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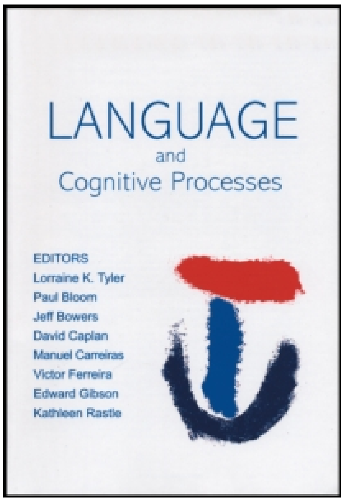

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Brief training with co-speech gesture lends a hand to word learning in a foreign language

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Brief training with co-speech gesture lends a hand to word learning in a foreign language

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Recent research in psychology and neuroscience has demonstrated that co-speech gestures are semantically integrated with speech during language comprehension and development. The present study explored whether gestures also play a role in language learning in adults. In Experiment 1, we exposed adults to a brief training session presenting novel Japanese verbs with and without hand gestures. Three sets of memory tests (at five minutes, two days and one week) showed that the greatest word learning occurred when gestures conveyed redundant imagistic information to speech. Experiment 2 was a preliminary investigation into possible neural correlates for such learning. We exposed participants to similar training sessions over three days and then measured event-related potentials (ERPs) to words learned with and without co-speech gestures. The main finding was that words learned with gesture produced a larger Late Positive Complex (indexing recollection) in bi-lateral parietal sites than words learned without gesture. However, there was no significant difference between the two conditions for the N400 component (indexing familiarity). The results have implications for pedagogical practices in foreign language instruction and theories of gesture-speech integration.

Keywords: Embodiment; Event-related potentials; Gesture; Familiarity; Recollection.

Learning words is one of the major challenges in acquiring a foreign language. At the heart of this difficulty is that words are arbitrary and bear no inherent relationship to their referents (Quine, 1960). For example, the English verb 'drink' and the Japanese word 'nomu' both refer to the same action, but there is no surface relationship between the two words, and certainly nothing in speech to connect either word to the concept of drinking. The present study

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offers a hand in simplifying this problem by exploring the role that information *not contained* in speech plays in connecting novel words to concepts. Specifically, it investigates how co-speech hand gestures help people learn and remember the meaning of words in a new language.

Iconic gestures are a natural and prevalent part of spoken language, but they are different from speech in that they are not arbitrary, and instead convey information that visually represents the concepts to which they refer (McNeill, 1992). For example, by forming a 'c-shaped' hand gesture and producing an upward arcing motion to the lips, a speaker (gesturer) can visually and non-arbitrarily capture the image of drinking, in this case, from a glass. So although there is nothing inherent in the word 'nomu' that relates to the idea of drinking, an accompanying iconic gesture can immediately and unambiguously connect the new word to the familiar action of drinking. In this way, iconic gesture is a form of embodied information that 'grounds' the meaning of language in physical representations of actions and objects (and perhaps even abstract concepts) that are contained in a speaker's mind (Barsalou, 2008; Glenberg & Kaschak, 2003).

Given the embodied nature of these co-speech gestures, researchers have argued that they play a significant role in language comprehension and development. Indeed, nonverbal actions, in general, are perfectly suited tools for helping infants to overcome the obstacle of linguistic arbitrariness during the earliest stages of language acquisition (Baldwin, 1991; Tomasello, 1998; Yu, Ballard, & Aslin, 2005). For example, Baldwin (1991) demonstrated that infants as young as 16 months old use a speaker's eye gaze to help indexically ground the meaning of new words to novel objects. Focusing on hand gestures, Morford and Goldin-Meadow (1992) demonstrated that 16-month-olds also use pointing and iconic gestures to help them understand an adult's meaning at early stages of vocabulary development.

Even after childhood, gestures continue to help ground meaning in adult language comprehension (Beattie & Shovelton, 1999; Cassell, McNeill, & McCullough, 1999; Feyereisen, 2006; Goldin-Meadow, 2003; Kelly, Barr, Church, & Lynch, 1999). For example, Kelly et al. (1999) demonstrated that adults understood more detailed information from an utterance when speakers produced iconic gestures with their speech (e.g., making a typing gesture and saying, 'He wrote to his friend.'). This additional clarifying information makes gestures well suited for the classroom – indeed, Singer and Goldin-Meadow (2005) demonstrated that iconic gestures help teachers make better assessments of children's knowledge of concepts.

This behavioural research suggests that humans may be optimally designed to use gesture to ground language to meaning (Barsalou, 2008; Bates & Dick, 2002; Kelly, Iverson, Terranova, Niego, Hopkins, & Goldsmith, 2002). This possibility has received support from neuroscientists who have identified overlapping neural mechanisms for the processing of speech

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and hand actions (Nishitani, Schürmann, Amunts, & Hari, 2005), and who have hypothesised that spoken language systems evolved from gestured systems in our evolutionary past (Corballis, 2002; Rizzolatti & Arbib, 1998). Focusing specifically on iconic hand gestures, cognitive neuroscientists have recently demonstrated that gesture is tightly integrated with the meaning of speech during language comprehension (Holle & Gunter, 2007; Kelly, Kravitz, & Hopkins, 2004; Ozyürek, Willems, Kita, & Hagoort, 2007; Skipper, Goldin-Meadow, Nusbaum, & Small, 2007; Willems, Özyürek, & Hagoort, 2007; Wu & Coulson, 2007). For example, Willems et al. (2007) used a functional imaging technique (fMRI) to show that Broca's area processes gestural and spoken information in a similar fashion during sentence comprehension, suggesting a common neural mechanism for processing the two modalities.

The present study builds on this research in psychology and neuroscience by exploring the role that iconic gestures play in learning words in a foreign language. Experiment 1 employs a behavioural paradigm and investigates the role that iconic gestures play in learning Japanese verbs. Experiment 2 is an exploratory and preliminary study that uses a cognitive neuroscience methodology (event-related potentials) to uncover a possible neural correlate of such learning. In both experiments, we hypothesise that co-speech gestures facilitate word vocabulary learning by linking words in one's native language and words in a foreign language through rich and non-arbitrary embodied meanings.

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EXPERIMENT 1

Mastering multiple languages has become more important in an increasingly globalised world, and it not surprising that researchers have begun to seriously consider the role that nonverbal actions, such as hand gesture, play in foreign language learning.[1] In a stirring call to action for more research on this important topic, Gullberg (2006) outlined several reasons why hand gestures may be a crucial tool in learning and mastering a new language. Most relevant to the present study is the argument that visually rich gestures, such as iconic gestures, may serve as useful input to learners of a second language during comprehension and learning.

[1] It should be noted that there is a long tradition of using the body as a tool for second language instruction and learning, such as the Total Physical Response (TPR) technique introduced by Asher (1969). The present research is different from the TPR approach because it does not rely on the whole body, but rather takes advantage of naturally occurring hand movements that accompany speech. Most importantly, because gestures are non-arbitrary, it does not require any special training for the learner or instructor.

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Although researchers have long claimed that gestures enhance second language instruction and learning (Moskowitz, 1976), there is a surprising paucity of experimental work investigating this issue (Quinn-Allen, 1995; Sueyoshi & Hardison, 2005). In one of the few controlled experiments on the role of hand gesture in learning a foreign language, Quinn-Allen (1995) found that native English speakers who listened to novel French expressions while simultaneously viewing and producing emblematic gestures – hand movements that are culturally determined and conventionalised, such as wiping the forehead with the back of the hand to indicate a 'close call' – were able to learn and retain the new expressions better than participants who did not view and produce the gestures. This study is an excellent start in empirically demonstrating the influence of gesture in second language learning, but clearly, many issues remain and much more work is needed in this important area.

The present experiment, which instructs native English speaking adults on novel Japanese words using different combinations of gesture and speech, extends this previous research in four ways. First, it explores the impact of more iconic (versus purely emblematic) gestures on vocabulary learning. Second, it investigates vocabulary learning by having people view, but not simultaneously produce, gesture with speech. Third, it tests memory for newly learned words without using gestures as part of the assessment battery (as in the Quinn-Allen study). And finally, and most importantly, it investigates whether gestures enhance learning because of the simultaneous semantic overlap of speech and gesture or their ability to simply capture attention.

Following up on this final point, the experiment made two predictions: (1) co-speech gestures will enhance learning because of their semantic content, not their ability to capture attention, and (2) simultaneously distributing information through gesture and speech will produce better learning than presenting the same amount of information through speech alone.

Method

Participants. Twenty-eight right-handed adults (mean age 18.5 years, 18 females and 10 males) participated in the experiment. Participants were recruited from an Introduction to Psychology class and received research credit. No participant had prior knowledge of the Japanese language. One participant was excluded because of a violation of the training protocol.

Materials and procedure. The training materials comprised of 12 Japanese verbs conveying common, everyday meanings (see Appendix A). Because some words were nouns and verbs (e.g., hammer) participants were told that they should think of the words as describing the action, not the object. The training was very simple, with the instructor introducing the verb, and then defining it twice: 'The next word is, nomu. Nomu means drink. Nomu means drink.' The words were presented in blocks of three according to four within-subjects conditions: Speech (S), Speech + Congruent Gesture (S + CG), Speech + Incongruent Gesture (S + IG) and Repeated Speech (RS). In the Speech condition, the instructor said the words while keeping her hands at her side. In the S + CG condition, the instructor produced congruent iconic gestures with the Japanese word and English translation, whereas in the S + IG condition, she produced incongruent iconic gestures. The purpose of these two conditions was to test Prediction 1 by determining whether gestures enhance learning because of the semantic overlap between speech and gesture or whether hand movements – regardless of content – might draw more attention to the words.[2] Lastly, the Repeated Speech condition was the same as the Speech condition, but the training was repeated. Note that the RS condition contained the same amount of information as the S + CG, with the only difference being that the information was distributed in parallel across modalities in the S + CG condition, but presented serially within speech in the RS condition. The purpose of this condition was to test Prediction 2 by determining whether simultaneous distribution of information through gesture and speech would produce better learning than the same amount of information presented through speech alone. See Appendix B for sample training scripts. There were four different training sets to ensure that all the words were trained in all conditions across participants.

After the first session, there was a 2-minute break, and then there was a second round of training. The order of the blocks was changed, but importantly, the same words were trained according to their original conditions. Following this round, there was another two-minute break, and then the instructor presented the final round of training (again changing the order of blocks). In the end, each word was trained 6 times (or 12 times in the RS condition) over the course of three different sessions.

After the final training phase, there was a 5-minute break, and then the experimenter presented two memory tasks. In the first task (a free recall test), the experimenter said each Japanese word, and the participants wrote down the English translation. In the second task (a recognition test), the experimenter said each Japanese word (in a different order from the recall task) and the participants circled the correct English translation out of a

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[2] An incongruent stimulus was created by taking a gesture that was congruent with one word (e.g., 'Nomu/drinking gesture/means drink/drinking gesture/') and placing it with a different word (e.g., 'Kiru /drinking gesture/means cut/drinking gesture/'). In this way, the congruent and incongruent conditions both presented the same content in speech and gesture across all words, but the difference was whether the content was congruent or incongruent *within* a particular word.

choice of four words. The total time for training and testing was approximately 30 minutes and 10 minutes, respectively.

After participants completed the two tests, the experimenter scheduled two more times for the participants to return and take two follow-up memory tests. The first follow-up was two days later and the second was one week later (four participants failed to take this final test). The memory testing procedures were identical to the first session, but the order of the questions in both the recall and recognition tests was different for the two additional sessions.

Results

A 3 (Test Time: Five Minutes, Two Days, One Week) × 4 (Training: Speech, Repeated Speech, S + IG, S + CG) repeated measures ANOVA (with a Huynh-Feldt correction) was performed on the arcsine transformed proportions of the words that participants correctly remembered for each of the memory tests. Dunn-Sidak corrected *t*-tests were used to control for multiple comparisons.

Referring to Table 1a and 1b, the general finding was that participants remembered the most words in the Speech + Congruent Gesture condition, fewer words in the Repeated Speech condition, fewer still in the Speech condition, and the fewest words in the Speech + Incongruent Gesture condition. These differences were significant, with the ANOVA uncovering a main effect of Training condition, $F(3, 66) = 37.39$, $p < .001$; $F(3, 66) = 29.70$, $p < .001$, for the free recall and forced choice questions, respectively. However, there were no significant main effects of Test Time, $F(2, 44) = 1.08$, *ns*; $F(2, 44) = 1.06$, *ns*, or interactions between Training and Test Time, $F(6, 132) = 1.37$, *ns*; $F(6, 132) = 1.46$, *ns*, for the free recall and forced choice questions, respectively.

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TABLE 1A
Proportions of words learned across the four training conditions at three test times using free recall

	Mean proportion recalled				*Standard deviation*			
Time of test	*Speech*	*Repeated speech*	*Speech + inc.*	*Speech + con.*	*Speech*	*Repeated speech*	*Speech + inc.*	*Speech + con.*
Five minutes	0.53	0.65	0.36	0.74	0.32	0.34	0.33	0.3
Two days	0.48	0.63	0.33	0.75	0.27	0.28	0.24	0.3
One week	0.36	0.65	0.3	0.7	0.28	0.29	0.28	0.24
Average	0.46	0.65	0.33	0.73	0.28	0.31	0.29	0.28

TABLE 1B
Proportions of words learned across the four training conditions at three test times using forced choice

	Mean proportion recalled				Standard deviation			
Time of test	*Speech*	*Repeated speech*	*Speech +inc.*	*Speech +con.*	*Speech*	*Repeated speech*	*Speech +Inc.*	*Speech +con.*
Five minutes	0.76	0.79	0.62	0.94	0.24	0.26	0.33	0.13
Two days	0.72	0.84	0.6	0.91	0.29	0.19	0.26	0.18
One week	0.66	0.77	0.58	0.88	0.22	0.21	0.27	0.16
Average	0.72	0.8	0.6	0.91	0.25	0.22	0.29	0.16

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From Table 1a and 1b, it is apparent that Speech condition yielded more learning than the S + IG condition, tDS(3, 26) = 3.55, $p < .001$ and tDS(3, 26) = 3.56, $p < .001$, for the two respective types of questions. In contrast, the Speech condition produced less learning than the S + CG condition for both questions, tDS(3, 26) = − 6.82, $p < .001$ and tDS(3, 26) = − 6.39, $p < .001$. These results support Prediction 1, which states that gestures will enhance learning because of their semantic content, not their ability to capture attention.

In addition, the S + CG condition produced more learning than the Repeated Speech condition for both types of questions, tDS(3, 26) = 3.06, $p = .006$ and tDS(3, 26) = 3.84, $p < .001$. These results support Prediction 2, which states that simultaneously distributing information through gesture and speech will produce better learning than presenting the same amount of information through speech alone.

Discussion

Experiment 1 demonstrated that gesture plays a role in learning and remembering words in a new language. Moreover, it has added to previous research by illuminating two possible ways that gesture boosts learning. First, the fact that congruent gestures produced better – and incongruent gestures worse – memory than speech alone suggests that gesture does not solely function to capture attention (i.e., it is more than mere hand waving) during foreign language learning. This finding is consistent with recent work showing that people remember sentences in one's native language better when they learn them with congruent representational gesture compared to non-representational gestures (beats) or incongruent representational gestures (Feyereisen, 2006). One explanation for Feyereisen's finding is that congruent gestures facilitate memory not because they enhance attention to speech, but because the meaning of congruent gestures is conceptually

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integrated with the meaning of speech, and this integration creates stronger and more multimodal memory representations. Similarly, the congruent gestures in the present experiment may enhance foreign word learning because they imagistically and non-arbitrarily reinforce the link between a newly learned word and a known word. In fact, this may be precisely why incongruent gestures lead to worse learning – they may have visually disrupted this link between new and old word, which may have created less stable memories of the meaning of new words.

Second, the positive effects that congruent gestures had on learning were not simply due to additional exposure to the meanings of the new words. For example, one might argue that participants learned more words in the S+CG condition versus Speech condition simply because there was more exposure to the meanings of the words in the gesture condition. After all, in the congruent gesture condition, participants heard the definitions six times for each new word, and they *saw* the definitions six times as well. However, the results from the Repeated Speech condition suggest otherwise. In that condition, participants heard definitions 12 times for each word, yet participants learned more words when those 12 definitions were distributed *across* speech and gesture than when everything was packed into speech. Finally, it is important to note that from a practical standpoint, not only did instruction comprised of speech and congruent gestures produce better learning than instruction comprised of repeated speech, it also took half as much time to teach!

EXPERIMENT 2

Recent research in cognitive neuroscience has demonstrated that the brain semantically integrates speech and gesture during language comprehension (see Introduction). However, no study to date has extended this research to explore neural processes associated with learning new linguistic information with and without hand gesture. The present experiment is a preliminary attempt to address this issue by using event-related potentials (ERPs) to explore possible neural mechanisms of how gestures help people learn and remember new words in a foreign language.

Event-related potentials measure the timing of electrical brain responses to a particular stimulus of interest, in our case, newly learned words. The peaks and valleys of these brainwaves, called components, correspond to different types of neurocognitive processes. The present study will focus on two particular components that are involved in semantic memory – the N400 and the Late Positive Complex (LPC).

The N400 component is a negative defection peaking at roughly 400 ms after stimulus presentation at centro-parietal sites, and is thought to reflect the activation of the semantic memory system during language comprehension (Kutas & Federmeier, 2000). Specifically, when the meaning of a word is easy to access from memory, the amplitude of the N400 is reduced. Although this N400 effect is traditionally associated with on-line sentence comprehension, it is also involved with long-term semantic memory processes. For example, there is a reduction of the N400 amplitude when linguistic items are repeated – repetition priming – over long delays and when people access readily available semantic information from long-term memory (Kutas & Federmeier, 2000). Researchers have interpreted this reduced N400 to reflect the ease of effort with which people can integrate a word into some previous discourse or memory structure (Holcomb, 1993; Kutas & Federmeier, 2000). In this way, learning the word 'nomu' with an iconic gesture may serve to prime the semantic activation of that word when it is repeated later during a recognition phase.

In addition to the N400 component, researchers have identified a later portion of the brainwave that is also involved in semantic memory – the Late Positive Complex (LPC). The LPC (sometimes, the P600 or 'old/new' effect) is a centrally distributed positive complex that peaks approximately 600 ms after stimulus presentation and reflects recollection of information in long-term memory (Rugg & Curran, 2007). The LPC is larger for words that have been primed by repetition, and researchers have claimed that words encoded deeply, versus shallowly, in long-term memory produce an enhanced LPC during the recollection of a word (Rugg & Curran, 2007; Rugg, Mark, Walla, Schloerscheidt, Birch, & Allan, 1998; Schott, Richardson-Klavehn, Heinze, & Düzel, 2002). Moreover, Klaver et al. (2005) showed that the LPC effect is greater when people access imageable vs. non-imageable words from long-term memory. In this way, an iconic gesture may create a deeper and stronger memory trace for the word 'nomu' because it creates a more imagistic memory for the meaning than just speech alone.

Research on both components suggests that the N400 and the LPC at retrieval may reflect two different aspects of long-term memory (Curran, 2004; Herzmann & Sommer, 2007; Rugg & Curran, 2007). For example, Curran (2004) had participants perform a divided attention task while they learned lists of words and then measured ERP responses during a test phase using a 'remember/know' procedure. He found that the N400 was sensitive to *familiarity* of the studied items (i.e., participants knew they had seen the word, but did not actually remember the experience of encoding the word), but the LPC was sensitive to the actual *recollection* of the items (i.e., participants knew they had seen the word and could actually remember the

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encoding experience). These results support a dual-process theory of memory, with the N400 reflecting a simple and automatic recognition of information in semantic memory, and the LPC reflecting more advanced and controlled processes involved in qualitatively recollecting the context and details of the learned items (Rugg & Curran, 2007).

In the present experiment, we investigated the effect of hand gestures on these two types of semantic memory processes for recently learned foreign words. Specifically, we taught adults Japanese words with and without gesture and then measured ERPs to the newly learned items. Based on the previous ERP literature on semantic memory, we advanced three hypotheses: (1) If gesture facilitates familiarity but not recollection of newly learned words, there should be only a smaller N400 to words learned with versus without gesture; (2) If gesture facilitates recollection but not familiarity of newly learned words, there should be only a larger LPC to words learned with versus without gesture; and (3) If gesture facilitates familiarity *and* recollection of newly learned words, there should be a smaller N400 *and* a larger LPC to words learned with versus without gesture.

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Method

Participants. Twenty-four right-handed adults (mean age 18.5 years, 15 females and 9 males) participated in the experiment. Participants were recruited from an Introduction to Psychology class and received research credit. As in Experiment 1, no participant had prior knowledge of the Japanese language.

Materials. The stimuli and procedure were similar to Experiment 1, but changes were made to adapt to an ERP methodology. Because this was an exploratory experiment, we streamlined the materials used in Experiment 1 to include only the S + CG (now labelled Speech + Gesture) and Speech conditions (see Experiment 1). Another difference was the procedure for presenting the training. We used video training to ensure that the auditory tokens of the Japanese words were identical from the instruction phase to the ERP test phase.

The training videos presented 10 Japanese words (we dropped two words: 'tataku' and 'haku') in a similar fashion as Experiment 1. That means that there were five words in the Speech + Gesture condition and a different five words in the Speech condition (we counterbalanced which words were in each condition across participants). In this way, participants learned five words with gesture and five words without gesture. But different from Experiment 1, rather than introducing the Japanese word and defining it twice, the word was introduced and defined only once per block. For example, when presenting the word 'nomu,' the instructor said: 'Nomu. Nomu means drink.' As in Experiment 1, the gesture condition presented two drinking gestures simultaneously with the words 'nomu' and 'drink'. In addition, instead of three blocks, the instruction in Experiment 2 included five blocks of presentation. In this way, the videos presented and defined all five Speech + Gesture words a total of 25 times, and the same was true for the Speech words. Importantly, there were two different training sets distributed across participants, so that the same words were not always trained in the same conditions across all participants (10 participants in Set A, and 9 in Set B).

Procedure. Participants were tested in the laboratory and watched the videos on LCD monitors. They were told that they would be learning Japanese verbs and the task was to simply watch the videos and remember as many of the words as possible because there would be a memory test at the end of the experiment. Different from Experiment 1, there were a total of three separate training sessions over the course of three days. This was done to ensure that participants would remember most of the words for the ERP session of the experiment.

The ERP measurements and memory test occurred on the afternoon of the third day of training (the ERP testing was in a room different from the rooms in which participants learned the Japanese words). Participants were first fitted with a 128-electrode Geodesic ERP net. The EEG was sampled at 250 Hz using a band pass filter of 0.1–30 Hz, and impedances were kept below 40 kohm (the Geonet system uses high-impedance amplifiers). The ERPs were vertex referenced for recording and linked-mastoid referenced for presentation. Following re-referencing, the brainwaves were baseline corrected to a 100 ms pre-stimulus window.

Eye artifacts during data collection were monitored with 4 EOG electrodes, with voltage shifts above 70 microvolts marked as bad (for more on the EOG algorithm, see Gratton, Coles, & Donchin, 1983; Miller, Gratton, & Yee, 1988). Non-EOG channels were marked as bad if there were shifts within the electrode of greater than 200 microvolts for any single trial. If over 20% of the channels were bad for a trial, the whole trial was rejected. In all, 18% ($SD = 24\%$) of all trials were rejected.

After the net was in place, participants were instructed that they would hear the 10 Japanese words that they had learned and also five new Japanese words. These new words ('naderu', tsuneru', 'mawasu', 'tataku', and 'nageru') were used to keep participants focused on the words during the ERP session. Their task was to indicate on a button box whether the words were old (the ten trained words) or new (the five untrained words).

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Importantly, the spoken words were presented in isolation (every 2 to 3 seconds) in the absence of any video information. Each word lasted approximately 500 ms. There were a total of 10 presentations of the 15 words, for a total of 150 stimulus presentations.[3]

Following the ERP session, there was an explicit memory test of the 10 trained words. The auditory token of the word was played on the computer, and participants were asked to give the English translation. The entire ERP and behavioural testing procedure took approximately 45 minutes.

Design and analysis. There were three within-subjects independent variables. The Training variable had three levels: Speech, Speech + Gesture, and No Instruction. The words in the first two conditions are ‘old’ words, and the words in the No Instruction condition are ‘new’ words – i.e., words that participants never learned during the training session. In addition, for the ERP analysis, there were two additional factors: Electrode Region and Hemisphere. These variables will be addressed below.

The dependent variables were behavioural and electrophysiological. The behavioural measures include how quickly and accurately participants recalled the learned (‘old’) words during the ERP session. In addition there was an offline memory task after the ERP session that tested for memory of the meaning of the 10 Japanese words that participants learned.

The ERPs were time-locked to the audio onset of the new and old words. The analysis focused on two components, the N400 effect and the LPC. To isolate the N400 effect, we took the average amplitude from 350 to 500 ms; and to isolate the LPC, we took the average amplitude from 500 to 650 ms. The electrophysiological analyses included the ‘old’ and ‘new’ items as part of the overall ANOVA, but in the interest of space and in accordance with our predictions, the *t*-test contrast focused on the differences between the ‘old’ words in the Speech and Speech + Gesture conditions.[4]

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[3] Note that each word is repeated 10 times during the memory test. This repetition likely made it more difficult for participants to accurately recall whether a word was old or new toward the end of the memory test. Although this is not ideal, note that if anything, it would make it more difficult to find significant differences among our conditions. Therefore, our ERP results likely under-represented the effects of gesture on memory in real language learning situations – although the small number of items limits the generalisability of the results.

[4] From the inspection of the figures, it is clear that the No Instruction condition produced a large P300 effect compared with the Speech and Speech + Gesture conditions. This P300 is likely due to the fact that the ‘new’ items were relatively infrequent (appearing 33% of the time) and were likely viewed as ‘oddball’ stimuli (Key, Dove, & Maguire, 2005). In the interest of space, this interesting – but not surprising – effect will not be discussed in the present manuscript.

Results

The N400 effect and LPC were subjected to two separate 3 (Instruction: Speech, Speech + Gesture, No Instruction) × 5 (Electrode Region: Central, Frontal, Occipital, Parietal, Temporal) × 2 (Hemisphere: Right, Left) repeated measures ANOVAs with a Huynh-Feldt correction. The Electrode Region manipulation refers to the location of clusters of electrodes on the scalp. Based on previous studies, the 128 electrodes were broken up into five clusters of channels per hemisphere. Refer to Figure 1 for a diagram. Average amplitudes were calculated within each electrode cluster. For significant ANOVA interactions, planned student's *t*-tests compared the 'old' words for the Speech and Speech + Gesture conditions. To view all of the brainwaves for the 10 electrode sites, refer to Figure 2.

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N400 effect. The ANOVA on the N400 time window did not reveal a main effect of Instruction, $F(2, 46) = 0.83$, *ns*, nor did it reveal significant interaction effects of Instruction × Electrode Region, $F(8, 184) = 1.43$, *ns*, Instruction × Hemisphere, $F(2, 46) = 0.38$, *ns*, or Instruction × Electrode Region × Hemisphere, $F(8, 144) = 1.38$, *ns*. Refer to Figure 2.

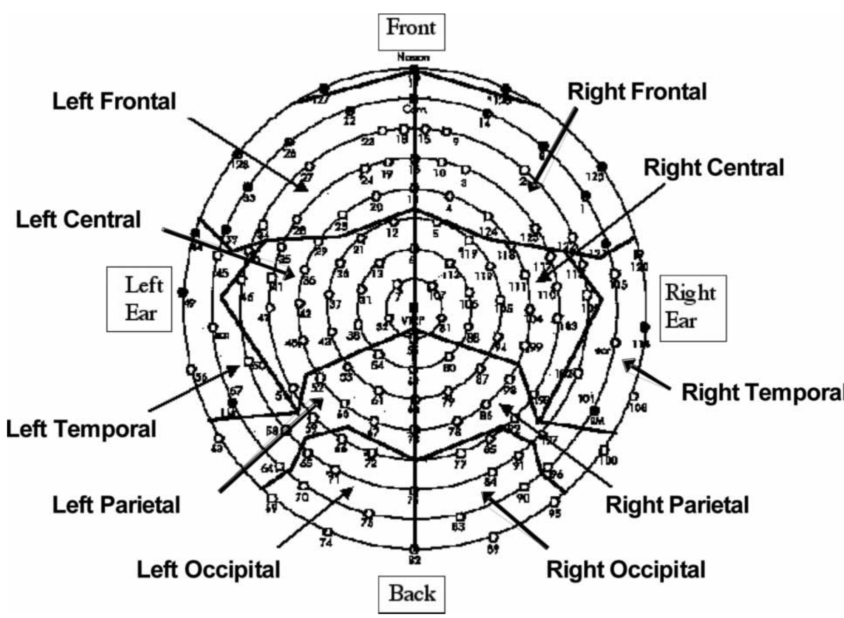

Figure 1. Ten electrode clusters for the 128 Geodesic electrode net. For more on the rationale for the clusters, see Kelly, Kravitz, and Hopkins (2004).

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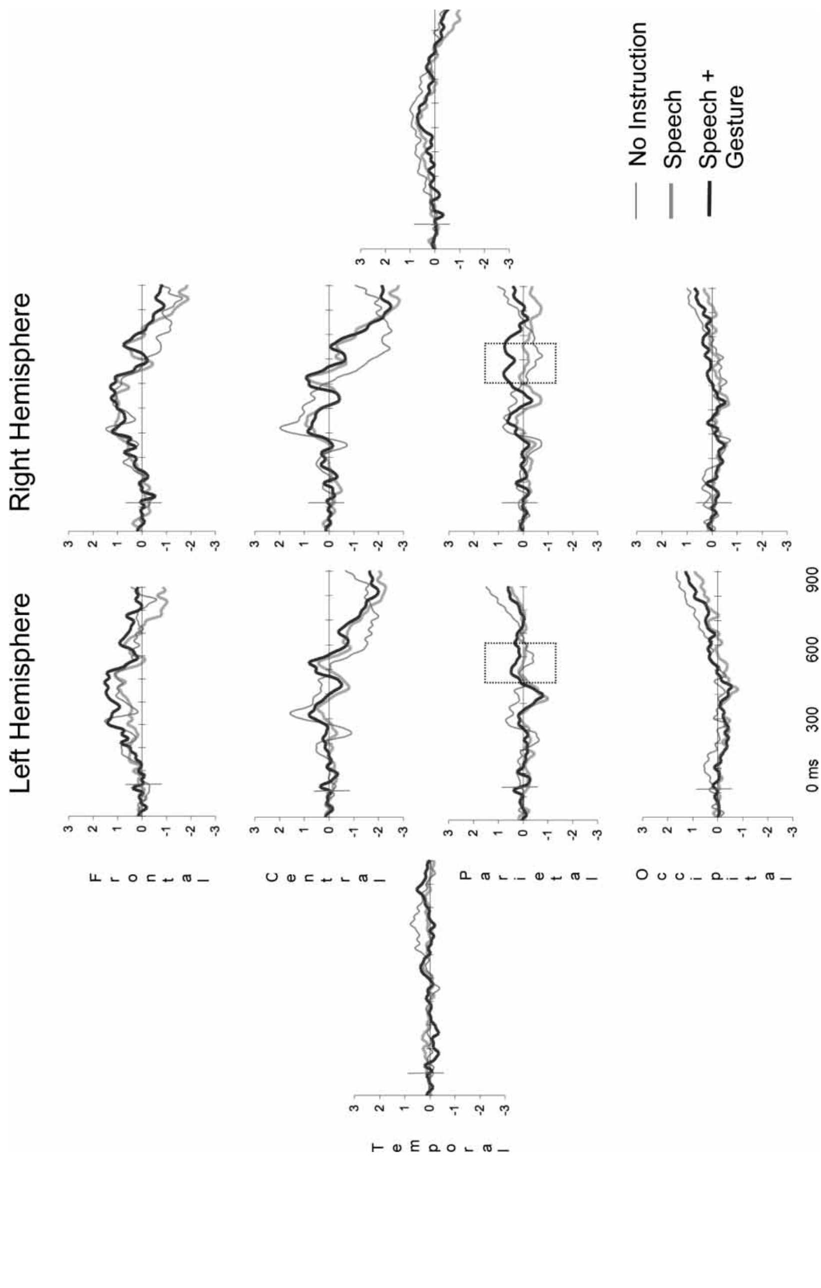

Figure 2

Late positive component (LPC). The ANOVA on the LPC time window did not reveal a main effect of Instruction, $F(2, 46) = 0.83$, *ns*, nor did it reveal significant interaction effects of Instruction × Hemisphere, $F(2, 46) = 1.10$, ns, or Instruction × Electrode Region × Hemisphere, $F(8, 144) = 0.38$, *ns*. However, there was a significant Instruction × Electrode Region interaction, $F(8, 144) = 2.45$, $p = .05$. This effect was driven by the Speech + Gesture condition producing a larger LPC in bi-lateral parietal sites compared with the Speech condition, $t(23) = 2.01$, $p = .029$. Refer to Figure 2 for the entire scalp distribution for all three conditions (in accordance with our predictions, only the Speech + Gesture and Speech conditions were analysed for the present paper). Finally, although the Training × Electrode Region × Hemisphere interaction was not significant, the LPC effect was stronger in right, $t(23) = 1.96$, $p = .031$, compared with left parietal region, $t(23) = 1.38$, $p = .091$.

Behavioural tasks. In order to determine whether there were differences in how participants behaviourally treated the trained ('old') items during the ERP session, we ran two student's *t*-tests on the accuracy scores and reaction times for the Speech + Gesture and Speech conditions. When identifying the trained words, participants were equally accurate for the Speech + Gesture ($M = 0.86$, $SD = 0.22$) and Speech ($M = 0.90$, $SD = 0.18$) conditions, $t(23) = 1.32$, *ns*). In addition, there were no significant differences in reaction time for the Speech + Gesture ($M = 1571$ ms, $SD = 295$ ms) and Speech ($M = 1575$ ms, $SD = 265$ ms) conditions, $t(23) = 0.14$, *ns*.

Finally, the behavioural memory test replicated Experiment 1, with participants accurately recalling the definitions of the Japanese words 82.4% of the time in the Speech + Gesture condition, compared with 67.9% for the Speech condition, $t(23) = 3.16$, $p = .002$. This demonstrates that although participants treated the words in the Speech and Speech + Gesture conditions similarly in the on-line memory test, they better remembered the words in the Speech + Gesture condition in the off-line memory test.

Discussion

The behavioural memory test in Experiment 2 replicated the results from Experiment 1 – in both experiments, participants remembered more words

Figure 2 (opposite). Event-related potentials for the No Instruction, Speech and Speech + Gesture conditions at the 10 electrode cluster sites (see Figure 1 for the specific electrodes that were averaged within each cluster). The No Instruction condition represents 'new' Japanese words and the two other conditions represent 'old' Japanese words that were part of the training. For the purposes of this paper, we focus only on the key comparison between the Speech and Speech + Gesture conditions. The main significant difference occurs at the LPC from 500 to 650 ms in bi-lateral parietal sites (boxed). Microvolts (positive up) are plotted on the y axis.

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when congruent gestures accompanied training compared with when no gestures were present. In addition, there were no significant differences in reaction times or accuracy scores between the two instruction conditions in the 'old/new' judgement task during the ERP portion of Experiment 2. This is noteworthy because it suggests that participants *behaviourally* treated Speech and Speech + Gesture words in a similar fashion during the ERP portion of the experiment.

The ERP results add to these behavioural findings by providing some preliminary evidence that there are neural changes associated with learning foreign words with hand gesture. The main finding was that Japanese words learned with gesture produced a larger LPC in bi-lateral parietal regions than words learned without gesture. In contrast, there were no significant N400 differences between the Speech + Gesture and Speech conditions. This pattern of results provides preliminary support for Hypothesis 2, which states that gesture affects recollection but not familiarity of newly learned words.

Focusing first on the significant LPC findings, previous research has demonstrated that this component reflects how easy or hard it is to retrieve information from long-term memory (Rugg & Curran, 2007). Moreover, others have argued that it taps into how deeply a memory is initially encoded, with a larger LPC reflecting retrieval of deeply compared with shallowly learned items (Rugg et al., 1998; Schott et al., 2002). In addition, a larger LPC at retrieval is associated with words that are encoded in a highly imagistic fashion (Klaver et al., 2005). In this way, instruction with gesture may create deeper and stronger memory traces during foreign word recollection than training without gesture. It should be noted that this LPC effect is normally left lateralised (Rugg & Curran, 2007), whereas the present effect seemed to be more right lateralised. However, this is consistent with previous research showing that the neural integration of gesture and speech during on-line language comprehension is right lateralised (Kelly et al., 2004). From this, one may speculate that the right hemisphere – because of its relative strength in spatial and imagistic processing – plays a special role when people use gesture to help them remember newly learned information. This possibility is intriguing and deserves more attention with future research.

This LPC finding is potentially more interesting in light of the lack of any N400 differences. Although there are similarities between the LPC and the N400 component, researchers have pointed out important differences between the two – the LPC reflects how well someone can recollect a specific instance of learning, whereas the N400 reflects general familiarity with something from memory (Rugg & Curran, 2007; Herzmann & Sommer, 2007). Moreover, these two components may index two different stages of memory recognition – with familiarity reflecting fast-acting automatic

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processes, and recollection reflecting slower controlled process (Rugg & Curran, 2007; Yonelinas, 2001). In this way, one may speculate that gesture does not facilitate memory for newly learned words by making them superficially familiar in an automatic fashion (the N400), but rather they may help only in later stages when people specifically identify and recall – perhaps in some sort of imagistic fashion – particular source items from memory (the LPC).

Of course, this speculation based on the absence of an N400 effect should be tempered, as it is unwise to make strong claims from null results. Previous research on the N400 component and memory processing has primarily focused on words in one's native language (Finnigan, Humphreys, Dennis, & Geffen, 2002; Kutas & Federmeier, 2000), and it is possible that the novelty of the Japanese stimuli created additional variability and dampened the N400 effect (interestingly, it does appear from Figure 2 that there is some sort of N400 effect in the left anterior region, but it was not statistically significant). Therefore, one must be very cautious in over-interpreting a lack of an N400 effect between the Speech + Gesture and Speech conditions.

Finally, it should be noted that the results from Experiment 2 are exploratory and quite preliminary. Indeed, as the first experiment to investigate neural correlates associated with learning words with and without hand gesture, it necessarily has its limitations (as mentioned above). However, the preliminary findings are suggestive and hopefully will pave the way for future research on this under-studied but important topic.

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GENERAL DISCUSSION

Consistent with our general hypothesis, the two experiments revealed that hand gestures facilitate learning of newly acquired words in a foreign language. Experiment 1 demonstrated that this enhanced learning and memory is not exclusively due to the attention-grabbing aspect of gesture – participants learned more words in the S + CG condition versus S + IG condition – nor is it due to gesture simply presenting additional information – participants learned more words in the S + CG condition versus the Repeated Speech condition. This suggests that the representational meaning of hand gestures that simultaneously accompany speech may imagistically index a newly learned word to an established concept, and this strengthened connection may help those words endure longer in memory.

Experiment 2 followed up on Experiment 1 by replicating the behavioural results and providing a possible neural mechanism for this enhanced learning. Japanese words learned with congruent hand gestures produced a larger LPC than words learned with only speech. However, instruction with speech and gesture did not produce a decreased N400 effect compared with speech instruction alone. Together, this ERP pattern suggests that gesture may not play a role in automatically processing the familiarity of newly learned words (N400 effect), but it may assist with controlled processes associated with recollecting the meaning of those words (the LPC) (Rugg & Curran, 2007; Herzmann & Sommer, 2007; Yonelinas, 2001). To put it another way, gesture may not make people superficially familiar with foreign word forms, but it may help people to conjure up the specific meaning of those words.

So why does gesture help people conjure up the specific meaning of newly learned Japanese words? One possible explanation is that co-speech gesture – because it captures meaning an embodied and non-arbitrary way – deepens the imagistic memory trace for a new word's meaning in the brain. This possibility gains support from recent neuroimaging research demonstrating that gesture is tightly integrated with the meaning of speech during on-line language comprehension (Holle & Gunter, 2007; Kelly, Kravitz, & Hopkins, 2004; Ozyürek, Willems, Kita, & Hagoort, 2007; Skipper, Goldin-Meadow, Nusbaum, & Small, 2007; Willems, Özyürek, & Hagoort, 2007; Wu & Coulson, 2007). From this line of work, researchers have theorised that gesture and speech form an integrated neural system of meaning during language comprehension (Özyürek & Kelly, 2007; Willems, Özyürek, & Hagoort, 2007). The present study provides further support but also extends this claim by demonstrating that this integrated relationship is present not just in the on-line comprehension of words in one's native language, but also in the memory for *new words* in a foreign language.

The results from the ERP experiment are exciting also because they contribute to the growing research on brain changes associated with non-native language learning (Key, Molfese, & Ratajczak, 2006; McCandliss, Posner, & Givon, 1997; McLaughlin, Osterhout, & Kim, 2004). For example, McLaughlin et al. (2004) found that 14 hours of L2 (French) instruction to native English-speakers was enough to produce distinct ERP discriminations (as measured by the N400) in semantic processing of pseudowords and real words in French. In addition, Key et al. (2006) found evidence for ERP changes to words learned in an artificial language after just 5 minutes of exposure. Interestingly, the ERP component that indexed this learning in the study by Key and colleagues was a late positivity ranging from 400 to 600 ms – an effect that is very similar to the LPC finding in the present study.

More generally, this line of research focusing on brain changes during second language learning is important because it reveals insights that would be missed if researchers focused on *behavioural* measures alone. For example, in the study by McLaughlin and colleagues (2004), they found that ERPs revealed vocabulary learning in French well in advance of overt behavioural measures. Similarly, the results of Experiment 2 of the present study enrich our behavioural findings. The ERP results illustrate a possible mechanism that can explain *why* congruent hand gestures aid learning: they facilitate

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learning because they help to index new words to concrete, imagistic, and embodied memory traces of the meaning of those words, and this enhances the accurate recollection – but not necessarily the superficial familiarity – of those words in memory.

In conclusion, the results from the present study directly bear on the philosophical problem posed by Quine (1960) about the arbitrary relationship between a new word and its meaning. We would like to argue that this problem is greatly diminished when one considers that words are produced by bodies, and bodies are naturally equipped with tools to convey non-arbitrary meanings (Barsalou, 2008; Glenberg & Kaschak, 2003). In this way, gesture may lend a hand to second language learning by grounding new linguistic items in meanings that are easily, readily, and transparently represented by the body.

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Appendix A

The 12 Japanese Words and English Translations

Item #	*Japanese Word*	*English Translation*
practice	*tsu-ne-ru*	*pinch*
1	Ho-ru	Dig
2	Hi-ku	Pull
3	A-ra-u	Wash
4	Ni-gu-ru	Squeeze
5	Ta-ta-ku	Hammer
6	Ta-be-ru	Eat
7	Ha-ku	Sweep
8	O-su	Push
9	Ka-ku	Scratch
10	No-mu	Drink
11	No-bo-ru	Climb
12	Ki-ru	Cut

Appendix B

Sample Scripts for the Four Instruction Conditions

1. Speech Condition (S)

The next word is no-mu. No-mu means drink. No-mu means drink.

2. Repeated Speech Condition (RS)

The next word is no-mu. No-mu means drink. No-mu means drink. Again, the next word is no-mu. No-mu means drink. No-mu means drink.

3. Speech + Incongruent Gesture Condition (S + IG)

The next word is no-mu. No-mu (gesture: wash) means drink (gesture: wash). No-mu (gesture: wash) means drink (gesture: wash).

4. Speech + Congruent Gesture Condition (S + CG)

The next word is no-mu. No-mu (gesture: drink) means drink (gesture: drink). No-mu (gesture: drink) means drink (gesture: drink).

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