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WHEN HANDS MAKE MEMORIES: THE RETRIEVAL AND REPRESENTATION OF GESTURE AND SPEECH

A dissertation submitted in partial satisfaction
of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

PSYCHOLOGY

by

Acacia L. Overoye

June 2019

The Dissertation of Acacia L. Overoye is approved:

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Abstract

When Hands Make Memories: The Retrieval and Representation of Gesture and Speech

Acacia L. Overoye

Gestures can both enhance and modify memory for speech when produced alongside it. Although much research has documented the beneficial effects of gesture, far less work has examined the boundaries of the benefits of gesture as well as the mechanisms by which it influences memory. The following series of experiments aimed to understand how and when gesture and speech are represented in memory in an attempt to construct a foundation for how gesture influences what listeners remember. The conditions under which gesture is coactivated during the retrieval of speech were investigated by measuring subsequent memory for gesture across six experiments. In each experiment, participants watched videos of an individual saying brief statements and producing gestures followed by a test on what was said for half of these statements before finally being tested on their memory for gestures themselves. Gesture and speech were said to form an integrated representation in memory in cases where there was an observed improvement in recall of gesture after retrieval of speech.

Overall, these experiments suggest that gesture and speech are coactivated during the retrieval of speech and form an integrated representation in memory. Results provided evidence that such coactivation and thus integration by demonstrating a greater enhancement in memory for gesture after the retrieval of speech when gesture and speech are meaningfully related and irrespective of whether gesture is redundant with the contents of speech. The results also showed that the coactivation of gesture and speech during the retrieval of speech is episodic in nature, implying that the representation of gesture and speech in memory retains episodic details of the experience of watching a speaker talk and move. The experiments presented here help us to better understand how gesture and speech are represented in memory and how such representation may lead to the influence gesture has on memory for speech by directly assessing memory for gesture, when gesture and speech are coactivated, and what processes in retrieval maximally encourage such coactivation.

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CHAPTER I

Introduction

Gestures are ubiquitous and spontaneous hand movements that occur alongside speech. The gestures we produce are not merely a mirror to our speech, instead gesture and speech interact to form an integrated system in which gesture conveys information that complements, extends, or even contradicts speech (Goldin-Meadow, 2005; McNeill, 1992). For example, a speaker might say, “The driver wasn’t paying attention,” while smashing their fist into an open palm – the implication being that not only was the driver not paying attention, but that not paying attention resulted in a car accident. Alternatively, a speaker could still say “The driver wasn’t paying attention,” while instead mimicking talking on a phone with their hands to indicate that the driver wasn’t paying attention because they were on the phone. These examples demonstrate how gesture and speech work together to convey meaning and how a change in the gestures produced with speech can create a change in the meaning of a spoken message. Research examining gesture and speech has found that these types of examples influence how speech is comprehended and remembered.

Gesture’s ability to convey meaning beyond the speech of an utterance gives it the power to influence other cognitive processes. When an individual listens to speech, gestures have been shown to enhance comprehension when compared to speech produced without gesture, especially when gestures are about motor actions and are nonredundant with speech (see Hostetter 2011 for a review). For example, listeners are better able to interpret an indirect request such as “I’m getting cold,” as meaning to close an open window when the request is accompanied by a gesture pointing to the open window (Kelly, Barr, Church, & Lynch, 1999). In another task, Driskell and Radtke (2003) found that listeners were able to guess a target word described by a speaker in fewer attempts when speakers were permitted to gesture than when they were not. These two examples illustrate that the gestures produced alongside speech help listeners to comprehend the meaning of speech more effectively than when gesture is not present.

The benefit of gesture does not stop at comprehension and has been shown to improve memory as well (Cook & Fenn, 2017). Listeners are better able to remember the speech of short statements and extended narratives when they include gesture than when they do not (Beattie & Shovelton, 1999; Kelly, Barr, Church, & Lynch, 1999; Macoun & Sweller, 2016; Straube, Meyer, Green, & Kircher, 2014; Riseborough, 1981; Thompson, 1995; Thompson, Driscoll, & Markson, 1998). For example, listeners are better able to answer questions about a previously encountered narrative when that narrative is presented with both speech and gesture than with speech alone (Beattie & Shovelton, 1999). Similarly, Kelly, Barr, Church, and Lynch (1999) found that listeners were more likely to recall the exact contents of speech from short statements having seen the statement uttered aloud with gesture compared to the speech alone.

Including gesture in instruction about mathematics and science can also improve learning when compared to instruction that does not include gesture

(Carlson, Jacobs, Perry, & Church, 2014; Cook, Duffy, & Fenn, 2013; Goldin-Meadow, Kim, & Singer, 1999; Valenzeno, Alibali, & Klatzky, 2003). For example, Carlson, Jacobs, Perry, and Church (2014) examined the influence of gesture on how college students learn the physics of gear movement. In their study, participants completed a pre-test related to gear movement and then watched an instructional video in which the instructor gestured while they spoke or used speech alone. Post-test results showed that participants who originally knew less performed better on the post-test after instruction that included gesture than instruction that did not. These results, along with the results of other studies showing a benefit for memory from inclusion of gesture, demonstrate gesture's faciliatory effect on memory.

To say gesture is just a general enhancer of memory would miss the more nuanced ability of gesture to modify and restructure an individual's memory for an event (Broaders & Goldin-Meadow, 2010; Church, Garber, & Rogalski, 2007; Gurney, Pine, & Wiseman, 2013; Kelly, Barr, Church, & Lynch, 1999). Some research has indicated that gestures both improve recall as well as influence the details of a recollection to include gestured-about information. For example, Kelly, Barr, Church, and Lynch (1999) showed participants short video clips of statements that included nonredundant gesture and speech (e.g., in speech "My brother was at the gym" and in gesture a pantomime of shooting a basketball). After watching the video clips, participants answered cued recall questions about what the actor in the video *said* (e.g., She talked about her brother, what did she say?). Participants' responses were not always faithful restatements of speech alone, but sometimes included information about the statement that was only found in gesture. Kelly et al. (1999) classified such responses – those that included information that could be traced back to gesture – as *traceable additions*. For the case of “My brother was at the gym,” if participants recalled “My brother was playing basketball” the response was coded as containing a traceable addition. Kelly et al. (1999) found that participants made traceable additions 23% of the time, meaning that participants included information that came not from speech but from gesture in 23% of their responses. The modification of memory by gestures produced at encoding has been shown to be maintained over time (Church, Garber, & Rogalski, 2007) and further evidence shows that gesture produced during the retrieval of information about an event can also modify memory (Broaders & Goldin-Meadow, 2010; Gurney et al., 2013). These findings show that gesture can influence the way in which information from speech is encoded and retrieved.

The mechanisms by which gesture influences memory are still widely unknown and the target of much investigation. In a recent chapter, Cook and Fenn (2017) summarize some potential mechanisms that have been put forth in the literature and propose that gestures enhance memory through several mechanisms such as (1) facilitating processing of information, (2) creating a multimodal and distributed trace in memory and (3) engaging a wide variety of memory systems. They argue that these mechanisms result in a representation in memory that is more resistant to interference and decay as well as more easily accessible and more likely to benefit from consolidation. The first proposed mechanism of interest for the purposes of the present discussion, facilitating the processing of information, refers to previously discussed ability for gesture to enhance the comprehension of speech. The reasoning being that if gesture improves the comprehension of speech, then said speech can be more effectively learned. The second mechanism, creating a multimodal trace in memory, relies on evidence that suggests perceiving gesture engages a listener's visuospatial and motor systems (Ping, Goldin-Meadow, & Beilock, 2014). Similar to the Enactment Effect (Engelkamp, 1995) in which performing an action is more memorable than merely reading it, speech produced with gesture is more memorable by virtue of being paired with a motor action that can be represented as a more distributed trace in memory. Finally, the third mechanism, engaging a wide variety of memory systems, refers to evidence that gestures influence memory at episodic, semantic, and procedural levels thus leading to an even more robust memory trace.

While the mechanisms summarized and proposed by Cook and Fenn (2017) are a promising start to understanding how gesture influences memory, they fail to make predictions about under what circumstances gestures are most likely to enhance or modify memory. Although the overwhelming majority of published research on gesture and memory show a beneficial effect of gesture for comprehension and recall, several studies have demonstrated situations where the presence of gestures did *not* result in enhanced memory when compared to speech alone (Kelly & Goldsmith, 2004; Ouwehand, Van Gog, & Paas, 2014; Thompson, 1995; Dahl & Ludvigsen, 2014). In one study, participants who viewed a videotaped lecture on neuroscience with or without gesture did not significantly differ in their understanding of the lecture material (Kelly & Goldsmith, 2004). Kelly and Goldsmith (2004) suggest that perhaps the lecture material was too familiar or too challenging for participants and that difficulty may play a role in the effectiveness of gesture for learning. In another study, Dahl and Ludvigsen (2014) found that gestures lead to more accurate drawings of cartoons that were described in a video, but only for participants who had a different native language than the speech in the video. Perhaps in these circumstances, gesture did not facilitate the processing of information or result in a widely distributed trace. But why? In order to explain results that deviate from the predominantly positive bias toward gesture, theories like the above must be refined and assert how and under what circumstances gesture is represented in memory.

CHAPTER II

Gesture-Speech Representation in Memory

The first step in understanding how gesture influences memory for speech, is to assess how and when gesture and speech are represented in memory. To that end, the following hypothesis of gesture speech integration is proposed. The central claim of the hypothesis is that gesture does more than enhance comprehension of speech, it forms an integrated representation with speech in memory. For gesture to influence the way in which speech is recalled, it must be involved in how speech is both represented in memory and retrieved. This integrated representation is such that during the retrieval of speech gesture is coactivated and, further, if such coactivation occurs, memory for gestures themselves should be strengthened. This main claim has two entailments, the first of which is that the extent of coactivation of gesture is dependent upon the relationship between gesture and speech. Gesture experiences the greatest coactivation when the gestures themselves are meaningfully related to and nonredundant with speech. The second entailment is that the integrated representation of gesture and speech is multimodal and episodic. As such, individuals should be able to consciously re-experience mental images of gesture during the episodic recall of speech.

The specifics of the present account can be illustrated by considering again the case of the statement, “The driver wasn’t paying attention” and the crashing-hands gesture. At encoding when a listener hears the statement, gesture provides a nonredundant and meaningful add-on to speech (the implication of a crash).

Alternatively, the same statement can be imagined with a gesture that mimics driving by holding the hands at a steering wheel or simply raising one hand and letting it fall. These gestures provide cases where the relationship with speech is meaningful but redundant (steering wheel gesture) or not meaningful but nonredundant (raising and falling hand). In the proposed account, the hand-crashing gesture would be more likely to become integrated with speech than the less meaningful or highly redundant gestures.

The formation of an integrated representation of gesture and speech in memory also implies that both gesture and speech should become coactivated during the retrieval of speech. This coactivation during retrieval may further bind gesture and speech in their integration in long-term memory structures as a form of rapid consolidation, a potential general function of retrieval as suggested by Antony, Ferreira, Norman, and Wimber (2017). Returning to the example, if the listener were later asked, “What was said about the driver?”, in order to reconstruct speech and answer the question they coactivate gestural information. This integrated and coactivated memory trace has the advantage of providing an explanation for several findings on gesture and memory. It echoes the sentiment that speech encoded with gesture forms a more distributed and easily accessible memory representation. If gesture and speech are both integrated and encoded in memory, the two are both entry points for retrieval and provide a greater chance to reconstruct the memory when compared to speech alone. Second, if speech and gesture are coactivated this could explain the appearance of traceable additions in recall. As similarly noted by Church, Garber, and Rogalski (2006), if a person first retrieves gestural information and uses that to re-construct speech, speech itself will show the impact of gestural information. For example, when asking the listener, “What was said about the driver?”, the car crash gesture may be retrieved first – following which speech may be reconstructed, leading to the ultimate response of, “The driver crashed”, instead of, “The driver wasn’t paying attention.”

CHAPTER III

The Present Studies

The following series of experiments examined the three assumptions of the present hypothesis: 1) gesture and speech form an integrated representation in memory; 2) gestures are most effectively integrated with speech when their relationship is meaningful and nonredundant; and 3) the retrieval of speech and coactivation of gesture is episodic and relies on visual imagery. To investigate these assumptions, the experiments observed the conditions under which coactivation, and thus strengthening of memory for gesture, occurs. Experiment 1 tested the first assumption of the present hypothesis, that gesture and speech form an integrated representation in memory. Experiments 2-5 assessed the second assumption of the hypothesis by investigating how meaningfulness and redundancy influences the integration of gesture and speech in memory. Finally, Experiment 6 addressed the extent to which episodic re-activation and visual imagery play a role in the coactivation of gesture and speech during retrieval.

Experiment 1

The goal of Experiment 1 was to address the main claim of the gesture speech integration hypothesis, namely that gesture and speech form an integrated representation in memory. Critical to this integration is the assumption that the retrieval of speech leads to the coactivation of information about gesture. Thus, if information about gesture is coactivated during the retrieval of speech, either as part of recalling the episode or in service of reconstructing speech itself, it should be possible to observe evidence of such a coactivation by examining the consequences of retrieval.

Retrieval not only enhances memory for the information being retrieved (Karpicke, 2017; Rowland, 2014; Roediger & Karpicke, 2006); under the right conditions, it has also been shown to enhance the later retrieval of highly related or well-integrated information that was not the original target of retrieval (Anderson & McCulloch, 1999; Chan, 2009; Chan, McDermott, & Roediger, 2006; Cranney, Ahn, McKinnon, Morris, & Watts, 2009; Rowland & DeLosh, 2014). There are many reasons to expect gestural information to be integrated with speech and for it therefore to benefit from this sort of retrieval-induced facilitation. Research has shown, for example, that people are able to recognize gestures they have previously seen (Krauss, Morrel-Samuels, & Colasante, 1991; Straube, Meyer, Green, & Kircher, 2014; Straube, Green, Weis, Chatterjee, & Kircher, 2009; Woodall & Folger; 1981; Woodall & Folger, 1985). Further, in a story-retelling task where participants watched a video tape of a person telling a story and had to re-tell it, during the re-telling participants would mimic the gestures they saw on the video tape as they spoke (Cassell, McNeill, & McCullough, 1998). In consideration of studies like the previous, McNeill (1992) has proposed that gesture and speech form an integrated system of communication. Recent neuroimaging data provide evidence supporting this idea by demonstrating that comprehension and retrieval of speech and gesture show activation in sensorimotor integration areas (Yang, Andric, & Matthew, 2015).

In Experiment 1, participants studied and retrieved spoken statements before being tested on their ability to recall gestural information from said statements. If gesture and speech are integrated in such a way that they are coactivated during retrieval, then it is expected that items that are retrieved will show an enhancement of memory for gesture. However, if gesture and speech are not integrated in a way that leads to their coactivation, then retrieval of speech should fail to enhance memory for gesture.

Method

Participants. Forty-one undergraduates from the University of California, Santa Cruz (UCSC), participated in the experiment for partial course credit. One participant was removed because they did not complete the experiment.

Materials and Procedure.

Encoding phase. Participants were instructed to watch a video of a woman saying 20 statements about different people and events, some with gesture and some without (a list of these statements and gestures are available in Appendix A). Ten of the statements were adapted from Church, Garber, and Rogalski (2007) while ten others were constructed to match the same general form of the original statements (a person or object in a location or performing an action). "My brother was at the gym" with the basketball gesture, and, "The driver wasn't paying attention" with the crash gesture, are examples of old and new statements included in this study. Statements consisted of an average of 5.95 words (*SD* = 1.28) with the longest statement containing 10 words and shortest 4. The gestures that accompanied speech did not repeat, and, while non-essential for comprehending speech, provided additional information about spatial configuration or movement about the topics discussed in speech. The set of statements that included gesture was counterbalanced across participants by creating two versions of the video such that all statements were equally likely to be paired with gesture across participants. Statements were presented in a fixed random order with gestures intermixed but not perfectly alternating to obfuscate the purpose of the study.

Retrieval phase. After participants watched one of the videos, they immediately answered cued-recall questions about half of the statements (e.g., when she talked about the driver, what did she say?). Half of the questions were about statements that were produced with gesture, half were about statements that did not include gesture. Participants were presented with all questions at once and had unlimited time to type in their responses on the computer.

Test phase. Immediately after the retrieval phase, participants were asked whether a gesture was present during a given statement by responding yes or no and describing the gesture if they remembered it being present (e.g., when she talked about the driver, did she gesture? If yes, please describe the gesture). All test questions were presented in the same order as in the video on a computer screen and participants were given unlimited time to type in their responses.

Coding. The responses during the retrieval phase were coded for accuracy of recall and number of traceable additions. For accuracy, participant responses were assigned a 1 if the response included the main idea of a statement regardless of exact wording and a 0 if not. For traceable additions, coders were given examples of possible traceable additions for each statement and assigned a 1 if the traceable addition was present and a 0 if not. Two independent coders had a Cronbach's alpha of .95 for evaluating recall and .65 for evaluating traceable additions. Disagreements between coders were resolved by a third coder deciding whether a 0 or 1 was most appropriate.

Participant responses describing gestures were also coded for accuracy. Coders were instructed to assign the description either a 1 or a 0 depending on how accurately the gesture was described. Participant descriptions earned a 1 if they either described what the gesture was of (e.g., she moved her hands to make it look like a car crash) or what the hand specifically did (e.g., she smashed her fist into her palm). Two independent coders had a Cronbach's alpha of .95 for evaluating the descriptions of gesture. Like the retrieval phase coding, a third coder evaluated disagreements and decided whether a 1 or 0 was the most appropriate code.

Results & Discussion

Retrieval Phase Performance. On average, participants correctly recalled the statements on .31 of the trials (SE = .03) during retrieval phase. Items that were associated with gesture (M = .39, SE = .05) were recalled significantly better than those that were not associated with gesture (M = .23, SE = .03), $t(39) = 3.62$, p = .001, d = .65. These findings support much of what has already been shown about gesture and memory - that speech associated with gesture is more recallable than speech alone. As for traceable additions, participants produced traceable additions on

.09 of the trails (SE = .02) which differed significantly from zero, *t*(39) = 4.30, *p* < .001, *d* = .68.

Gesture Recall Performance. For the final gesture test, participants' yes/no responses to whether they remembered gesture being paired with a given statement were used to calculate hit rates, false alarms, and from those d' scores to measure participants' sensitivity to gesture for retrieved and non-retrieved items. A summary of the hit rate and false alarm rate performance are presented in Table 1. When d' scores were analyzed, it was found that participants more accurately remembered whether gestures were associated with statements they retrieved (*M* = 1.06, *SE* = .15) than those they had not (*M* = 0.47, *SE* = .12), *t*(39) = 3.43, *p* = .001, *d* = .68.

Table 1

Hit and False Alarm Rates for Retrieved and Non-Retrieved Items

Measure	Retrieved	Non-Retrieved	*t*
Hit Rate	.61	.36	4.76***
	(.04)	(.04)	
False Alarm Rate	.22	.18	1.05
	(.03)	(.03)	

Note. Standard Error appear in parenthesis below the means. *** = p ≤ .001.

A similar pattern of results came from the follow-up question on the final gesture test that asked participants to describe the gestures they remembered. As shown in Figure 1, the proportion of gestures described accurately was higher for items they attempted to retrieve (*M* = .47, *SE* = .05) than those they did not (*M* = .24, *SE* = .03), $t(39) = 5.17$, $p < .001$, $d = .82$. Again, these results reflect how retrieval enhanced memory for gesture – not only in the recognition of cases when gesture was present but in memory for what the gestures themselves were. These results suggest that gestures are integrated in memory in such a way that prompts them to become coactivated during retrieval of speech, with such coactivation facilitating the recall of gesture information later.

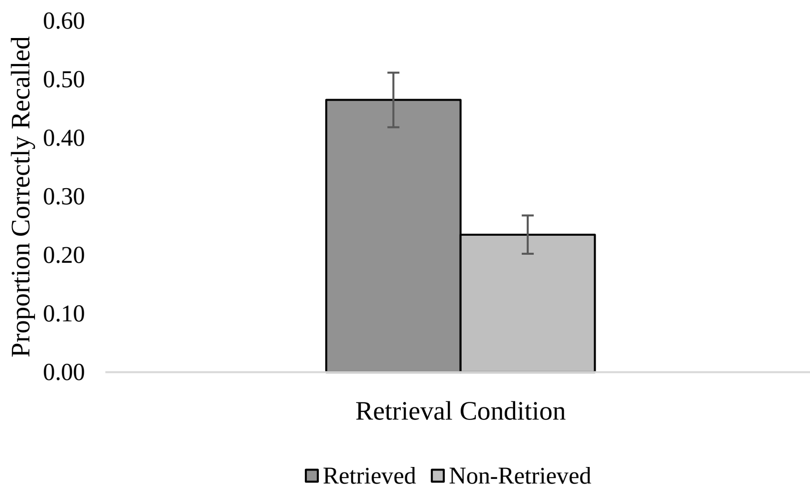


Figure 1. Proportion of gestures correctly recalled for retrieved and non-retrieved items.

Error bars represent standard error.

Experiment 2

The results of Experiment 1 are consistent with the idea that gesture and speech form an integrated representation in memory, and that retrieval of speech leads to the coactivation of gesture. One important consideration of the results in

Experiment 1 is the type of gestures used in the video stimuli and how they were related to speech. The type of gestures from Experiment 1 were meaningfully related to speech (that is, they represented information that was semantically associated with what was being said). According to the first entailment of the gesture speech integration hypothesis, it is predicted that such gestures emphasize the connection between gesture and speech at encoding and are thus more likely to become integrated with speech than gestures that are not meaningfully related to speech. During retrieval of speech, coactivation of gesture may prioritize gestures that complement speech as they can be useful in reconstructing speech, whereas gestures that do not represent any semantic meaning would be less likely to be coactivated. Further, top-down processes during the retrieval of speech may prioritize meaning in the reconstruction of a statement leading to greater coactivation of gestures that are associated with the message conveyed in speech than gestures that are not. In Experiment 2, the influence of the meaningful relationship between gesture and speech on coactivation during retrieval was examined by comparing different types of gesture paired with speech.

One way to distinguish between the relative meaningfulness of gestures is to make use of established types of gesture – specifically, representational and beat gestures. In Experiment 1, all gestures produced alongside speech can be classified as representational. Representational gestures are those which are semantically related to speech and spatially depict information about objects, actions, people, and events (McNeill, 1992). For example, the basketball and crash gestures in

Experiment 1 both depict actions like shooting a basketball and a car crashing into something. Representational gestures are meaningfully related to information conveyed in speech. Although representational gestures are arguably the most studied type of gesture, there is another type of gesture, beat gestures, which serves as a natural contrast.

Unlike representational gestures, beat gestures are not closely semantically related to speech but instead follow the rhythmic pattern of speech with hand movement (McNeill, 1992). Although beat gestures do not provide semantic information about speech, they do indicate to listeners what speech may be important and emphasize a speaker's main points (Biau & Soto-Faraco, 2013; McNeill, 1992). For example, in a lecture when a speaker pulses their hands up and down with the accent of their words the speaker is producing beat gestures. Representational gestures complement and add on meaning to speech, whereas beat gestures may highlight spoken information rather than elaborate on it (Kushch & Prieto, 2013).

Why may the meaning of gestures matter? Behavioral evidence of memory performance that addresses the type and relatedness of gesture to speech is mixed. Whereas some have argued that the beneficial effect of gesture for memory is reliant upon the meaning of the gestures themselves (Feyereisen, 2006), other evidence has shown that less meaningful (So et al., 2013), and unrelated hand movements (Straube et al 2014) can enhance memory. Feyereisen (2006) compared memory for spoken sentences with meaningful (representational) and non-meaningful (beat and unidentifiable) gestures and found that participants recalled more sentences having seen meaningful gestures. Although Feyereisen (2006) concluded that the meaningfulness of a gesture is key for when gesture enhances memory, So, Chen-Hui, and Wei-Shan (2012) found evidence that beat gestures do improve recall. So et al. (2012) compared recall of lists of words in children and adults when accompanied by representational gestures, beat gestures, or no gestures at all. While children showed only a beneficial effect of gesture on recall for representational gestures, adults' memory for words was enhanced by both representational and beat gestures. Although the debate about the relative effectiveness of beat and representational gestures on memory is ongoing, most agree that the two types of gesture convey different information about speech to the listener.

Another source of data that can disambiguate the difference between meaningful and non-meaningful gestures comes from neuroimaging research. Several fMRI studies confirm that audiovisual integration areas such as the posterior superior temporal sulcus (STSp) are involved in the processing of gesture and speech, but that only the right inferior frontal gyrus (IFG) is uniquely sensitive to the semantic meaning of gestures (Dick, Goldin-Meadow, Hasson, Skipper, & Small, 2009; Dick, Goldin-Meadow, Solodkin, & Small, 2012; Holle, Gunter, Ruschemeyer, Hennenlotter, & Iacoboni, 2010). Based on the findings above and others, Yang, Andric and Mathew (2015) propose that three networks are involved in gesture comprehension – action observation (a network including the STSp), conceptual processing (a network including the right IFG), and emotive processes. The distinction made by Yang, Andric, and Mathew (2015) between an action observation and conceptual processing network for gesture parallels the idea that different types of gestures are processed uniquely and may be remembered and coactivated differently based on their meaningful relation to speech.

In Experiment 2, representational gestures are taken to represent a case where gesture and speech are meaningfully related, whereas beat gestures as a case where there is less of a meaningful relationship. When compared using the same paradigm as Experiment 1, if gestures that are meaningfully related to speech are more likely to be integrated with speech at encoding and coactivated at retrieval, then there should be a greater retrieval benefit for memory of gesture for representational than beat gestures. However, if gesture and speech are integrated and coactivated irrespective of the meaningful relationship between the two, the retrieval benefit for memory of gesture should not differ between them.

Method

Participants. One hundred and twenty UCSC undergraduates participated for course credit. A power analysis was conducted using the mean difference and standard deviation of d' scores from Experiment 1 as well as the mean difference of the first 8 participants in the beat gesture condition. The analysis indicated that a sample size of 120 would be sufficient to detect a significant interaction between beat and representational gestures with an $\alpha = .05$ and $1 - \beta = .80$.

Materials and Procedure. The two videos created for Experiment 1 were used for the representational gesture stimuli in the present study. Additionally, two new videos were created with the same statements and order of statements but with beat gestures. For example, for the speech "My brother was at the gym," was accompanied by a beat gesture where the actress lifted one hand and casually bounced it on the words "brother" and "gym." The procedure was identical to that of Experiment 1 except for the added between-subjects condition of gesture type (beat vs. representational). The same coders from Experiment 1 coded participant responses during the retrieval phase for both beat and representational gestures for accuracy, and then traceable additions and descriptions of gesture during the final test for representational gestures only. For coding the accuracy of recall, the coders achieved a Cronbach's alpha of .93. For traceable additions their agreement was a .92, and for descriptions of gesture a .91. As in Experiment 1, all disagreements were evaluated by a third coder who decided on the most appropriate code for each response.

Results & Discussion

Retrieval Phase Performance. Overall, participants recalled statements correctly on .34 of trials (*SE* = .02). A 2 (Type of Gesture: Representation vs. Beat) x 2 (Type of Statement: Gesture vs. No Gesture) mixed-design ANOVA was run with type of gesture serving as a between-subjects factor. No significant main effects were observed, either with regard to type of gesture, $F(1, 118) = .08$, $p = .78$, $\eta_p^2 = .00$, or type of statement, $F(1, 118) = 1.64$, $p = .20$, $\eta_p^2 = .01$. A numerical interaction was observed but also not statistically significant, $F(1, 118) = 2.56$, $p = .11$, $\eta_p^2 = .02$. For participants in the beat gesture condition, performance was roughly similar with beat gestures (*M* = .34, *SE* = .03) as it was without (*M* = .35, *SE* = .03), $t(59) = .26$, *p*

= .80, *d* = 0.04. For participants in the representational condition, performance was at least numerically better with representational gestures (*M* = .38, *SE* = .04) than it was without (*M* = .29, *SE* = .03), $t(59) = 1.84$, $p = .07$, $d = 0.36$, with the direction of the effect replicating what was observed in Experiment 1 and in the literature at large. Traceable additions (analyzed in the representational gesture condition) were produced by participants on .10 of the trials (*SE* = .02), a rate which differed significantly from zero, $t(59) = 5.92$, $p < .001$, $d = .77$.

Gesture Recall Performance. Hit rates, false alarms, and d' scores were calculated as a function of type of gesture and retrieval condition. The d' data were analyzed using a 2 (Type of Gesture: Representation vs. Beat) x 2 (Retrieval Condition: Retrieved vs. Non-Retrieved) mixed-design ANOVA with type of gesture serving as a between-subjects factor. A summary of the hit rate and false alarm rate performance are presented in Table 2. Participants were significantly more accurate in remembering representational gestures (*M* = 1.07, *SE* = .08) than beat gestures (*M* = .22, *SE* = .08), $F(1, 118) = 64.51$, $p < .001$, ηp2 = .35. More importantly, participants were once again significantly more accurate in remembering whether the actor gestured for retrieved items (*M* = .75, *SE* = .08) than they were for non-retrieved items (*M* = .54, *SE* = .06), $F(1, 118) = 4.56$, $p = .03$, ηp2 = .04.

Table 2

Hit and False Alarm Rates for Retrieved and Non-Retrieved Items with Representational and Beat Gestures

	Representational Gestures		Beat Gestures	
Measure	Retrieved	Non-Retrieved	Retrieved	Non-Retrieved
Hit Rate	.63 (.03)	.44 (.03)	.35 (.03)	.27 (.03)
False Alarm Rate	.15 (.03)	.10 (.02)	.26 (.03)	.20 (.03)

Note. Standard Error appear in parenthesis below the means.

A significant interaction was not observed between retrieval condition and gesture type, $F(1, 118) = 2.36$, $p = .13$, ηp2 = .02. When representational gestures were analyzed separately, the results of Experiment 1 replicated, with participants performing significantly better for retrieved items than non-retrieved items, $t(59) = 2.75$, $p = .01$, $d = 0.36$. When beat gestures were analyzed separately, however, a significant difference was not observed, $t(59) = .40$, $p = .69$, $d = 0.11$. Making these conditions particularly difficult to compare, however, notwithstanding the non-significant interaction, was the sizeable difference in overall performance. Indeed, the lack of an effect in the beat condition could be attributable at least in part to the fact that performance was so close to floor with participants barely performing better than chance. Thus, even if a significant interaction had emerged it would have been difficult to interpret.

Finally, participants ability to accurately describe the gestures they remembered was analyzed. As can be seen in Figure 2, a significant interaction was observed between retrieval condition and gesture type, $F(1, 118) = 6.82$, $p = .01$, ηp2 = .06. Overall, participants accurately described significantly more gestures associated with statements for which they had tried to retrieve the speech portion of the statement ($M = .31$, $SE = .02$) than they did for those they did not ($M = .22$, $SE = .02$). Consistent with what was observed in Experiment 1, for representational gestures participants described significantly more gestures accurately for statements they retrieved ($M = .48$, $SE = .04$) than for those they did not ($M = .33$, $SE = .03$), t(59) = 3.58, p < .001, d = .46. For beat gestures, however, a significant difference between the proportion of gestures that were described correctly for retrieved ($M = .14$, $SE = .02$) and non-retrieved ($M = .11$, $SE = .02$) statements was not detected, $t(59) = 1.59$, $p = .12$, $d = .19$. Thus, attempting to retrieve the speech portions of the statements facilitated memory for the representational gestures that accompanied those statements, while such facilitation was not found for beat gestures.

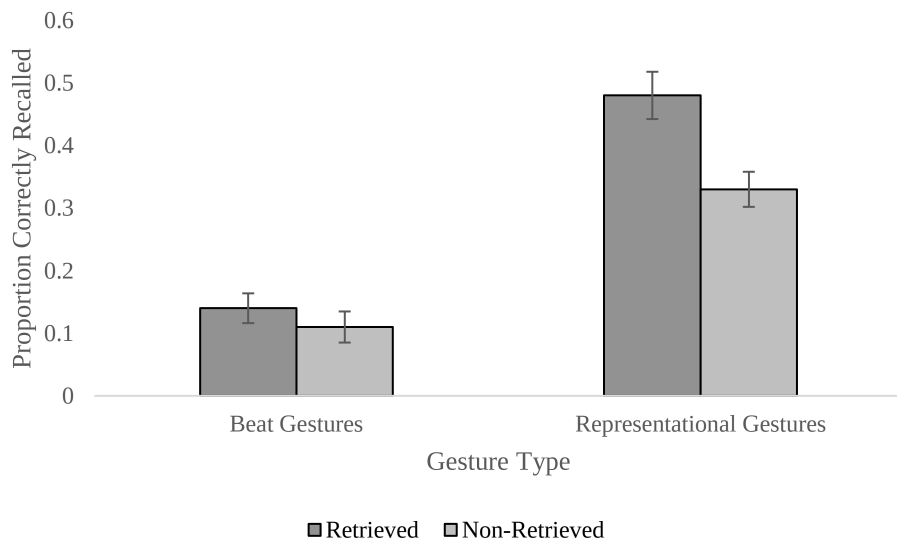


Figure 2. Proportion of representational and beat gestures correctly recalled for retrieved and non-retrieved items. Error bars represent standard error.

Experiment 3

In Experiment 2, the findings from Experiment 1 were replicated and the impact of retrieval on memory for a second type of gesture - beat gestures - was examined. The replication of Experiment 1 demonstrates that, at least in the case of representational gestures, retrieval enhances memory for gestures themselves. The interpretation of the beat gesture condition is more challenging. Although there was no significant interaction between the recognition of gestures for representational versus beat conditions, the numerical differences that show a larger benefit of retrieval for representational gestures than beat gestures is promising.

A potential issue with the use of beat gestures was a floor effect in their overall recallability. The recognition of beat gestures was significantly lower than that of representational gestures (d' scores for representational gestures were .85 higher than beat gestures). One reason for the lower rates recognition of beat gestures is that all the beat gestures were highly similar to each other. During the speech of the statement, the actress would raise one or two hands as she spoke the subject of the sentence, move them slightly to punctuate a few words, and then return them to rest. These gestures did not vary systematically as they were produced with the goal of seeming most natural. Another issue was merely the size of the beat gestures. Most beat gestures occurred in the lower third of the frame, whereas the representational gestures often took advantage of the whole field of view.

In Experiment 3, the potential limitations of beat gestures were addressed so that the meaningful relationship between gesture and speech could be examined more directly through the use of *nonsense* gestures. These gestures were artificially created to be large, distinctive, and thus designed in a way to be more memorable than beat gestures.

The rationale and hypotheses for Experiment 3 mirror those of Experiment 2. As proposed in this manuscript, the meaningful relationship between gesture and speech should emphasize their connection at encoding and result in integration in memory as well as coactivation during retrieval. If gestures that do not share a meaningful relationship with speech are less likely to be coactivated to the same extent during retrieval as gestures that do share a meaningful relationship with speech, then nonsense gestures should show a reduction of the retrieval benefit for gesture. However, if coactivation of gesture during retrieval of speech occurs irrespective of the relationship between gesture and speech, the retrieval benefit for nonsense gestures will be similar to the size of the benefit for representational gestures.

Method

Participants. Sixty UCSC undergraduates participated for partial course credit. A power analysis using the d' scores from Experiments 1 and 2 indicated that a sample size of 60 (thus matching Experiment 2) would be sufficient to detect a significant effect with a with $\alpha = .05$ and $1 - \beta = .80$.

Materials & Procedure. The procedure was identical to that of Experiments 1 and 2 but with the representational gestures replaced by nonsense gestures in the videos. Ten nonsense gestures were created to be of approximately the same size as the representational gestures used in Experiments 1 and 2 (as determined by the amount of space they occupied on the screen). Moreover, to make them more distinctive, the nonsense gestures were designed to each involve a unique handshape-movement combination, a factor which also made it possible to more reliably code gesture recall performance. The nonsense gestures were produced alongside speech as described in the introduction to Experiment 3. “My brother went to the gym,” for example, was accompanied by the nonsense gesture of both hands starting far apart with index fingers extended coming together to tap twice then separate. Counterbalancing ensured that all ten gestures were seen by each participant but paired with different statements.

Results & Discussion

Retrieval Phase Performance. Participants did not perform better on the spoken statement retrieval task when the statements were paired with gesture (*M* = .23, *SE* = .05) than when they were not (*M* = .26, *SE* = .03), *t*(59) = .86, *p* = .39, *d* = .13. This finding is not surprising given that the nonsense gestures were not designed to provide any additional meaning or connection to the speech.

Gesture Recall Performance. Unlike what was observed for representational gestures in Experiments 1 and 2, memory for nonsense gestures did not differ significantly as a function of whether participants attempted to retrieve (M = .60, SE = .13) or did not attempt to retrieve (M = .65, SE = .10) the speech portion of the statements, *t*(59) = .35, *p* = .73, *d* = .05. Hit rates and false alarms are available in Table 3.

Table 3

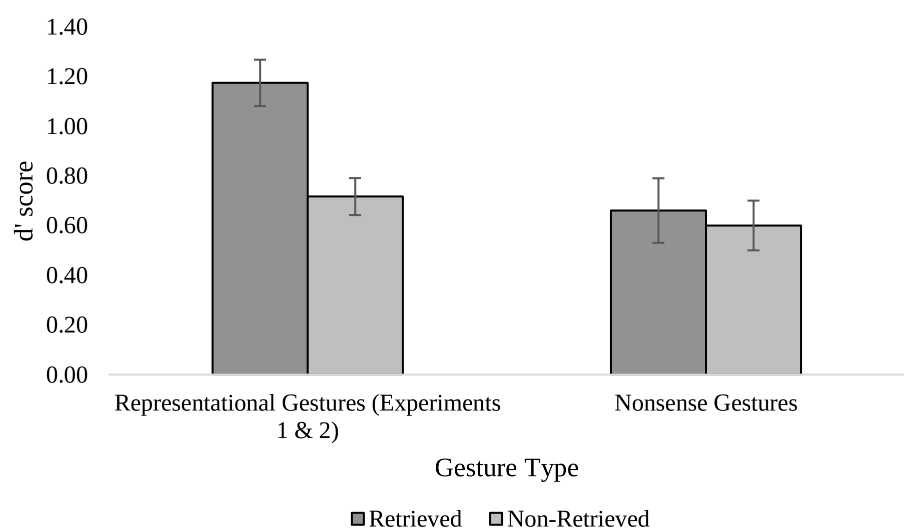
Hit and False Alarm Rates for Retrieved and Non-Retrieved Items

Measure	Retrieved	Non-Retrieved	*t*
Hit Rate	.56	.45	2.34*
	(.03)	(.03)	
False Alarm Rate	.33	.20	3.76***
	(.03)	(.02)	

Note. Standard Error appear in parenthesis below the means. * = p ≤ .05, *** = p ≤ .001.

Performance also failed to differ in terms of whether participants could describe the gestures they remembered, *t*(59) = 1.76, *p* = .08, *d* = .23. Specifically, the extent to which participants accurately described the gestures associated with retrieved items (*M* = .19, *SE* = .03) did not differ significantly from those of non-retrieved items (*M* = .13, *SE* = .02). It is interesting to note that there was a numerical difference, but a comparison with Experiments 1 and 2 (available in Figure 3) suggested that this difference was substantially smaller than that which was observed with representation gestures. As confirmed by a 2 (Type of Gesture: Representational vs. Nonsense) x 2 (Type of Item: Retrieved vs. Non-Retrieved) mixed-design ANOVA collapsing across data from all three experiments, a significant interaction was observed for both d' scores ($F(1, 158) = 8.00$, $p = .005$, $\eta_p^2 = .05$) and gesture recall ($F(1, 158) = 7.71$, $p = .01$, $\eta_p^2 = .05$). Although strong caution is encouraged when interpreting cross-experiment comparisons, these results offer at least some evidence to suggest that nonsense gestures may not be affected by the retrieval of speech in the same way that representational gestures are affected by the retrieval of speech.

a)



b)

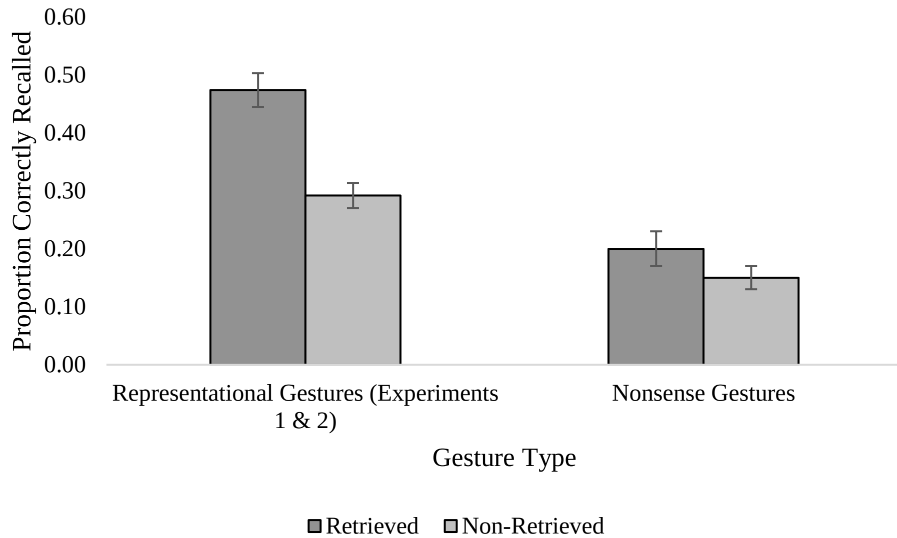


Figure 3. Performance on measures of memory for gesture for representational gestures in Experiments 1 & 2 and nonsense gestures in Experiment 3. Recognition test performance (d' scores) (a) and gesture recall (b). Error bars represent standard error.

Experiment 4

The results of Experiments 2 and 3 support the idea that the meaningful relationship between gesture and speech influences their integration as well as coactivation during retrieval. These experiments indicate that when gesture and speech share a meaningful relationship, they are more likely to be bound and thus coactivated during retrieval. Experiment 4 examined another dimension that could influence the integration of gesture and speech – redundancy.

Redundancy refers to the extent to which a gesture provides additional meaningful information to speech. In the previous experiments, all representational gestures were both meaningful and nonredundant (e.g., "The driver wasn't paying attention" with the car crash gesture). There are situations, however, where gestures can be more redundant with speech and provide less additional information (e.g., "The driver wasn't paying attention" with a steering wheel gesture). Integration of gesture and speech may be more likely if the gestures themselves provide additional, nonredundant, information that is essential for interpreting speech. This integrated nonredundant information may also be more likely to be drawn upon during retrieval of speech as it is a key part of understanding the spoken message. Unlike nonredundant gestures, redundant gestures do not share such properties and do not drastically alter the comprehension of speech so should not be expected to result in as much integration or coactivation during retrieval.

What is known about the impact of redundancy and gestures at present? In a recent meta-analysis on the communicative benefits of gesture, Hostetter (2011) examined the role of redundancy on comprehension and memory. Hostetter (2011) found that effect sizes for the benefit of gesture were substantially larger for nonredundant than redundant gestures. Although Hostetter (2011) admits that there is a lack of studies that directly compare redundant and nonredundant gestures (especially in the case of memory) these results show some promise that redundancy may be important for how gestures influence comprehension and memory.

Like the logic of the previous experiments, if gestures that are redundant with speech are not coactivated to the same extent as nonredundant gestures during retrieval, then the redundant representational gestures should show a reduction of the retrieval benefit for gesture. However, if coactivation of gesture during retrieval of speech occurs irrespective of the relative redundancy between gesture and speech, then a retrieval benefit for redundant representational gestures should be similar to the size of the benefit for nonredundant gestures.

Method

Participants. Sixty UCSC undergraduates participated for partial course credit. A power analysis using the d' scores from Experiments 1 and 2 indicated that a sample size of 60 (thus matching Experiment 2) would be sufficient to detect a significant effect with $\alpha = .05$ and $1 - \beta = .80$.

Materials & Procedure. A set of videos were created for Experiment 4 with the same statements as Experiments 1-3 but accompanied by redundant gestures. Redundant gestures were selected so that the gestures conveyed information that identified either the subject, object, or main action of a statement. For example, the statement "The driver wasn't paying attention," was produced with a hands-on steering wheel gesture to indicate driving. Other examples include the statement "My brother was at the gym" with a palm on the chest referring to "my" and "The teacher was looking for her supplies" with a hand at the brow to indicate "looking." Although all gestures convey some additional visuospatial information to speech, these redundant gestures were created to be as similar to the contents of speech as possible. The procedure was the same as Experiment 1 but with redundant gestures.

Results & Discussion

Retrieval Phase Performance. Participants recalled statements that had been paired with redundant gestures (*M* = .42, *SE* = .03) better than statements that were not paired with redundant gestures (*M* = .33, *SE* = .03), *t*(59) = 2.16, *p* = .04. These findings are consistent with the general finding that speech presented with gesture is more recallable than speech presented alone.

Gesture Recall Performance. Participants' yes/no responses to whether they remembered gesture being paired with a given statement were used to calculate hit rates, false alarms, and from those d' scores were calculated to measure participants' sensitivity to redundant gesture for retrieved and non-retrieved items. A summary of the hit rate and false alarm rate performance are presented in Table 4. When d' scores were analyzed, it was found that participants more accurately remembered that redundant gestures were associated with statements they retrieved (M = .98, SE = .10) than those they had not (M = 0.56, SE = .10), *t*(59) = 2.74, *p* = .008, d = .53.

Table 4

Hit and False Alarm Rates for Retrieved and Non-Retrieved Items

Measure	Retrieved	Non-Retrieved	*t*
Hit Rate	.55	.39	3.95***
	(.03)	(.03)	
False Alarm Rate	.18	.17	.195
	(.03)	(.03)	

Note. Standard Error appear in parenthesis below the means. *** = $p \leq .001$.

A similar pattern of results was found for participant descriptions of redundant gestures (Figure 4) where participants were more likely to accurately describe a gesture when having attempted to retrieve speech (M = .34, SE = .03), than when they did not make a retrieval attempt (M = .25, SE = .03), *t*(59) = 2.22, *p* = .03, d = .37.

Unlike the original prediction for Experiment 4, the results from the d' scores and gesture recall performance suggest the retrieval of speech enhances memory for redundant gestures. These findings indicate that redundant gestures also become coactivated during the retrieval of speech and may also be integrated with speech in memory.

Figure 4. Proportion of redundant gestures correctly recalled for retrieved and non-retrieved items. Error bars represent standard error.

Experiment 5

Experiment 4 examined the retrieval benefit for gesture in the context of redundant gestures. Results showed that participants more accurately remembered redundant gestures for statements they had previously retrieved than those they had not. These results suggest that even redundant gestures may be integrated with speech in memory and experience a similar coactivation and subsequent facilitation of recall to nonredundant gestures.

While these results are at odds with the original hypothesis, there are several reasons why they are not entirely surprising. First, while redundant gestures have been shown to be less robust in their influence of speech comprehension and memory, they still convey benefits to communication when compared to no gesture at all (Hostetter, 2011), albeit less than nonredundant gestures. Further, redundant gestures still share a meaningful relationship with speech which Experiments 2 and 3 demonstrated was important for the retrieval benefit for gesture. Finally, one can argue that no gesture is truly entirely redundant with speech as all convey some visuospatial information about the situation being described. Perhaps the gestures used in Experiment 4 were different enough from speech to still benefit from retrieval.

Experiment 5 was designed to further compare redundant and nonredundant representational gestures with two goals in mind. First, was to investigate the influence of repeated retrieval practice of speech on memory for nonredundant and redundant gestures. In all previous experiments, participants were given one opportunity to engage in retrieval of speech. However, there are reasons to believe repeated retrieval, or retrieval practice, of speech may lead to different memory representations for speech and gesture. In some cases, retrieval practice of some information can lead to better memory for that information in addition to other non-retrieved by related information (Anderson & McCulloch, 1999; Chan, 2009; Chan, McDermott, & Roediger, 2006; Cranney, Ahn, McKinnon, Morris, & Watts, 2009; Rowland & DeLosh, 2014). This phenomenon, known as retrieval-induced-facilitation (RIFA), highlights situations where retrieval practice not only benefits retrieved items, but non-retrieved items as well. In other cases, retrieval practice of some information from memory has a detrimental impact on other information in memory that shares associated cues (Anderson, Bjork, & Bjork, 1994). This phenomenon is known as retrieval-induced forgetting (RIF) and is an effect that has been demonstrated across a broad variety of materials and contexts (see Anderson, 2003 for a review). Across several studies that use the retrieval practice paradigm, researchers have observed RIF when items are either less semantically related or when instructions do not invite integration, and RIFA when items are chosen to be highly semantically related or instructions direct participants to integrate information (Anderson & McCulloch, 1999; Chan, 2009; Goodmon & Anderson, 2011). From this distinction, it can be inferred that when information is highly integrated in the underlying memory representation, resulting retrieval manipulations should cause RIFA.

When applied to gesture and speech, one possibility is that engaging in the repeated retrieval of speech may differentially influence the integration of gesture and speech in memory depending on the redundancy of the gestures. For nonredundant gestures, the gestures themselves add information to the contents of speech and thus may be coactivated during each retrieval, leading to the subsequent strengthening of memory for gesture. For redundant gestures however, the gestures do not add information to the contents of speech and multiple retrievals could encourage participants to rely more exclusively on their memory for speech since the gestures are nonessential for comprehending the meaning of speech. Repeated retrieval would then create a stronger association between cue (the retrieval practice question) and target (speech) while causing the forgetting of gesture. In this case, one would expect a diminished retrieval benefit for gesture when retrieval is repeated.

The second goal of Experiment 5 was to investigate whether the retrieval benefit for nonredundant gestures (as used in Experiments 1 and 2) and redundant gestures persist after a delay. It is possible that any retrieval benefit for gesture found thus far for redundant and nonredundant gestures is a product of the immediacy of the final gesture test after retrieval. Memory for gestures may be only temporarily enhanced after the retrieval, but their coactivation may be differentially reduced if a longer delay is included after the retrieval of speech. The inclusion of such a delay can demonstrate the extent to which the integration of gesture and speech in memory is maintained over time for different types of gesture.

Method

Participants. A power analysis determined that 128 participants were required to detect a medium effect size ($d = .5$) for the interaction between redundancy and repeated retrieval (0 vs 5) on the retrieval benefit for gesture with $\alpha = .05$ and $1 - \beta = .80$. A total of 138 participants were recruited from the UCSC subject pool to ensure even counterbalancing groups. Participants received partial course credit for their participation.

Materials & Procedure. The materials and procedure of Experiment 5 were similar to Experiment 2 with several critical changes. First, two new videos (a nonredundant gesture video and a redundant gesture video) were created for use in the encoding phase. These two videos both consisted of 24 statements, each of which was always paired with a representational gesture. This change from previous experiments allowed for more observations of a participant's ability to describe gesture, a measure which in previous studies was shown to demonstrate the same pattern of results as d' scores. In the nonredundant gesture video, the same 20 statements and nonredundant gestures used in previous experiments were used in addition to 4 new statements and gestures. In the redundant gesture video, the same 24 nonredundant gestures were used but the statements were altered such that the nonredundant gestures became redundant with speech. For example, the statement used in the representational gesture video "My brother went to the gym" was changed to "My brother was playing basketball" for the redundant gesture video and both videos used the same "shooting hoops" gesture. In keeping the gestures consistent across nonredundant and redundant conditions, memory for gesture could be more reliably compared as the gestures themselves could be scored as accurate in the same way across conditions.

Another change in Experiment 5 was the inclusion of multiple retrievals. In the retrieval phase, the 24 statements were divided equally into 3 retrieval conditions: No Retrieval, 1 Retrieval, and 5 Retrievals. Each cued-recall question was presented one at a time in a fixed order that matched the order of the statements in the video and required a response before the participant could continue to the next retrieval trial. The subset of 8 out of the 24 statements was assigned to each retrieval condition was counterbalanced across participants. After the retrieval phase, participants engaged in an idea generation task for 30 minutes before continuing to the final test phase.

The final test phase was altered to accommodate the new stimuli. Instead of being asked whether they remembered a gesture being present at all, participants in Experiment 5 were asked to describe the gesture for each statement (e.g., "Describe what she did with her hands when she talked about her brother.")

Results & Discussion

Retrieval Phase Performance. Performance on the retrieval phase was collapsed across all trials and examined between subjects. Participants who viewed speech with nonredundant gestures ($M = .35$, $SE = .03$) did not significantly differ in retrieval phase performance from participants who viewed speech paired with redundant gestures ($M = .40$, $SE = .02$), $t(136) = 1.717$, $p = .131$, $d = .29$. While some previous literature has suggested an advantage for nonredundant over redundant gestures for speech memory (Singer & Goldin-Meadow, 2005), the vast majority of research on gesture has not directly compared or specified the redundancy of gesture and speech and there are plenty of cases where presumably redundant gestures yielded an advantage over no gestures (Hostetter, 2011). Further, the speech being retrieved across the two conditions was slightly different (e.g., my brother went to the gym vs my brother played basketball) which led to different scoring of the retrieval practice phase across conditions. It is possible that a benefit for either nonredundant or redundant gesture was overshadowed by the relative memorability of the different speech recalled in each condition.

Gesture Recall Performance. Two independent raters coded participants' descriptions of gestures for accuracy achieving a Cronbach's alpha of .95. A third rater resolved all disagreements. These data were analyzed using a 2 (Type of Gesture: Nonredundant vs. Redundant) x 2 (Retrieval Condition: 5 Retrievals Vs. 1 Retrieval vs. 0 Retrievals) mixed-design ANOVA with type of gesture serving as a between-subjects factor. A significant main effect of retrieval condition was observed, $F(2, 137) = 21.97$, $p < .001$, ηp2 = .243 with participants recalling gestures more accurately for statements they had previously retrieved. While all previous experiments showed a retrieval benefit for gesture at an immediate test, the present results demonstrate that such a benefit persists over a 30-minute delay. This suggests that the binding of gesture and speech through retrieval occurs immediately and can be maintained over time.

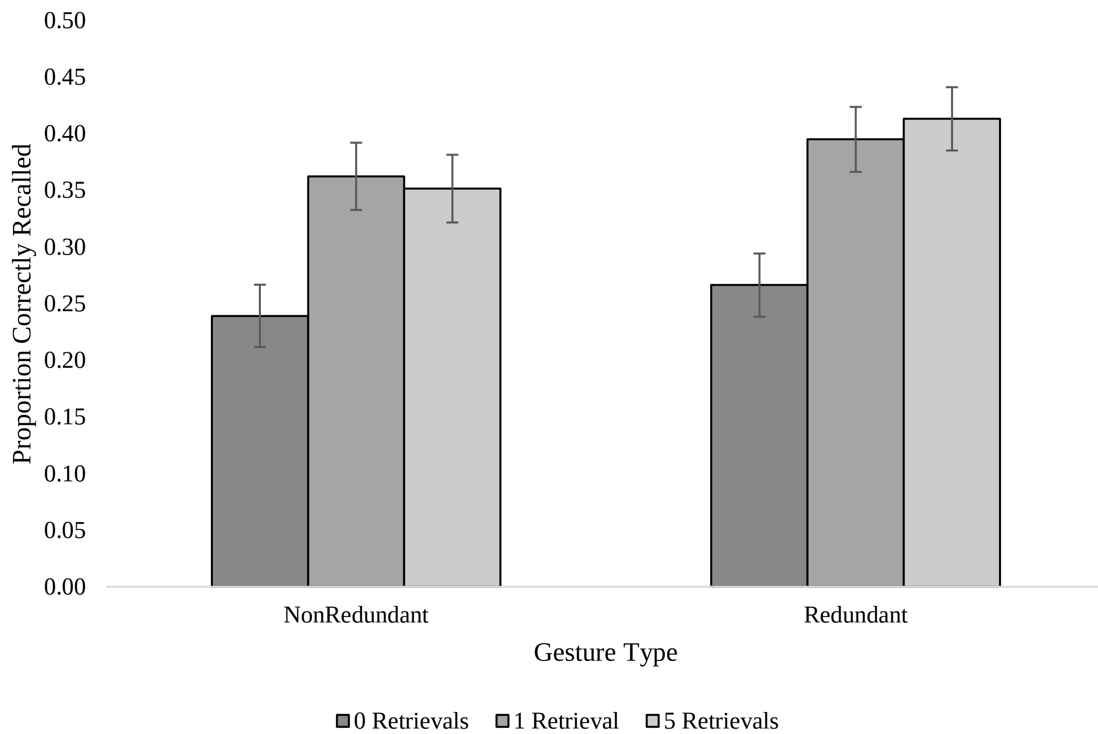


Figure 5. Proportion of gestures correctly recalled for nonredundant and redundant gestures at 0, 1, and 5 retrievals. Error bars represent standard error.

As visualized in Figure 5, follow-up paired samples t-tests showed that memory for gestures for speech that was retrieved 5 times (M = .39, SE = .02) and 1 time (M = .38, SE = .02) significantly differed from speech that was not retrieved at all (M = .26, SE = .02), $t(139) = 5.997$, $p < .001$, d = .54 and $t(139) = 5.872$, $p < .001$, d = .51 respectively. The findings from the single retrieval provide another replication of the retrieval benefit for gesture. All together however the results were unable to detect a difference between gesture recall for items with single and multiple retrievals, thus failing to provide evidence that multiple retrievals cause the forgetting of gesture.

There was no significant main effect of type of gesture ($F(1, 138) = 2.106$, p = .149, $\eta p2 = .015$) and no interaction between type of gesture and retrieval condition $F(2, 137) = .433$, $p = .650$, $\eta p2 = .006$. Contrary to initial predictions, these results failed to detect a difference between redundant and nonredundant gestures for gesture recall in any and all retrieval conditions.

Experiment 6

The results of Experiments 1-5 provided evidence of a retrieval benefit for gesture and explored how this benefit is tied to the relationship between gesture and speech in terms of meaningfulness and redundancy. One caveat regarding the results of Experiment 5 is that participants in the redundant condition may have relied on their memory for speech to guess what gestures were paired with speech. According to the gesture speech integration hypothesis, the retrieval of speech and coactivation of gesture is episodic and relies on visual imagery. If participants in the redundant condition for Experiment 5 were merely inferring the correct gesture from their memory of speech, the resulting retrieval benefit for gesture would not be the result of an episodic reactivation of gesture and speech but instead guessing based on the meaning of speech.

In Experiment 6, the type of processes involved in the retrieval of speech was explored further. It is possible that the coactivation of gesture during retrieval of speech is primarily episodic, and when individuals attempt to recall speech they re-experience both speech and gesture as a form of "mental time travel" (Schacter & Addis, 2007; Studdendorf & Corballis, 1997; Tulving, 2002). If the retrieval benefit for gesture is due to the explicit and automatic coactivation of gesture during episodic retrieval of speech, then the extent to which retrieval is episodic should moderate the size of the effect. Alternatively, it is possible that coactivation of gesture during retrieval of speech is implicit and does not rely on explicit episodic reactivation. In this case, the benefit of retrieval for gesture should be observed regardless of how episodic that retrieval is.

Coactivation of gesture and speech during episodic retrieval can be understood in terms of a theory of retrieval-based learning, the Episodic Context Account (ECA). The ECA explains that during retrieval, an individual uses cues from the environment and episodic memory to reinstate the learning context to guide memory search (Karpicke, Lehman, & Aue, 2014). According to this theory, if a participant is studying word pairs like "shirt – pants" and is given a cued-recall test of "shirt – ?" they retrieve the episodic context of when the word-pair was first presented (e.g., the room they were in, how the word-pair was presented, what color the word-pair was in) to facilitate the search for the target "pants." During subsequent retrievals, both the episodic context at encoding and retrieval come to mind – further refining the search process. According to ECA, memory representations include information about the episodic context of an event and with each retrieval comes the inclusion of additional episodic information. Much as the ECA predicts that episodic context is retrieved alongside the target of retrieval, the present experiment tested whether gestures are coactivated as part of a conscious episodic reinstatement of speech.

One way to examine the extent to which episodic retrieval is responsible for the retrieval benefit for gesture is to draw upon techniques that allow for metacognitive evaluations of one's own memory such as Remember/Know judgements. As developed by Tulving (1985), Remember/Know judgements have been used as a way to identify episodic memories based on a participant's evaluation of their retrieval. Remember judgements are considered to indicate an episodic trace as they are often accompanied with the ability to retrieve more episodic details than Know judgments (Dudukovic & Knowlton, 2006). In Experiment 6, a variation of Remember/Know judgements were added to the retrieval phase of the experiment to evaluate whether participants reexperienced statements similar to when they were first presented with them (i.e., episodically and visually). These evaluations were used to examine the relationship between episodic retrieval and the size of the retrieval benefit for gesture.

Some reasons to expect a relationship between gesture and speech in episodic memory come from research on using gestures themselves as cues to memory (Woodall & Folger; 1981; Woodall & Folger, 1985). For example, Woodall and Folger (1985) demonstrated that videos of gestures without audio could cue memory for speech. In their study participants watched a video of two people having a conversation while either producing emphasizing gestures, emblematic gestures, or no gestures. After a brief distractor task, participants were cued with muted video of the conversation to recall speech and were better able to recall speech when the video contained gestures than when it did not. In a second experiment, this effect was shown to persist for one week after original viewing of the video. The ability to recognize gestures as well as the ability for gesture to cue further episodic recollection indicates that information about gestures themselves may be stored episodically.

In the present experiment, if statements that are judged to be more episodically retrieved during the retrieval phase show a greater retrieval benefit for gesture, then coactivation of gesture may be linked to episodic retrieval processes. Alternatively, if the episodic judgements of retrieval do not systematically vary with the retrieval benefit for gesture, then the coactivation of gesture may be a more implicit process that does not draw on episodic reinstatement.

Method

Participants. Ninety-Six participants were recruited to satisfy a power analysis to detect a small correlation (Pearson's = .3) with $\alpha = .05$ and $1 - \beta = .85$. Participants received partial course credit for their participation.

Materials & Procedure. Materials and procedure were the same as the nonredundant gestures in Experiment 5 with two additions. First, a metacognitive follow-up question was added to the retrieval phase in order to evaluate the extent of episodic reinstatement and use of imagery during retrieval. After answering each cued-recall question, participants answered the follow-up question, "To what extent did you visually re-experience the statement when you answered the question?" on a scale of 1-7. The follow-up question and scale were explained at the beginning of the retrieval phase. Participants were told, "If when you answered the question about what was said you clearly and vividly pictured the woman in your mind as she said the statement you would provide a rating of 7. If instead, you did not picture the woman at all but just know what she said you would provide a rating of a 1."

The second addition was the inclusion of the Vividness of Mental Imagery Questionnaire (VVIQ) after completing the final test phase of the experiment (Marks, 1973). Participants completed the full VVIQ twice, once with eyes open and once with eyes shut. The VVIQ served as a measure of a participant's individual imagery ability to see if general imagery ability correlates with the retrieval benefit for gesture.

Results & Discussion

Retrieval Phase Performance. Participants recalled statements correctly on .45 (*SE* = .02) of trials. Participants also produced traceable additions on .05 (*SE* = .01) of trials. Participants also reported an average episodic judgement score of 3.93 (*SE* = .13).

VVIQ Scores. Participants completed the VVIQ with eyes opened and closed. A composite score from the averages of both the open and closed eyes VVIQ showed participants had an average VVIQ of 2.17 (SE = .06), with a minimum score of 1.09 and maximum of 4.28.

Gesture Recall Performance. Participants more accurately described gestures for statements they had attempted to retrieve (M = .50, SE = .02) than for those they had not (M = .36, SE = .02), $t(89) = 7.014$, $p < .001$, $d = .68$. These results replicated the findings present in previous experiments.

A summary of Pearson's correlations for episodic judgement scores, VVIQ composite, and gesture recall are available in Table 5. Most relevant for the goals of the present study, a significant correlation ($r(89) = .37$, $p < .01$) was found between the retrieval benefit for gesture and episodic judgement scores, suggesting that participants who evaluated their retrieval as more vivid and clear experienced a larger retrieval benefit for gesture. Interestingly, there was almost no correlation detected ($r(89) = -.04$, $p = .74$)) between the retrieval benefit for gesture and VVIQ scores. This suggests that the relationship between the retrieval benefit for gesture and episodic imagery may be constrained to a particular episode of retrieval and not general imagery ability.

To further explore the episodic judgement scores, participants were rank ordered by their average episodic judgement score to create two groups of participants, those who had episodic judgements scores higher than the median (M = 4.98; N = 42), and those who had episodic judgement scores lower than the median (M = 2.94; N = 44). Participants who reported a higher episodic judgement score showed a larger retrieval benefit for gesture (M = .22, SE = .02) than who had lower episodic judgement scores (M = .08, SE = .02), $t(85) = 6.951$, p < .001, d = .71.

Table 5

Means, standard error, and Pearson Correlation matrix

	M	SE	1	2	3	4
1. Episodic Judgement	3.93	.13	-			

2. VVIQ Composite Score	2.17	.07	-.04	-		
3. Gesture Recall (Retrieved)	.52	.02	.77**	-.14	-	
4. Gesture Recall (Non-Retrieved)	.36	.02	.49**	-.12	.55**	-
5. Gesture Recall (Effect)	.15	.02	.37**	-.04	.57**	-.38**

Note. ** = $p < .01$

Chapter IV

General Discussion

The goal of this dissertation was to examine the integration of gesture and speech in memory and to evaluate several entailments of a hypothesis about their integration. First, it investigated whether gesture and speech form an integrated representation in memory. Second, it evaluated how the relationship between gesture and speech (in terms of meaningfulness and redundancy) impacted gesture speech integration. Finally, it explored how the retrieval of speech and coactivation of gesture was related to episodic memory and visual imagery.

Together, all six experiments of the dissertation help to illustrate how and when gesture and speech form an integrated representation in memory. Experiment 1 first established a retrieval benefit for gesture, one which suggested that gesture and speech do form an integrated representation in memory. This representation is such that retrieval of speech leads to the coactivation of information about gesture. After observing this phenomena, Experiment 2 provided both a replication of the retrieval benefit for representational gestures and attempted to examine how less meaningfully related gestures, beat gestures, were influenced by retrieval. Experiment 3 further clarified the role of meaningfulness through the utilization of nonsense gestures and demonstrated that the retrieval benefit for gesture (and therefore, integration of gesture and speech) is less, if at all, present for nonsense gestures. In Experiment 4 the redundancy aspect of the hypothesis was examined, and it was found that memory for redundant gestures was enhanced after the retrieval of speech. These results on redundancy, conceptually replicated in Experiment 5, suggest that unlike the hypothesis predicted, redundant gestures are also coactivated during the retrieval of speech and integrated with speech in memory. Experiment 5 also demonstrated that the retrieval benefit for gesture persists after a delay and becomes established for both redundant and nonredundant gestures after one retrieval. Further, Experiment 5 showed that repeated retrieval of speech did not lead to the forgetting of gesture, meaning that each retrieval consisted of a coactivation of speech and gesture. Finally, findings from Experiment 6 showed that more episodically experienced retrieval of speech is associated with a stronger retrieval benefit for gesture. This suggests that the coactivation of gesture and speech is episodic and multimodal.

Collapsing across gesture recall performance for all the experiments reported in this dissertation (n = 508), the retrieval benefit appears to be a robust effect with an average mean difference of .12 (SE = .01), 95% CI [.09, .14]. Two follow-up analyses examined the moderating effect of meaningfulness and redundancy. The meaningfulness analysis compared mean differences from Experiment 1, the representational gestures from Experiment 2, Experiments 4, 5, and 6 to the beat gestures from Experiment 2 and nonsense gestures from Experiment 3 and found a significant mean difference of .10 (SE = .02), $t(507) = 4.9$, $p < .001$, 95% CI [.06, .14]. These results suggest that meaningfulness is a significant moderator of the retrieval benefit for gesture, providing further support that a critical component of gesture speech integration is the meaningful relationship between gesture and speech. In the redundancy analysis the mean differences from Experiments, 1, 2, 3, 6, and the nonredundant gestures from Experiment 5 were compared with the mean differences in Experiment 4 and the redundant gestures of Experiment 5. Results found a nonsignificant mean difference of .003 (SE = .03), $t(507) = 0.01$, $p = .92$, 95% CI [-.05, .06]. These results suggest that redundancy is not a significant moderator of the retrieval benefit for gesture, providing further support that both redundant and nonredundant gestures have similar levels of integration with speech.

Another factor, while not part of the original hypothesis but interesting to examine across studies, is the role of retrieval success in mediating the retrieval benefit for gesture. A simple linear regression was calculated to predict the average retrieval benefit for gesture for gesture recall based on recall accuracy for speech that was paired with gesture. A significant regression equation was found ($F(1,506) = 82.368$, $p < .001$), with an R^2 of .140. Participants' retrieval benefit for gesture increased .375 for each unit of recall accuracy. These results indicate that successful retrieval of speech is an important factor for subsequent enhancement in memory for gesture. One possibility is that gesture is most strongly coactivated during the retrieval of speech when that retrieval is successful and accurate. That is, during the retrieval of speech items where participants accurately recall information from speech (whether by immediately recalling gesture and speech simultaneously or recalling either gesture and speech and subsequently coactivating the other) are more likely to coactivate gestural information and show a larger retrieval benefit for gesture for those items. As it appears that retrieval success is an important part of the retrieval benefit for gesture, it may be interesting for future work to explore whether retrieval is in fact a necessary condition for the retrieval benefit for gesture and whether re-exposure to gestural information affects memory differently.

Several alternative interpretations should be noted in the interpretation of the body of work in this dissertation. First, the gestures used in all the experiments (representational, beat, nonsense) likely differed from each other in many ways other than their inherent meaningfulness and redundancy (e.g., distinctiveness, concreteness, size, conventionality, etc.), and it is possible that such differences contributed to the effects that were observed. Second, as alluded to in Experiment 5, it is possible that the gestures were not coactivated or strengthened as a result of retrieval, but that participants were simply better able to take advantage of the strengthened speech information to recover the associated gesture information. In other words, retrieving speech might have strengthened speech information, thereby allowing participants to use that speech information to retrieve or infer the gesture information. Although this possibility cannot be ruled out completely, it seems unlikely for the case of nonredundant representational gestures. For nonredundant gestures, the gestures themselves were selected so that they would convey information in gesture that was not available from speech alone. Thus, retrieving the speech would not have been sufficient to help people remember the gesture. Second, although participants did commit traceable additions in which they erroneously reported hearing speech consistent with the gestures (e.g., Kelley et al., 1999), the rate of traceable additions was fairly low (M = .09 in Experiment 1 and M = .10 in

Experiment 2) and would likely not account for the differences in retrieved and non-retrieved statements observed in the retrieval benefit for gesture

The present work suggests a number of implications for theories of gesture and the relationship between gesture and memory. For one, it provides empirical support for the claim that speech encoded with gesture forms a more distributed and easily accessible memory representation. If gesture and speech are both integrated and encoded in memory, then the two are both entry points for retrieval and provide a greater chance to reconstruct the memory when compared to speech alone. Second, the findings speak to how gesture might act to modify memory. As discussed in the introduction, if speech and gesture are coactivated during retrieval, for example, then such dynamics could explain the phenomenon of traceable additions. Finally, the present findings parallel theories of gesture processing which emphasize the integration of verbal information with visuospatial and motor information during speech production (e.g., The Information Packaging Hypothesis, Kita, 2000; Gesture as Simulated Action Framework, Hostetter & Alibali, 2008). It appears that gesture and speech form an integrated representation of information when produced as well as when comprehended and remembered.

These findings also complement current theoretical explanations of the Enactment Effect, most notably the episodic integration theory (Korminouri and Nilsson, 2001). According to the episodic integration theory, individuals retain action phrases that are acted out better than those that are merely read or listened to because motor actions promotes episodic integration in two ways: integration between the person performing the task and the environment and integration of items in an action. Korminouri and Nilsson (2001) explain that performing motor actions during encoding helps to "glue" components of an action into a single memory unit. For example, for the action phrase "shake the bottle" performing a shake motion on a bottle results in the specific binding of "shake" and "bottle" in episodic memory. Similarly, the results from the present dissertation suggest that observing gesture and speech together during encoding result in a binding between information in speech and gesture. The motor information available in gesture may facilitate memory for speech by integrating the actor of a statement with an action (such as "my brother" and "went to the gym") with a motor action in gesture. Taken together, both the integration theory of the enactment effect and findings of this dissertation suggest that motor actions (performed or observed in the case of gesture) may promote the integration of multiple units of information in memory and consequently enhance memory for phrases when compared to phrases presented without motor information.

The gestures that co-occur with speech enhance and modify memory for speech. The present dissertation has begun to account for such effects by establishing how and when gesture and speech are integrated in memory. The hypothesis that gesture and speech are most effectively integrated in memory when gestures themselves are meaningfully related to and nonredundant with speech – and that this integration leads to episodic coactivation of gestural information during retrieval of speech was found to partially describe the findings reported throughout the dissertation. Critically, it appears the meaningful relationship between gesture and speech is a key factor in the integration of gesture and speech in memory, while the relative redundancy of gesture and speech has little effect on their coactivation during retrieval of speech and integration. In addition, the retrieval benefit for gesture related to participants' self-reported episodic experience suggesting that the coactivation of gesture and speech during retrieval may be episodic. These findings provide a starting point for future research on gesture and memory, suggesting a nuanced approach that explores the boundaries of the benefits of gesture.

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Appendix A

Table of statements and representational gestures for Experiments 1, 2, & 6

Speech	Gesture
It’s bad in that room	Wave hand in front of face
She told her best friend the story	Talking on phone
The weightlifter was out of shape	Round belly
My brother went to the gym	Shooting basketball
The church is that way	Hand forward and to the left
The stockbroker was up late last night at the restaurant	Drinking gesture
The lawyer got ready for work	Combing hair gesture (Exp 1 & 2) Brushing teeth gesture (Exp 6)
The camper caught a fish	Hands wide to indicate size
The cook went outside	Smoking cigarette gesture
The carpenter was working in the garage	Hammering gesture
The photographer was really annoying	One hand mimicking talking
The farmer sold a pig	Mimicking holding a big pig
The artist was working in the studio	Sculpting gesture
The child wasn't feeling very well	Rubbing stomach
My sister was playing a game	Using a videogame controller
My cousin went to the kitchen	Grabbing a cup gesture
The teacher was looking for her supplies	Scissor gesture
The weather wasn't great today	Fanning oneself with hand
My aunt sent me a present	Holding wrist
The driver wasn't paying attention	Hands crash into each other