether speakers gestured while producing their answers.

It is possible, however, that time spent in explanation (rather than gesturing per se) accounts for the memory patterns seen in Figures 1 and 2. Gesturing while speaking could allow participants to represent more information in less time, which would result in a shortened explanation. Because short-term memory deteriorates with time, a shortened explanation would produce better recall. To examine this possibility, we measured the time participants took for each explanation. We began timing when the letters or words were first presented and stopped when the participant began recalling the items. We found that both children and adults spent slightly more time in explanation when gesturing than when not gesturing (children: $M = 12.9$ s, $SD = 7.0$ s vs. $M = 11.1$ s, $SD = 5.5$ s; adults: $M = 27.7$ s, $SD = 16.7$ s vs. $M = 26.6$ s, $SD = 13.9$ s). The timing difference was reliable for chil-

2. Not surprisingly, children who solved the math problems correctly also gave a significantly higher proportion of correct explanations than children who did not: .97 ($SD = .05$) versus .05 ($SD = .15$), $F(1, 24) = 581.4$, $p < .0001$. However, success on the explanation task was not affected by the other two factors, gesturing and list length. Children were equally correct on the explanation task whether or not they gestured ($M = .64$, $SD = .45$ vs. $M = .67$, $SD = .47$), $F(1, 24) = 0.80$, n.s., and whether they remembered one- or three-word lists ($M = .66$, $SD = .46$ vs. $M = .65$, $SD = .46$), $F(1, 24) = 0.02$, n.s.

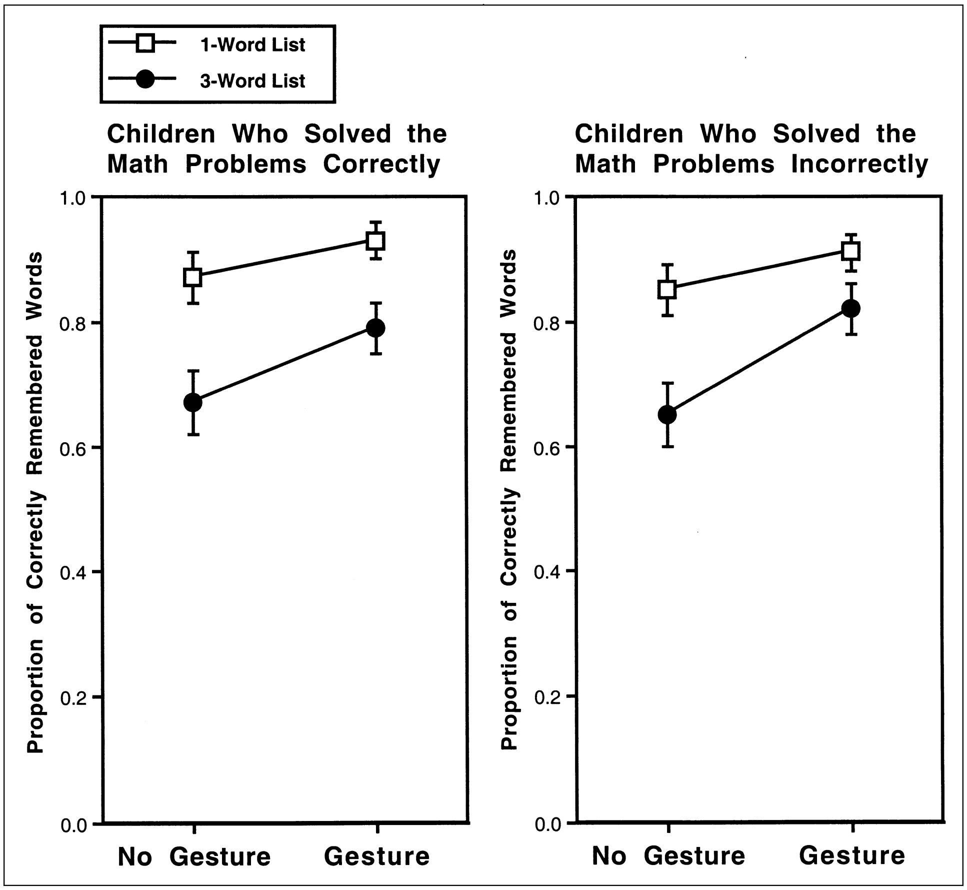

Fig. 2. Proportion of correctly remembered words on short and long lists for children who solved the math problems correctly (left) versus incorrectly (right). Error bars indicate standard errors.

dren, $F(1, 24) = 5.23$, $p = .03$, but not adults, $F(1, 31) = 0.93$, n.s.; there was no effect of list length on timing for either group. If the time interval prior to recall had driven our results, we would have expected participants to remember less when gesturing than when not gesturing—just the reverse of what Figures 1 and 2 show.

An Alternative Possibility: Not Gesturing Is Itself a Cognitive Load

The data in Figures 1 and 2 are consistent with the hypothesis that gesturing increases cognitive capacity. An alternative possibility, however, is that being forced not to gesture hurts memory, that is, that the observed effect is due not to the beneficial effects of gesture, but to the deleterious effects of the constraining instructions. Asking speakers not to gesture is, in effect, asking them to do yet another task, which could add to their cognitive load.

The fact that 9 children and 10 adults gestured on some, but not all, of the problems in the gesture-permitted condition allowed us to address this concern.[3] We reanalyzed these participants' data, separating memory when the participants did not gesture by choice from memory when they did not gesture by instruction. As before, we found that memory was affected by gesturing, $F(2, 16) = 3.54$, $p = .05$, for children; $F(2, 18) = 3.55$, $p = .05$, for adults. However, this was true only when the participants were taxed on long lists, $F(2, 16) = 4.87$, $p = .02$, for children; $F(2, 18) = 5.99$, $p = .01$, for adults. Memory for short lists was not affected by gesturing, $F(2, 16) = 1.29$, n.s., for children; $F(2, 18) = 0.34$, n.s., for adults. The important point is that participants remembered more on long lists when gesturing than when not gesturing either by choice or by instruction, $F(1, 8) = 5.71$, $p = .04$, and $F(1, 8) = 14.11$, $p = .006$, respectively, for children; $F(1, 9) = 8.07$, $p = .02$, and $F(1, 9) = 7.37$, $p = .02$, respectively, for adults (see Fig. 3). Memory did not differ when participants chose versus were instructed not to gesture, $F(1, 8) = 0.001$, n.s., for children and $F(1, 9) = 0.003$, n.s., for adults; this result suggests that instructing participants to remain still did not systematically add to cognitive load.[4]

3. The 9 children failed to gesture on 4.3 ($SD = 1.2$) of the 10 problems on which gesture was permissible, and the 10 adults failed to gesture on 4.5 ($SD = 2.0$) of the 12 problems on which gesture was permissible.

4. It is possible that refraining from gesturing, even if it is done spontaneously (i.e., without instruction from the experimenter), could add to a speaker's cognitive burden. However, if gesturing is so central to speaking that refraining from it adds to load, gesturing must be playing some sort of role in cognitive processing—which is the core of the argument we are making.

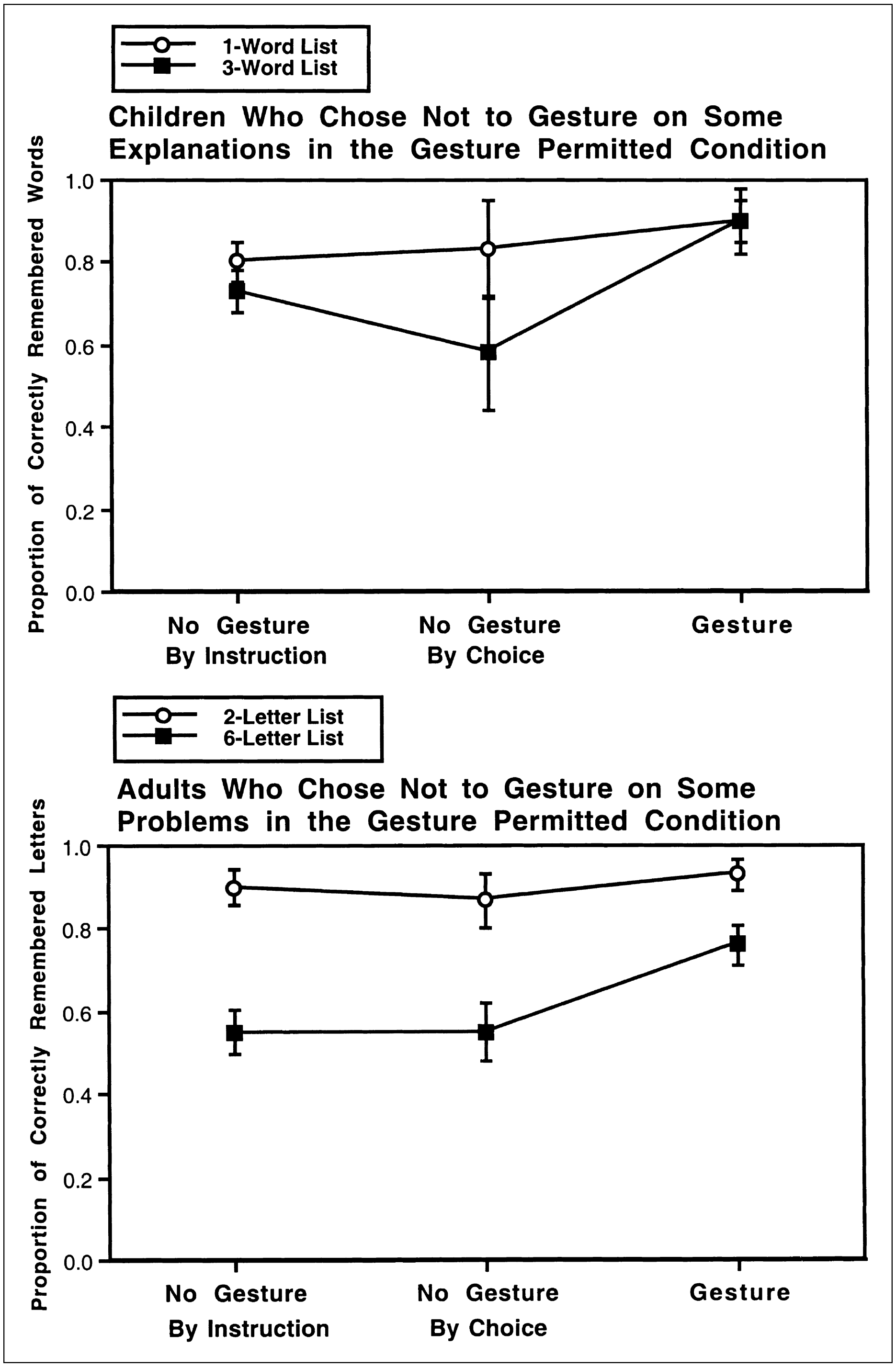

Fig. 3. Proportion of correctly remembered items on short and long lists for children (top) and adults (bottom) who chose not to gesture on some explanations in the gesture-permitted condition of the math task. Error bars indicate standard errors.

Is it possible that the math problems on which these 9 children and 10 adults chose not to gesture were particularly difficult? We calculated the percentage of problems these participants solved correctly when they gestured, did not gesture by choice, and did not gesture by instruction; the differences were not reliable: 40% (SD = 49%) versus 33% (SD = 50%) versus 39% (SD = 46%), $F(2, 16) = 0.61$, $p = .55$, for children; 96% (SD = 10%) versus 98% (SD = 11%) versus 96% (SD = 9%), $F(2, 18) = 0.47$, $p = .63$, for adults. Thus, the memory pattern observed when participants gestured versus when they did not gesture by choice or by instruction cannot be attributed to difficulty in solving the math problem.

DISCUSSION

Speakers often gesture while explaining a task. These gestures are systematically related to the speakers' cognitive performance—they predict how the speakers will go about solving the task (Alibali, Bassok, Solomon, Syc, & Goldin-Meadow, 1999), and even whether they are likely to learn the task (Church & Goldin-Meadow, 1986; Perry et al., 1988). Thus, gestures reflect a speaker's cognitive state. But do they go further—do gestures play a role in fashioning that state? Might gesture play a causal role in thinking itself? This question is difficult to address simply because most speakers are not aware that they are gesturing.

In our experiment, we manipulated gesture directly and explored the effects of that manipulation on a cognitive process. We instructed participants not to move their hands on some trials, and found a consequent detrimental effect on memory. Manipulating gesture experimentally is, of course, essential to determine whether gesture plays a causal role in cognition. However, by raising gesturing to a conscious level, we ran the risk of altering the phenomenon we wished to study.

We managed to avoid this pitfall because a subset of our participants spontaneously (and presumably, unconsciously) did not gesture on some of the problems on which gesturing was allowed. We could thus compare the effects on memory of removing gesture by experimental design versus by the participant's spontaneous inclination. The effects turned out to be identical in the two situations: Speakers remembered more when they gestured than when they did not gesture. These findings suggest that gesture reduces the cognitive load of explanation, freeing capacity that can be used on a memory task performed at the same time.

How might gesture increase available cognitive resources? As Tables 1 and 2 illustrate, gesture can convey the same basic idea as speech; however, it does so using a visuospatial rather than a verbal representational format. This distinct representational format can enrich the way information is encoded and might allow gesture to facilitate information processing and reduce effort. Thus, producing gesture can actually lighten a speaker's burden. For example, gesturing may prime a speaker's access to a temporarily inaccessible lexical item and thus facilitate the processing of speech (Rauscher, Krauss, & Chen, 1996). Or gesturing can facilitate the link between the words a speaker utters and the world that those words map onto, not only in comprehension (as Glenberg & Robertson, 1999, have shown), but also in production. Finally, gesturing can help speakers organize information (particularly spatial information[5]) for the act of speaking and thus facilitate conceptualization of the message (Alibali, Kita, & Young, 2000). Gesturing may play a role at each of these levels. The theme underlying all three is that gesture and speech form an integrated and, indeed, synergistic system in which effort expended in one modality can lighten the load on the system as a whole.

An alternative possibility is that, rather than simply lightening cognitive load, gesturing shifts some of the load from verbal working memory to other cognitive systems. Recent work in cognitive neuroscience suggests that different types of information—verbal versus spatial material, for example—are represented in distinct cortical areas (e.g., Smith & Jonides, 1995). Moreover, gesture appears to be represented in cortical areas that differ from those that handle verbal material (Decety et al., 1997), suggesting that gesture and speech may make demands on different memory stores. In the speech-only explanations in our study, all the representations were verbal-propositional and therefore competed for working memory capacity with our secondary task (memory for words or letters), which was itself a verbal task. In contrast, in the speech-with-gesture explanations, some of the verbal-propositional information could be encoded into gesture and represented in a different cortical area. The effect of this shift from verbal to gestural representation might be to reduce demands on verbal working memory, thus making it possible to remember more words or letters. Note that, under this view, shifting load from a verbal to a motor-gestural system ought to make it more difficult to perform a secondary task that involves memory for gestural (as opposed to verbal) items. Gesturing, compared with not gesturing, should then decrease performance on a secondary task of this sort. We are currently testing this prediction.

Whatever the mechanism, our findings suggest that gesturing can help to free up cognitive resources that can then be used elsewhere. Traditional injunctions against gesturing while speaking may, in the end, be ill-advised.

5. The fact that the biggest effects for gesture have been found in spatial tasks (e.g., Alibali, Kita, & Young, 2000) or in utterances with spatial content (Rauscher et al., 1996) raises the possibility that gesture may lighten a speaker's load only when explanations involve spatial information.

Acknowledgments—We thank M.W. Alibali, B. Bertenthal, J. Cacioppo, J. Huttenlocher, B. Keysar, J. Jonides, M. McClintock, J. McClelland, and D. McNeill for insightful comments on earlier drafts of the manuscript, and our reviewers, T. Carr and A. Glenberg, and editor, S. Glucksberg, for suggestions that greatly improved the final product. This work was supported by a grant from the Spencer Foundation to S.G.-M. Adult participants and parents of all participating children gave informed consent.

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(RECEIVED 8/7/00; REVISION ACCEPTED 2/1/01)