J Sci Educ Technol (2013) 22:825–837
DOI 10.1007/s10956-012-9433-5

The Different Benefits from Different Gestures in Understanding a Concept

Seokmin Kang · Gregory L. Hallman · Lisa K. Son · John B. Black

Published online: 4 January 2013

Abstract Explanations are typically accompanied by hand gestures. While research has shown that gestures can help learners understand a particular concept, different learning effects in different types of gesture have been less understood. To address the issues above, the current study focused on whether different types of gestures lead to different levels of improvement in understanding. Two types of gestures were investigated, and thus, three instructional videos (two gesture videos plus a no gesture control) of the subject of mitosis—all identical except for the types of gesture used—were created. After watching one of the three videos, participants were tested on their level of understanding of mitosis. The results showed that (1) differences in comprehension were obtained across the three groups, and (2) representational (semantic) gestures led to a deeper level of comprehension than both *beat* gestures and the no gesture control. Finally, a *language proficiency effect* is discussed as a moderator that may affect understanding of a concept. Our findings suggest that a teacher is encouraged to use representational gestures even to adult learners, but more work is needed to prove the benefit of using gestures for adult learners in many subject areas.

Keywords Mitosis · Level of understanding · Gesture · Complex system

S. Kang (✉) · G. L. Hallman · J. B. Black
Institute for Learning Technologies, Columbia University, New York City, NY, USA
e-mail: sk2587@tc.columbia.edu

L. K. Son
Barnard College, Columbia University, New York City, NY, USA

Introduction

When instructors explain a concept, gestures often accompany words; for instance, the instructor may point at an object, with one or both hands. The hands may embody the relationship between two objects and may even be used to draw out a diagram, figure, or chart—none of which are actually visible in space. While supplementary material in a classroom setting, such as a diagram, may provide ample information for the students and help their learning (Ainsworth and Loizou 2003; Butcher 2006), instructors are able to provide further information through hand movements. We can ask what, if any, information is being delivered to the mind of the listener through the hand movements, and is that information beneficial? The purpose of the current study is to explore whether different gesture types differentially affect adults' understanding of a concept and, if any, to measure potential benefits.

Why do people gesture? Early on, Cohen (1977) investigated whether a speaker gestures for the sake of the listener or for the sake of the speaker himself. In that study, participants were assigned to conditions that varied across dimensions, such as how well the listener could view the speaker. The results showed, as one might logically expect, that the number of gestures decreased as the listener's visibility decreased. Cohen concluded, from this study, that gestures were largely intended for the listener.

Since Cohen's early study, the role of gestures in communication has been extensively explored and the majority of the data has suggested that gestures help the listener. In particular, gestures can help the listener by providing contextual cues or by providing information with the hands in speech (Beattie and Shovelton 1999; Graham and Argyle 1975; Riseborough 1981; Roger 1978; Thompson et al. 1998; Thompson and Massaro 1994; Woodall and Folger 1985). For example, in Riseborough's (1981) study, the author created videos in which the speaker had to describe particular objects. In the "Sound Mode" condition, participants (i.e., listeners) were only presented with verbal information from the video—they did not have any visual information. In the "Face Mode" condition, only the speaker's face could be seen with the speaker's verbal utterance. In the third condition, the "Body Mode" condition, the speaker's entire body, including gestures, was presented. Riseborough measured the time it took for participants to guess which object was being described and found that the Body Mode condition led to the fastest and most accurate responses. In other words, the gestures, above and beyond mere verbal information, allowed the listeners to more quickly comprehend what the speaker was trying to convey.

Woodall and Folger (1985) investigated the function of gestures from the opposite perspective—how might gestures in conversation affect the speaker's ability to retrieve linguistic information? Gestures, they argued, could act as a salient contextual cue during encoding and thus would be helpful during retrieval. In other words, the researchers hypothesized that gestures would follow the classic "encoding specificity principle" (Tulving and Thompson 1973)—if a particular gesture was associated with an utterance, then exhibiting that gesture would lead to retrieval of that utterance. In their study, videos comparing various types of gesture, either emphasis gesture, emblematic gesture, gesture semantically related, or a no gesture condition, were used. Results showed that gesture type was a key determinant of language recall. People who used emblematic gestures had better recall than those using emphasizing gestures. This study opened the possibilities for a new benefit of gesture use in memory.

From the studies above, we learn the gestures' role in communication and the communication benefit listeners get from a speaker's gestures. So then, can we expand this benefit of gesture to educational purpose?

Children's Learning Benefit from Gestures

Many studies have tested the role of gestures and proved the benefit of using gestures in children's learning concepts and it encompasses the concept of conservation (Church et al. 2004; Ping and Goldin-Meadow 2008), the concept of math equivalence (Cook and Goldin-Meadow 2006; Goldin-Meadow et al. 1999; Singer and Goldin-Meadow 2005), or the concept of symmetry (Valenzeno et al. 2003). Even though a handful of the research tested the role of gestures as contextual cues in adults' conversation, compared to children's benefit from gestures, the benefit which adult learners can get from gestures has been somewhat overlooked.

Thompson et al. (1998) compared the benefit of gestures for both children and adults with representational gestures, gestures with semantic values, when recalling words. In the study, nine-year-old children and adults (17–24 years old) were told to recall as many words as possible after watching a female speaker reciting short sentences. It was observed that children showed better performance in word recall when they were given sentences with gestures. Also, unlike adults, children benefited from gestures more when recalling verbs than nouns in sentences spoken by a speaker in videotape. They assumed that gestures accompanying verbs pictorialized characteristics of action in a very direct manner and helped children remember those words. The benefits of using gestures with predicates such as verbs would presumably play a more important role in children's concept understanding, where cognitive process becomes more complicated. Considering limited cognitive capacities in children such as working memory capacity, cognitive skill, background knowledge, and so on, children would be able to get more benefit from a speaker's gestures than adults in the word recall task. However, it is still not clear whether and what learning benefit that adult learners can get from gestures, because the study compared different benefit from gestures between adults and children by only measuring the number of recalled words. While quite a few studies have showed children's learning benefit from gestures, it has been rarely investigated what learning benefit adult learners can get from different gesture types. Not only can gestures carry information that is redundant with speech, but also gestures often carry critical information not carried in speech (e.g., Bavelas 1994; Church and Goldin-Meadow 1986); especially, in case of delivering complex concepts such as emergent processes which require understanding of both micro- and macrolevel (Chi et al. 2012), and sequential processes that are sometimes hard to observe with naked eyes, gestures play an important role in listeners' understanding of a concept. This means that adult learners also can get learning benefit from an explainer's gestures. In this sense, the present study further investigates the role of a speaker's gestures on adult learners, specifically by examining the levels of understanding that can be reached though different gestures. We will test the different benefits of different types of gestures on learning, in particular, the extent to which adult learners can benefit from different types of gestures.

Information Embedded in Gestures

Gestures during conversation increase comprehension (Beattie and Shovelton 1999). What are the various types of gestures that people use during conversation? According to McNeill (1992), gesture categories have varied as a function of the gesture's referent, the particular environment in which it is used, its information value, as well as across other dimensions; for instance, McNeill distinguished between gestures depending on its referent. If a specific gesture bears a close formal relationship to the semantic content of speech, it is called an *iconic* gesture. Consider the following iconic gestures: when a speaker describes a path by tracing its outline or uses a closed fist to represent a rock. *Metaphoric* gestures, alternatively, depict abstract referents or ideas metaphorically, where the hand movement does not directly correlate with the physical information, that is, they present an image of the invisible. For example, one may point over one's shoulder with a thumb to refer to an event that happened in the past. In this case, it is not that this type of gesture indicates something in the back. *Deictic* gestures refer to an object or region of space that is given referential value through the shape and movement of the hands. For example, a speaker points with his index finger to one cell in a diagram of mitosis while saying "this cell moves to the other side." In relation to children's comprehension of verbal utterances, deictic gestures facilitate children's comprehension through the visual input provided by the pointing gestures, which amplify the semantic content (Tfouni and Klatzky 1983). While these three types of gestures—iconic, metaphoric, and deictic—are distinguishable, they all fall under one umbrella of *representational* gestures in that they convey semantic value.

According to the *information packing hypothesis*, when a speaker describes a certain image which has visuo-spatial information, the speaker's *representational* gestures help reduce cognitive load by parsing the visuo-spatial information into smaller parts rather than processing the visual image as a whole. In other words, representational gestures help organize visuo-spatial knowledge into a series of discrete units (see Hostetter et al. 2007 for a review). Information delivered in representational gestures has a relatively smaller unit of the image; therefore, it can be assumed that a listener who receives information with such gestures would have more mental capacity to deal with given information, which, presumably, would lead to deeper understanding of a given concept.

Representational gestures seem to help knowledge construction, whereas other gestures seem not to have similar beneficial effects. *Beat* gestures, for example, are usually defined by a quick stroke of the hands or fingers in the air. They have semiotic value and may also be used to index words or phrases (McNeill 1992). Beats are usually thought to be nonnarrative, motorically simple, rhythmic gestures that do not convey semantic content related to speech (Alibali et al. 2001; Krauss et al. 1996). Therefore, *beat* gestures may look insignificant. However, they do play a certain role in a conversational situation. For example, they can reveal a speaker's conception of the narrative discourse as a whole. Based on studies that had examined the relationship between pitch accents and nonverbal cues, such as eyebrow movements and head nodding (Bolinger 1983; Cavé et al. 1996; Morgan 1953), Krahmer and Swerts (2007) argued that beat gestures play a similar role in conversation to facial cues. They investigated the function of visual gestures (eyebrow movements and manual beat gestures) and explored whether seeing a gesture increased the perceived prominence of that particular word. They found that when participants saw a speaker's beat gesture on a specific word, the realization of that spoken word was perceived as more prominent than when they did not see the beat gesture. This result supports the studies of stress and accent in language understanding (Cutler 1984; Terken and Nooteboom 1987). For example, Terken and Nooteboom (1987) argued that the correct placement of pitch accents on important words helps in a listener's processing of the words. When we think about the similar role between nonverbal cues and pitch accents on word perception, it is assumed that beat gestures help a listener's word recognition, which may in turn help retrieval of words and longer lasting memory for those words.

Cassell et al. (1999) have stated that beat gestures can attract and engage a listener without referring to the actual content in the conversation. In other words, they help a listener stay focused and attentive to the parts of the conversation that are emphasized. It is also assumed that a speaker's beat gestures may help a listener to segment topics into chunks or discern explanation structures. In this sense, beat gesture may play a role in "meta-explanation." Without mentioning the actual contents, beat gestures help a listener better recognize the speaker's intention and organize the conversation.

Regarding other benefits from different gestures, while a few studies (Church et al. 2000; Kelly and Church 1998) have shown that there were different benefits of representational gestures across development, only memory performance has been tested. Also, learning benefits from beat gesture have been rarely explored. Here, we investigate how different types of gesture may benefit adult listeners to varying degrees—from basic understanding to deeper knowledge. In addition to find out beat gestures' effect on learning, this study explore how semantically related gestures affect adults understand a concept. To test this, we use the following gesture grouping strategy: representational gestures are those that include deictic, iconic, and metaphoric gestures; beat gestures are expressed with a quick stroke of a speaker's right hand toward a listener without delivering semantic contents.

Therefore, our research question was: How much information do adult listeners gain from various types of gestures? Specifically, what is the adult learners' learning benefit from representational gestures and whether beat gestures contribute learning by increasing listeners' perceived prominence of the words accompanying gestures will be tested.

Different Learning Benefit from Different Gestures

To address whether different types of gestures lead to different levels of improvement in understanding in an instructional situation, we created instructional videos in which a speaker provided an explanation of mitosis using a diagram. We chose a mitotic process as a topic that contains both structural and behavioral information embedded. Also, its structure and movements of each part are complex and cannot be observed with naked eyes, which means the concept is hard to delivered only with speech. Therefore, it is assumed that there will be enough room that accompanying gestures play a role for learners.

Video technology has been used before to investigate the role of gestures, and such methods would be ideal for our study as well, so as to have strict control over the gestures that are used. Three versions of the video were created, varying by gesture type: *representational* gestures, *beat* gestures, or no gestures. Participants were asked to watch one of the three videos twice and then posttest were administered for the contents in the video. The methods differed from previous studies in several ways. First, unlike most of the past studies on the benefits from gesture, which focused on children (Church et al. 2000; Kelly and Church 1998; McNeil et al. 2000), adults were tested. This is an important point given that adult learners are likely to have deeper and more complicated prior knowledge that is readily applied during watching a video. Second, the material being learned in previous studies was confined to math equivalence concepts (Goldin-Meadow et al. 1999; Church et al. 2001; Singer and Goldin-Meadow 2005) or conservation concepts (Ping and Goldin-Meadow 2008; Church et al. 2004). Here, we attempt to expand the content to a complex science concept aided by a diagram. In addition, we more clearly implemented beat gestures, along with improving the explanation context in the instructional videos. For example, Woodall and Folger (1981, 1985) used what they called "emphasizing gestures." However, this did not *purely* represent the emphasis of the speech—since what they termed "pounding" or "chopping" movements toward or away from the body could communicate more than an emphasis. In other words, these gestures could convey meaning that would also be conveyed through representational gestures. Therefore, in our study, we defined a beat gesture strictly as a short stroke of an open right hand in the air.

Lecture-based instructional videos were created. Previous studies had investigated gestures' roles mostly aimed at a social setting and used recall or recognition tests to measure retrieval of information from a conversation in video. This video material makes it possible to observe the role of gestures as a contextual cue; yet, there is a limit as to how much one can observe about gestures' effect on learning. For example, Woodall and Folger (1985) used video materials where the conversation of two interlocutors was embedded into the video. In the conversational context, a speaker's gestures were directed to the conversation partner, not a viewer who was watching the video. Participants viewed their conversation from the third-person perspective where gestures were not intended for the participants. Therefore, it was difficult to investigate gestures' pure learning effect on viewers. We created lecture-based instructional videos and added a diagram displaying the mitotic process to look specifically at the effect of different gestures on learning.

We hypothesized the following: participants will get the most learning benefit from representational gestures, which deliver semantic information. For beat gestures, we suggest two possibilities. By raising the level of prominence in the words that beat gestures accompany, beat gestures may lead to more accessible retrieval of descriptive knowledge, therefore improving memory at the recognition level, as compared to the no gesture group. In other words, since beat gestures can play a role as a contextual cue, it may be that both the beat gesture and representational gesture groups will not show any difference in the recognition test which does not require a deep understanding of a concept. On the other hand, beat gestures may hamper understanding of a concept. Imagine an instruction with a supplementary material such as a diagram or map in an instructional video. Listeners in the beat gesture group should shift their attention or would be tempted to pay attention to beat gestures which actually do not deliver semantic values. As a result, their attention can be distributed by beat gestures. Even though beat gestures help perceive prominence of a particular word, in this case, paying attention to beat gestures would lead to the use of more mental resources and may function as a cognitive constraint (Mayer et al. 2001). It is expected that the representational gesture group will outperform the two other groups, particularly on questions which require a deeper level of understanding, such as what-if questions. As a result, by integrating information in a diagram, participants would benefit most from learning with representational gestures.

Methods

Participants

Fifty-one (35 female) graduate students ranging in age from 22 to 45 ($M = 29$) participated in the study for course

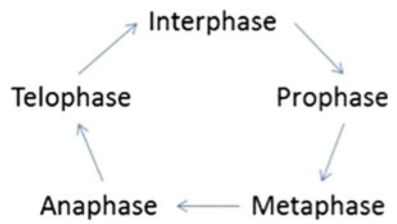

Fig. 1 Mitotic process

credit or voluntarily. The participants' major was diverse from education to law. Among the participants, 34 were native English speakers[1] and 17 were non-native English speakers.[2] None of the participants had been exposed to the content (on mitosis) for at least for 4 years, and none had majored in the content-related domain (Biology) during college. A total of 16 students were in the representational gesture group, 18 made up the beat gesture group, and 17 were in the no gesture group.

Materials

Our goal was to design a context that would closely mimic a true-to-life instructional setting. We created three instructional videos. In each video, the speaker (the explainer) stood next to a diagram of the mitotic process. Mitosis is the cell division process during which one cell undergoes nuclear division to form two genetically identical daughter cells. The description of mitotic concept was selected from about.com biology section (http://biology.about.com/od/mitosis/ss/mitosisstep.htm), and then we edited it suitable for a tutorial video (see Appendix 1 for the video script and detail of gestures accompanied with the script). We chose the mitotic process for several reasons. First, mitosis is fast and highly complex—the sequence can be divided into distinct stages that can be named (e.g., interphase, prophase, metaphase, anaphase, and telophase, see Fig. 1).

Second, describing the mitotic process is likely to encourage a great deal of gesturing. For example, hand gestures can mirror chromosomes moving to opposite poles of the cell. Third, mitosis is a process that is educationally relevant, but cannot be observed with the naked eye. This, again, would foster dialogue that would be rich in hand movements.

In the instructional videos, a speaker gave a step-by-step explanation of cell division processes for about 5 min. Based on the verbal script, gestures appropriate for each word or phrase were devised. The videos were identical in language and number of gestures but differed in kinds of gesture. For example, in the *representational gesture* video (Fig. 2), while the speaker describing a sentence in the script, *"…the paired chromosomes, or sister chromatids, separate and begin moving to opposite ends of the cell…"* he pointed at chromosomes on the diagram with his index finger, turned toward a camera, and then splayed his fingers with two hands stretching them outside to show chromosomes' moving to opposite ends of the cell.

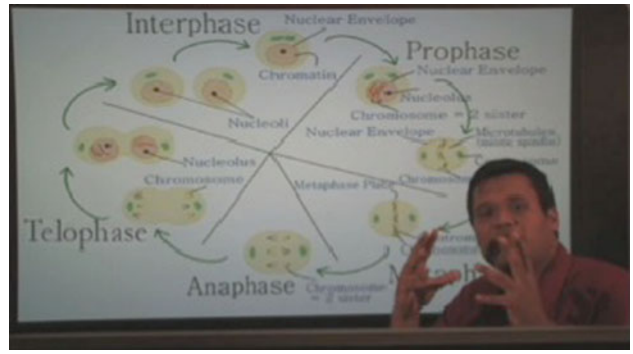

Fig. 2 A snapshot from the representational gesture video

The *beat gesture* video showcased the speaker using only beat gestures. Beats were shown using a speaker's open right hand so as to decrease the probability of gestures' effect overlapping with other gestures. For example, beat gestures could be displayed using the index finger with chopping movements or tapping the palm of the opposite hand. However, when beats are delivered with an index finger, especially over a diagram, it can be interpreted as a deictic gesture, that is, pointing to a certain object or area. Also, when beats happen consecutively with an index finger, it can also be misinterpreted as segmentation. Therefore, in this study, beats were limited to stroke of a speaker's open right hand held vertically in the air.

The third condition was the *no gesture* video. Here, only the speaker's face and torso—but not the hands—were visible to the listeners.

Procedure

Upon a participant's arrival, he or she was guided into a quiet room, seated in front of a table, and randomly assigned to one of the three video groups (*representational gesture*, *beat gesture,* and *no gesture* conditions) that he/she could learn about mitosis: Each video was approximately 5 min long. Participants watched the video twice via a laptop computer with a 12.1″ WXGA LED panel. They were also told that they would be tested afterward. Conditions were the same except for the type of gesture displayed. Immediately after watching a video twice, a posttest was given to participants. The posttest was

[1] In the current study, participants who did not complete their secondary schooling taught in English were regarded as non-native English speakers.

[2] None of the participants had trouble with the instructions given during the experiment.

composed of two sessions. In the first session, participants were given 15 min to answer recognition, immediate transfer, and what-if questions. Immediately following the first session, a 3-min drawing session followed. During the drawing session, participants had to the draw about anaphase in as much detail as possible based on the video that they had watched. Finally, participants were debriefed about the study.

Posttest

To measure the effect of gestures on learning, we created four different types of questions: *retention*, *immediate transfer*, *what-if*, and *drawing*. The questions were written based on the contents in the video. The posttest was divided into two sessions and was administered separately. The first session was composed of 20 retention questions, 5 immediate transfer questions, 5 what-if questions, for a total of 30 questions in total (To see examples of each test, see Appendix 2). One point was given for each correct answer. All questions in the first session were randomly ordered. The retention test was composed of 12 cued recall and 8 multiple-choice questions asking about participants' descriptive knowledge of a mitotic process. For example, participants were asked "In what stage does the nuclear envelope disappear?"

The immediate transfer test was composed of five multiple-choice questions. Participants were asked to apply the information presented in the video to situations that were not explicitly mentioned in the instructional video. For example, participants had to reason about how many daughter cells are produced and what number of chromosomes these cells have.

Finally, "what-if" type questions asked the learners to engage in thought experiments to explain and predict the outcomes of scenarios in which the values of key parameters had changed, such as "What results can be expected during metaphase if the nuclear envelope does not break in the prophase stage?" Participants were required to imagine possible scenarios in the event that the nuclear envelope did not break and integrate possible results from what they had learned from the instructional video.

In the second session, a drawing test was administered, where participants were asked to draw the anaphase, one of the cell division stages in as much detail as possible based on what they watched from the video (Fig. 3). The major event of anaphase is the sister chromatids moving to opposite poles of the cells, due to the action of the condensing spindle fibers. The moving sister chromatids form a V shape as they move through the cytoplasm. This is because the centromeres are pulled by the spindle fibers and lead the rest of the chromatid. Therefore, the anaphase is assumed to be the most critical and active step in the cell division process, requiring learners to understand the movements of each part and its paths. Points for the drawing were earned as follows: The participant got 1 point if they drew one of the three elements (*chromosomes*, *microtubles*, and *centrosome*) regardless of its relative position in the cell. They earned an additional point if each element in anaphase was placed in the right position. Therefore, if participants placed all three components in the correct positions, they could receive 6 points in total.

To check participants' knowledge representation of anaphase, visual components in the drawing were counted and compared. From the participants' drawing, we tried to assess how each group constructed their knowledge from different types of gesture. According to Tversky (1999), a diagram is a cognitive tool that is developed to facilitate information processing. She claimed that by interacting with space either implicitly or explicitly, people yield different mental representations depending on different elements in space and its spatial relations. Therefore, through diagrams, we can observe an individual's mental representation. Assuming that gestures in instructional videos are also elements which change within the listener's environment, it is possible that knowledge representation is uniquely influenced by different types of gesture. In other words, specific types of gestures could influence a listener's knowledge construction in a certain way. This corresponds to a situated cognition theory that environment plays a central role in shaping cognitive mechanisms (Gibson 1979). This also implies that humans have a tendency to possess varying interactions with the environment as its elements change. Therefore, given that the gestures in three instructional videos are based on different interactions with its elements and deliver different types of knowledge, we can assume that people who are exposed to different types of gestures develop their representation of a concept based on the attributes of the gestures that they watched. For example, representational gestures deliver actions or movements that use space. Participants in the

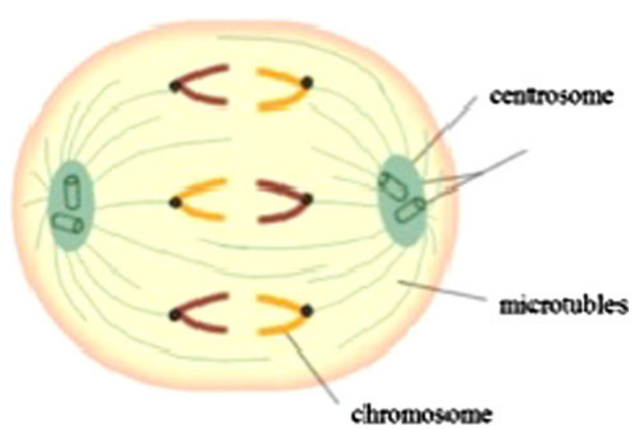

Fig. 3 Anaphase stage

representational gesture group should elicit more action-related knowledge constructions, which would, in turn, be reflected in participants' drawings. In other words, participants may embody gestures differently when watching a video and express it later within drawing. In *anaphase*, for instance, chromosomes align in the center of a cell, separate, and then begin moving to opposite ends of the cell. Since representational gestures deliver behavioral and structural information such as movement of chromosomes and the relative position of elements, we expect that the representational gesture group will develop and show more accurate knowledge of each position and movement of the chromosomes such as with the use of arrows or action effects that deliver behavioral information of a chromosome. An interrater reliability analysis using the Kappa statistic was performed to determine consistency among raters.

Results

We first calculated the total number of points earned (out of 36) for each participant. The participants in the *representational gesture* condition scored numerically the best, $M = 18.94$ (SD = 3.45), while the *beat gesture* group scored numerically the lowest, $M = 15.00$ (SD = 3.96). The *no gesture* group mean was 16.91 (SD = 4.97). In the Table 1, we presented the mean scores separately for each posttest. The ANOVA resulted in a significant difference among the three groups, $F(2,48) = 3.76$, MSE = 65.68, $p < 0.05$. The post hoc test (Tukey HSD) specified that there was a significant difference between the *representational gesture* group and the *beat gesture* group ($p < 0.05$).

From the analysis comparing the mean scores for each test across each condition, there were no differences among the three groups on the retention, immediate transfer, and drawing test.[3] However, on the what-if test, which measures participants' reasoning and scenario-based problem-solving skill, the *representational gesture* group outperformed the two other groups, $F(2,48) = 7.34$, MSE = 7.45, $p < 0.01$ (see Fig. 4). The post hoc test (Tukey HSD) further revealed that the *representational gesture* group outperformed both the *beat gesture* group and the *no gesture* group on the what-if test. There was no significant difference between the *beat gesture* and *no gesture* groups.

To investigate the difference between groups on the rate of correct responses by test type, a chi-square independence test was performed. We assumed that this analysis would enable us to determine the different benefits that each group receives from the varying gesture types. We found group differences for questions 13, 18, 24, and 25 ($p < 0.05$, respectively), and for question 8 ($p = 0.058$) and 22 ($p = 0.059$) that were marginally significant.

Question 8, 13, and 25 are retention questions whose answer was explained in the verbal script. Question 18 and 22 are what-if questions. Question 24 was a retention question whose answer was presented in the diagram. Though there were group differences in these questions, no systematic pattern was found in the rate of correct responses by test type among the groups.

Finally, visual components expressed in the drawing test were counted and compared. This is to check how participants in each group developed behavioral knowledge involved in anaphase based on the instructional videos. We first counted the number of participants who showed chromosomes movement information in their drawing by counting action arrows and action words. Four participants out of 16 in the *representational gesture* group showed movement information using arrows or action words. Only one out of 18 participants in the *beat gesture* group expressed movement information by using either arrows or action words. In the *no gesture* group, three out of 17

Table 1 Three groups' mean scores in the posttest

	Representational gesture	Beat gesture	No gesture
Retention	10.94 (3.15)	9.00 (3.16)	10.24 (2.61)
Immediate transfer	2.69 (1.01)	2.50 (0.92)	2.47 (1.23)
What-if	2.75 (0.86)	1.61 (1.09)	1.56 (1.04)
Drawing	2.63 (1.63)	2.06 (1.21)	2.35 (1.66)
Total	18.94 (3.45)	15.00 (3.96)	16.91 (4.97)

Numbers in parentheses are standard deviations

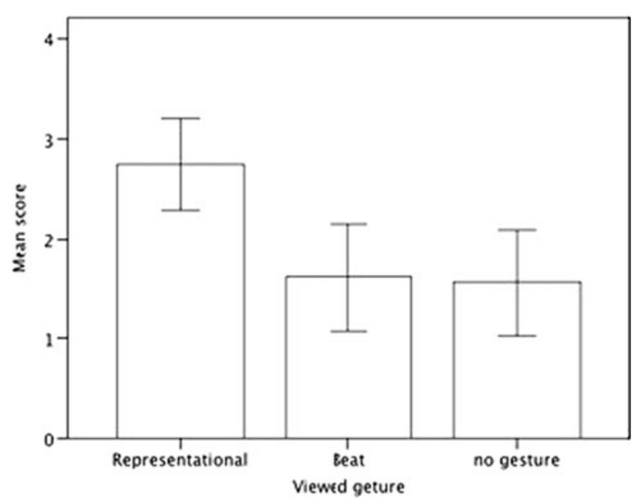

Fig. 4 Mean scores in each group on what-if questions. *Error bars* represent standard errors of the mean

[3] For the drawing test scores, an interrater reliability for the raters was found to be $\kappa = 0.74$ ($p < 0.01$), which is a substantial agreement.

participants expressed movement information in their drawings. No significant differences were found in action information between the three groups ($p = 0.29$).

Secondary Analyses

What other factors may contribute to the group differences? According to a study which investigated the influence of gestures on the processing of figurative language in non-native speakers, the level of second language proficiency affects the processing of meaning constructed from different gesture types (Ibáñez et al. 2010). In the study, they argued that in semantic processing in the learning of a second language, the amplitude modulation and latency of ERPs might depend on the speaker's proficiency level. This may imply that it is possible that speech-accompanying gestures affect comprehension differently depending on language proficiency. Based on this assumption, this study observed whether there was a difference in knowledge benefit depending on their language proficiency. Regardless of gesture type, native English speakers ($M = 10.71$, SD = 2.84) scored higher than non-native English speakers on the posttest ($M = 8.65$, SD = 3.02), $t(49) = 2.39$, $p < 0.05$. ANOVAs were administered to look more closely into the effect of different types of gestures on learning for different level of language proficiency.

There was no group difference in the posttest for native English speakers. However, there was a group difference among non-native English speakers in retention, $F(2, 14) = 3.55$, $p = 0.057$, which was marginally significant. Figure 5 shows mean scores for the three groups on the retention test by language proficiency. For non-native English speakers, the *representational gesture* group scored 11.2 (SD = 4.02); *beat gesture* group 8.00 (SD = 2.00); *no gesture* group 7.00 (SD = 1.41). Also, in a post hoc test (Tukey H*SD*), the *representational gesture* group received marginally higher average scores than the *no gesture* group ($p = 0.059$) irrespective of language proficiency.

For the *what-if* test, native English speakers did not show mean score differences depending on the gestures viewed in the posttest. However, there was a group difference for non-native English speakers, $F(2,14) = 6.71$, $p < 0.01$. Figure 6 shows the mean scores for each gesture group by language proficiency.

The mean score of the what-if test for non-native English speakers was 3.20 (SD = 0.84) in the *representational gesture* group, 1.14 (SD = 1.21) in the *best gesture* group, and 1.10 (SD = 1.02) in the *no gesture* group. A post hoc test (Tukey H*SD*) showed that for the non-native English speakers, the *representational gesture* group performed better than the other two groups on the what-if test ($p < 0.05$, respectively).

On the *immediate transfer* test, there were no gesture group differences for both native English speakers and non-native English speakers. However, as in previous tests, the learning benefit that non-native English speakers gained was strongest when watching representational gestures. The mean score of non-native English speakers was 3.00 (SD = 1.22) for the *representational gesture* condition, 2.00 (SD = 1.00) for the *beat gesture* condition, and 2.00 (SD = 1.58) for the *no gesture* condition.

Discussion

The results show that adult learners can have learning benefit from representational gestures in "what-if" type

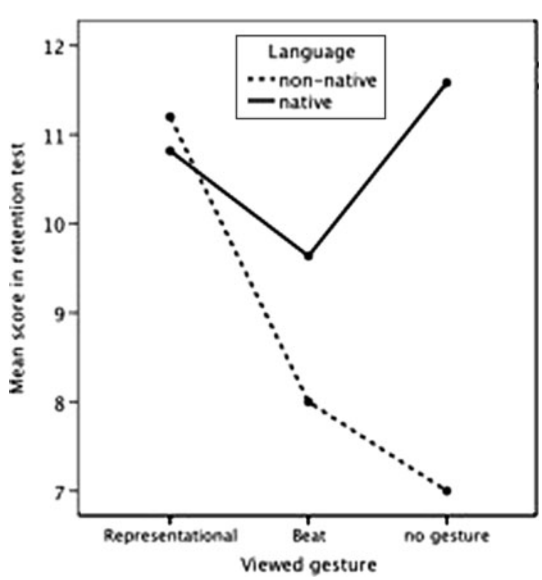

Fig. 5 Mean scores for the retention test by language proficiency

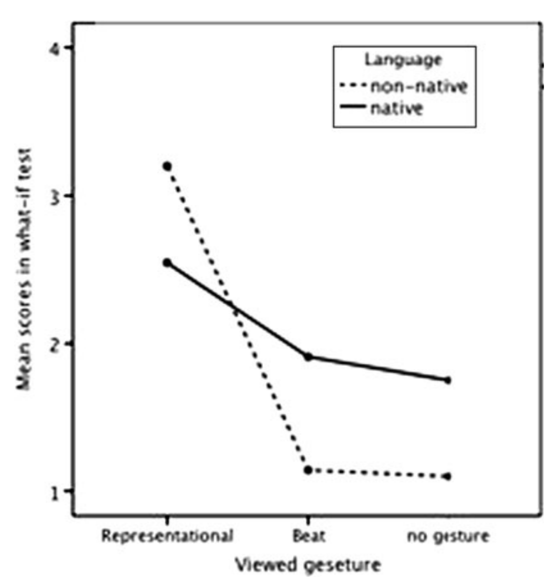

Fig. 6 Mean scores for the what-if test by language proficiency

questions that require deeper understanding of a given concept. Learners in the representational gesture group were able to quickly grasp key concepts and allocate their resources to expand their knowledge, allowing for better performance.

So then how could representational gestures lead adult learners to deeper understanding of the concept? Since representational gestures contain semantic values, it is possible that representational gestures helped the listener to represent objects' behaviors that were hard to be delivered with a static diagram or with speech in a visible and a more concrete way. The literatures on knowledge representation in problem-solving show that chess masters can hold richer and highly structured mental representations of an "appropriate"—or true—configuration of pieces on a chessboard as compared to novice players. However, there are no differences in their ability to recall random or "inappropriate" chess positions (de Groot 1966; Chase and Simon 1973). Cognitive processing of a series of complex configurations of chess positions is based on processing the sum of several simple deployments of pieces, but it does not mean that a chess master is able to remember all those simple configurations. Representational gestures may have functioned in a similar way during knowledge construction. They can provide learners with more contextual cues and help expand given information into various situations by visualizing a given concept in a more meaningful way. Therefore, we assume that, without adhering only to remembering information given in the video, the representational gesture could help the participants get involved in the thought experiment by making invisible objects' behavior visible and finally lead the participants to better performance on the what-if questions.

While a group difference was observed on what-if questions, there were no group significant differences in retention, immediate transfer, and the drawing questions. Among other reasons for why adult learners with representational gestures did not show more learning gain than those with beat gestures and no gesture on the retention and immediate transfer questions, background knowledge that the adult participants had can be one of the possible reasons to influence the test performance. Adult learners already have prior knowledge that probably was related to understanding a mitotic concept. Even if the knowledge that the participants had was not exactly about mitotic processes, those in the beat gesture and no gesture group could answer for the relatively shallow questions based on what they already knew. In addition, although a mitotic concept is complex and movements of the object in the processes are invisible, the processes between cell division phases are based on direct causal relations, which do not require understanding of complex relations of objects such as interaction in both macro- and microlevels. As a result, it could be relatively easy for the participants to answer for the shallow questions.

Analysis of the language proficiency effect was performed to see whether there were different knowledge benefits based on participants' language proficiency. Except for the retention test, there were no differences in the posttests between native English speakers and non-native speakers. It is not surprising that native English speakers performed better than non-native English speakers on the retention test, but how could non-native speakers make up for their lack in language proficiency on the immediate-transfer and what-if test? One possibility is that even though we recruited participants who were not exposed to a given concept for at least 4 years, they might still hold basic prior knowledge of the mitotic process, which they could have looked through various media or remembered from their schooling at the pre-college level. Therefore, although non-native English speakers had problems with remembering terminologies of each part, they could reconstruct knowledge from pieces of their prior knowledge and make up for the gap based on representational gestures. Another possibility is, as mentioned earlier, the benefit that non-native English speakers had from representational gestures. Since representational gestures deliver semantic information of a corresponding word or a phrase, and the gestures were delivered with the diagram, this learning environment would be able to provide the participants with richer information than meaning of the word itself.

To prove this hypothesis, we compared the posttest scores by language proficiency and found that the average score of non-native English speakers in the representational gesture group drastically increased compared to native English speakers on each test. In other words, we can argue that the non-native participants relied more on gestures, especially on representational gestures, than the native speakers. Therefore, non-native English speakers received more learning benefit from representational gestures than native English speakers, which may have lead non-native English speakers in the representational gesture group to higher average scores than native English speakers in both the beat gesture group and no gesture group. It seems that with representational gestures, non-native English speakers were able to compensate for information in the script that they might not fully follow. This interpretation corresponds to a previous study (Church et al. 2004) where children who watched a video with speech and its accompanying representational gestures were better at understanding the Piagetian conservation concept than those who watched a video either with emphasizing gestures or no gestures, even when the concept was delivered not in their mother tongue. In the same vein, posttest scores of non-native English speakers in this study drastically dropped when they were not aided by representational gestures.

In sum, this study not only confirmed learning benefit of adult learners from a speaker's gestures, but also showed a level of understanding by specific type of gesture, suggesting that adult learners benefit from representational gestures in a deeper understanding of a concept, but not in a shallow memory level. Teachers are recommended to use more meaningful, articulated gestures even for adult learners, instead of just moving their hands around in the air. Learners received more learning benefit from representational gestures. The finding in this study is also encouraging in that learners in higher education who had already showed English proficiency to enter for higher education system in the United States received learning benefit from a tutor's gestures and its benefit was greater than the benefit native speakers received.

Limitation and Future Study

While this study showed some implication of gestures in adult learning, there are some limitations. Firstly, because of the small sample size of non-native English speakers in our study (five non-native English speakers in the representational gesture group, seven in the beat gesture group, and five in the no gesture group), further investigation is needed to see how representational gestures are more efficient when compared to adult native English speakers.

Also, in the drawing test, there was no difference in delivering a specific knowledge representation by gesture groups. We assumed that this was because there was not enough time for the participants to fully embody information from the representational gestures in the video since the instructional video was shown to them only twice. The time assigned to the movement of a chromosome in anaphase was only 2 s. This means that participants had a chance to watch only 4 s to construct knowledge of the movement of chromosomes in the anaphase. Therefore, the representational gestures containing movement information would not be much beneficial to participants' constructing behavioral knowledge of chromosomes. Second reason is a limited time assigned to the drawing test. Instead of allowing as much time as they wanted, the participants were given 3 min to draw anaphase. We initially decided to set time limit to control information retrieval in the drawing test. At the same time, we also gave an instruction for the drawing that they needed to draw anaphase as detailed as possible. As a result, the participants had to manage accuracy and retrieval speed at the same time. Considering that when learners were instructed to focus on task accuracy, their performance became lower than when they were instructed to focus on retrieval speed (Wilkins and Rawson 2011), the participants in our study were challenged by both accuracy and retrieval speed. This must be a demanding task to the participants.

Another issue is that even though the participants in this study were not exposed to mitotic processes at least for 4 years, their background knowledge for the to-be-learned concept was not measured with a pretest. This could blur the learning benefit of each gesture on the posttest.

Finally, this study explored the influence of gestures in explanation with an external aid, a diagram. Since we tried to create an explanation situation with a diagram as another external cognitive aid, the effect of different types of gesture on learning would be different than when a speaker gestures without a diagram. First of all, the instructional video we created would impose more cognitive load on participants. As mentioned above, we tried to make the instructional videos as close to a real instructional situation as possible, and based on that, we designed an instructor's explanation of a concept with a diagram. This results in learners being exposed to too much information at once: visual, audio, and written text with named parts and mitosis stages in the diagram. Under these circumstances, learners may find it hard to efficiently cope with all the given information. Furthermore, to the non-native speakers in the beat gesture group, a speaker's hands movements could function as distracting their attention, which later would limit their mental resources. In our study, a speaker explained a science concept with hand gestures next to a diagram. In other words, a listener's attention could become distributed between both hand gestures and the diagram in the middle of the speaker's explanation. This would make the listener have less mental resources in processing information and result in low performance on the posttests. Even though some representational gestures were delivered over the diagram, about 28 % of them (13 out of 47) were provided in front of the speaker, which means the listeners had to switch their attention away from the diagram when paying attention to gestures. Apart from theories of increased prominence on words which accompany beat gestures, a speaker's hands movements next to a diagram would negatively affect learners' paying attention to the information in the diagram.

According to cognitive load theory (Sweller 1988, 1993), complex tasks impose an excessive cognitive load that interferes with the major learning mechanisms of schema acquisition and leading learners to have limited working memory capacity. This assumption explains why the beat gesture group showed relatively lower performance on the posttest. Therefore, it can be interpreted that their attention could be distributed to different visual stimuli: a diagram and a speaker's gestures. When they pay attention to the beat gestures which do not have semantic value, they also miss a chance to incorporate information in the diagram with verbal information at that moment. Again, it is possible that listeners with beat gestures lost the chances to acquire semantic information once they pay attention to a speaker's beat gestures, because it possibly limits their mental resources.

For future studies, further investigation is needed of the influence of gestures on listeners' knowledge representation with more elaborated instructional videos under various subject topics.

Appendix 1

A script used in the *representational gesture* video

Letters in parentheses are a gesture type that represents following words.

d: deictic gesture
i: iconic gesture
m: metaphoric
on: on-diagram gesture
off: off-diagram gesture

for example, "… (d-on) chromatin…" was presented with a speaker's sweeping a word "chromatin" with his index finger on the diagram.

I am going to explain about nuclear division, known as (d-on) "mitosis".

Cell division is a process that enables organisms to grow and reproduce. Dividing cells go through an ordered series of events called the cell cycle.

Mitosis is a phase of the cell cycle in which the genetic material from a parent cell is divided equally between two daughter cells. Before a dividing cell enters mitosis, it undergoes a period of growth called (d-on) interphase. Some 90 % of a cell's time in the normal cellular cycle may be spent in interphase. The cell still has (d-on) nucleoli present during interphase. It is also important to note that the nucleus is bounded by a (i-on) nuclear envelope and the cell's chromosomes have duplicated but are in the form of (d-on) chromatin. In (d-on) prophase, the chromatin condenses into discrete chromosomes. The (i-on) nuclear envelope (i-on) breaks down and spindles form at (i-off) opposite "poles" of the cell. During prophase, the (d-on) nucleoli (m-off) disappear and the chromatid structure of the (d-on) chromosomes becomes apparent.

Many consider (d-on) prophase, as opposed to interphase, to be the first true step of the mitotic process. A change that occurs in a cell during prophase is that (d-on) chromatin fibers (i-on) become coiled into chromosomes with each chromosome having two chromatids joined at a (d-on, i-off) centromere. Also, two (d-on) centrosomes appears, formed from the replication of one pair in interphase (d-on). Also, the two pairs of centrioles within the (d-on) centrosome move away from one another toward (i-off) opposite ends of the cell due to the lengthening of the microtubules that form between them. In late prophase, the (d-on) nuclear envelope (i-off) breaks up. Polar fibers, c, travel from each cell pole to the (i-on) cell's equator. The chromosomes begin to migrate (i-on) toward the cell center. In (d-on) metaphase, the spindle (i-off) fully develops and the chromosomes align at the (i-on) metaphase plate—a plane that is equally distant from the (d-on) two spindle poles. A change that takes occurs in a cell during metaphase is that the (d-on) nuclear envelope (m-off) disappears completely. Polar fibers, which, as we said are microtubules that make up the spindle fibers, continue to (d-on) extend from (i-off) opposite poles to the center of the cell (d-on). Chromosomes move randomly until they attach to polar fibers from both sides of their (d-on) centromeres. Chromosomes are held at the metaphase plate by the equal forces of the polar fibers pushing on the centromeres of the chromosomes. In (d-on) anaphase, the paired chromosomes or sister chromatids (d-on, i-off) separate and begin moving to opposite ends of the cell. Spindle fibers not connected to chromatids (i-off) lengthen and elongate the cell. In preparation for telophase, the two cell poles (i-off) move further apart during the course of anaphase. At the end of anaphase, each pole contains a complete compilation of chromosomes. In (d-on) telophase, the (d-on) chromosomes are (i-off) cordoned off into new distinct nuclei in the emerging daughter cells. The following are changes that occur in a cell during telophase. The polar fibers continue to lengthen. The (d-on) pair of nucleoli reappears. Also, chromatin fibers of (d-on) chromosomes uncoil. After these changes, mitosis cycle is largely complete and the genetic "contents" of one cell have been divided (i-off) equally into two. Finally, we return to the (d-on) interphase stage. A new, separate nucleus is produced.

Appendix 2

Example questions of each test

- Retention question

Example 1 When the chromatids are separated and move to the opposite poles, what is the chromatids called?

Example 2 Some 90 % of a cell's time in the normal cellular cycle may be spent in this phase.
A. interphase B. prophase C. metaphase D. telophase

- Immediate transfer question

Example When the DNA in a cell is uncoiled and spread throughout the nucleus, it is called

A. chromosomes B. chromatids C. centromeres D. chromatin

- What-if question

Example If microtubules were eliminated from prophase, what would be the direct influence on the mitosis process?

References

Ainsworth S, Loizou AT (2003) The effects of self-explaining when learning with text or diagrams. Cogn Sci 27:669–681

Alibali MW, Heath DC, Myers HJ (2001) Effects of visibility between speaker and listener on gesture production: some gestures are meant to be seen. J Mem Lang 44:169–188

Bavelas JB (1994) Gestures as part of speech: methodological implications. Res Lang Soc Interact 27:201–221

Beattie G, Shovelton H (1999) Do iconic hand gestures really contribute anything to the semantic information conveyed by speech? An experimental investigation. Semiotica 123:1–30

Bolinger D (1983) Intonation and gesture. Am Speech 58:156–174

Butcher KR (2006) Learning from text with diagrams: promoting mental model development and inference generation. J Educ Psychol 98:182–197

Cassell J, Bickmore T, Billinghurst M, Campbell L, Chang K, Vilhjalmsson H, Yan H (1999) Embodiment in conversational interfaces: rea. In: Proceedings of computer-human interaction, Pittsburgh, pp 520–527

Cavé C, Guaïtella I, Bertrand R, Santi S, Harlay F, Espesser R (1996) About the relationship between eyebrow movement and F0 variations. In: Proceedings of the international conference on spoken language processing (ICSLP), Philadelphia, pp 2175–2179

Chase WG, Simon HA (1973) The mind's eye in chess. In: Chase WG (ed) Visual information processing. Academic Press, New York

Chi MTH, Roscoe R, Slotta J, Roy M, Chase M (2012) Misconceived causal explanations for "emergent" processes. Cogn Sci 36: 1–61

Church RB, Goldin-Meadow S (1986) The mismatch between gesture and speech as an index of transitional knowledge. Cognition 23:43–71

Church RB, Kelly SD, Lynch K (2000) Immediate memory for mismatched speech and representational gesture across development. J Nonverbal Behav 24:151–174

Church RB, Ayman-Nolley S, Estrada J, Glover D, Dullum T (2001) What role can gesture play in teaching mathematical concepts? Paper presented at the society for research in child development, Minneapolis

Church RB, Ayman-Nolley S, Mahootian S (2004) The role of gesture in bilingual education: does gesture enhance learning? Int J Biling Educ Biling 7:303–319

Cohen AA (1977) The communicative functions of hand illustrators. J Commun 27:54–63

Cook SW, Goldin-Meadow S (2006) The role of gesture in learning: do children use their hands to change their minds? J Cogn Dev 7:211–232

Cutler A (1984) Stress and accent in language production and understanding. In: Gibbon D, Richter H (eds) Intonation, accent and rhythm studies in discourse phonology. De Gruyter Berllin, pp 77–90

de Groot AD (1966) Perception and memory versus thought: Some old ideas and recent findings. In: Kleinmuntz B (ed) Problem solving. Wiley, New York, p 1966

Gibson JJ (1979) The ecological approach to visual perception. Houghton Mifflin, New York

Goldin-Meadow S, Kim S, Singer M (1999) What the teacher's hands tell the student's mind about math. J Educ Psychol 91:720–730

Graham JA, Argyle M (1975) A cross-cultural study of the communication of extra-verbal meaning by gestures. Int J Psychol 10:57–67

Hostetter AB, Alibali MW, Kita S (2007) I see it in my hands' eye: representational gestures reflect conceptual demands. Lang Cogn Process 22:313–336

Ibáñez A, Manes F, Escobar J, Trujillo N, Andreucci P, Hurtado E (2010) Gesture influences the processing of figurative language in non-native speakers: ERP evidence. Neurosci Lett 471:48–52

Kelly SD, Church B (1998) A comparison between children's and adult's ability to detect conceptual information conveyed through representational gestures. Child Dev 69:85–93

Krahmer E, Swerts M (2007) The effects of visual beats on prosodic prominence: acoustic analyses, auditory perception and visual perception. J Mem Lang 57:396–414

Krauss RM, Chen Y, Chawla P (1996) Nonverbal behavior and nonverbal communication: What do conversational hand gestures tell us? In: Zanna M (ed) Advances in experimental social psychology. Academic Press, San Diego, pp 389–450

Mayer RE, Heiser J, Lonn S (2001) Cognitive constraints on multimedia learning: when presenting more materials results in less understanding. J Educ Psychol 93:187–198

McNeil NM, Alibali MW, Evans JL (2000) The role of gesture in children's comprehension of spoken language: now they need it, now they don't. J Nonverbal Behav 24:131–150

McNeill D (1992) Hand and mind. University of Chicago Press, Chicago

Morgan B (1953) Question melodies in American English. Am Speech 2:181–191

Ping R, Goldin-Meadow S (2008) Hands in the air: using ungrounded iconic gestures to teach children conservation of quantity. Dev Psychol 44:1277–1287

Riseborough MG (1981) Physiographic gestures as decoding facilitators: three experiments exploring a neglected facet of communication. J Nonverbal Behav 5:172–183

Rogers WT (1978) The contribution of kinetic illustrators toward the comprehension of verbal behavior within utterances. Human Commun Res 5:54–62

Singer MA, Goldin-Meadow S (2005) Children learn when their teachers' gestures and speech differ. Psychol Sci 16:85–89

Sweller J (1988) Cognitive load during problem solving: effects on learning. Cogn Sci 12:257–285

Sweller J (1993) Some cognitive processes and their consequences for the organisation and presentation of information. Aust J Psychol 45:1–8

Terken J, Nooteboom S (1987) Opposite effects of accentuation and deaccentuation on verification latencies for given and new information. Lang Cogn Process 2:145–163

Tfouni LV, Klatzky RL (1983) A discourse analysis of deixis: pragmatic, cognitive and semantic factors in the comprehension of 'this', 'that', 'here', and 'there'. J Child Lang 10:123–133

Thompson LA, Massaro DW (1994) Children's integration of speech and pointing gestures in comprehension. J Exp Child Psychol 57:327–354

Thompson LA, Driscoll D, Markson L (1998) Memory for visual-spoken language in children and adults. J Nonverbal Behav 22:167–187

Tulving E, Thompson DM (1973) Encoding specificity and retrieval processes in episodic memory. Psychol Rev 80:352–373

Tversky B (1999) What does drawing reveal about thinking? In: Gero JS, Tversky B (eds) Visual and spatial reasoning in design. Key Centre of Design Computing and Cognition, Sydney, pp 93–101

Valenzeno L, Alibali MW, Klatzky R (2003) Teachers' gestures facilitate students' learning: a lesson in symmetry. Contemp Educ Psychol 28:187–204

Wilkins NJ, Rawson KA (2011) Controlling retrieval during practice: implications for memory-based theories of automaticity. J Mem Lang 65:208–221

Woodall WG, Folger JP (1981) Encoding specificity and nonverbal cue context: an expansion of episodic memory research. Commun Monogr 49:39–53

Woodall WG, Folger JP (1985) Nonverbal cue context and episodic memory: on the availability and endurance of nonverbal behaviors as retrieval cues. Commun Monogr 52:319–333