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Iconic gestures prime related concepts: An ERP study

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To assess priming by iconic gestures, we recorded EEG (at 29 scalp sites) in two experiments while adults watched short, soundless videos of spontaneously produced, cospeech iconic gestures followed by related or unrelated probe words. In Experiment 1, participants classified the relatedness between gestures and words. In Experiment 2, they attended to stimuli, and performed an incidental recognition memory test on words presented during the EEG recording session. Event-related potentials (ERPs) time-locked to the onset of probe words were measured, along with response latencies and word recognition rates. Although word relatedness did not affect reaction times or recognition rates, contextually related probe words elicited less-negative ERPs than did unrelated ones between 300 and 500 msec after stimulus onset (N400) in both experiments. These findings demonstrate sensitivity to semantic relations between iconic gestures and words in brain activity engendered during word comprehension.

During discourse, speakers use hand and body movements to depict conceptual content salient to their talk. Individuals have traced an oval shape in the air while describing a platter, for example, or demonstrated running legs by wiggling two fingers (McNeill, 1992; Wu & Coulson, 2005). It has been proposed that movements such as these, known as iconic gestures (McNeill, 1992), affect listener comprehension. A number of behavioral studies have demonstrated listener sensitivity to information conveyed in gestures (Alibali, Flevares, & Goldin-Meadow, 1997; Cassell, McNeill, & McCullough, 1999; Goldin-Meadow & Sandhofer, 1999), as well as improved comprehension of spoken discourse when speakers' gestures are visible (Beattie & Shovelton, 1999, 2002; Rogers, 1978; Valenzeno, Alibali, & Klatzky, 2003). Measuring event-related potentials (ERPs), researchers have also shown differences in brain activity elicited by words presented with congruent as opposed to incongruent gestures, or with no gestures (Kelly, Kravitz, & Hopkins, 2004). These findings suggest that iconic gestures are analyzed for meaning, and can produce measurable effects on observer comprehension.

Recent research has investigated commonalities in semantic processes mediating the comprehension of iconic gestures and the comprehension of more conventional visual representations such as pictures. Picture probes, for example, have been shown to elicit more-negative ERPs around 300 msec (N300) and 400 msec (N400) poststimulus when they are preceded by unrelated picture primes in comparison with related ones (Barrett & Rugg, 1990; Ganis, Kutas, & Sereno, 1996). The N400 relatedness effect elicited by pictures is similar to the "classic" N400 elicited by words. Originally discovered in response to sentence-final words, the lexical N400 was described as a negative-going deflection of the ERP waveform peaking between 300 and 500 msec poststimulus, with an enhanced amplitude for incongruous items in comparison with congruous ones (Kutas & Hillyard, 1980, 1984). Subsequently, similar effects were obtained in congruency manipulations involving a number of different stimulus types, including written and spoken word pairs (Holcomb & Neville, 1990), photographs (McPherson & Holcomb, 1999), and videotaped actions (Sitnikova, Kuperberg, & Holcomb, 2003). Further, American Sign Language (ASL) hand signs (Neville et al., 1997), which recruit more bilateral cortical resources than spoken language (Bavelier et al., 1998), and emblematic gestures (e.g., "thumbs up"; Gunter & Bach, 2004) have also elicited N400-like activity. These findings suggest that the N400 class of negativities—although it probably results from overlapping, but nonidentical, neural generators—is a brain response triggered by meaningful stimuli. Because the amplitude of the N400 is inversely correlated with the degree to which an item is expected in its context (Kutas & Hillyard, 1984; Van Petten & Kutas, 1990), this brainwave component is generally thought to index the integration of incoming semantic information into a higher order mental model.

To test for N400-like responses to gestures, we recorded ERPs while participants watched spontaneously produced iconic gestures preceded by either congruous or incongruous cartoon contexts (Wu, 2005; Wu & Coulson, 2005). In comparison with congruous trials, incongruous gestures elicited more-negative ERPs between 450

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and 600 msec poststimulus (gesture N450). This effect displayed a time course and polarity similar to those of the N400 family of negativities, as well as similar eliciting conditions. These data suggest that, like words and pictures, iconic gestures also engage meaning-based representations that are integrated with other contextually active information.

Further support for this view was uncovered by extracting static freeze-frames from gesture videos, and pairing them with congruent or incongruent cartoon contexts (Wu, 2005). In addition to exhibiting enhanced N450, incongruent freeze-frames also elicited more-negative ERPs between 300 and 400 msec (N300). Like the N400, the N300 is sensitive to manipulations of relatedness between images and prior context. However, because the N300 has only been observed in response to pictures and photos, it is thought to reflect the activation of image-specific conceptual representations. The finding that incongruent static gestures elicited a larger N300 suggests that understanding these items' semiotic features (e.g., hand shape, location, and orientation) recruits similar comprehension processes as well. It is possible that dynamic gestures did not yield N300 effects because processes indexed by the N300 might become activated slightly later in response to moving, visually complex stimuli than they would in response to static objects, overlapping with processes indexed by the N450.

The present study investigates whether iconic gestures activate meaning-based representations in the absence of supporting linguistic context. Because iconic gestures are not part of a conventionalized symbolic system, it has been argued that their meaning is determined largely by speech accompanying them (Krauss, Morell-Samuels, & Colasante, 1991). However, given evidence that understanding gestures engages semantic processes analogous to those recruited by pictures, people may be capable of integrating the semiotic features of gestures with stored knowledge about their referents, even in the absence of contextual support.

To test this hypothesis, we recorded ERPs while healthy adults watched spontaneously produced iconic gestures followed by probe words. In Experiment 1, participants classified probes as related or unrelated; in Experiment 2, they attended to stimuli and completed a test of incidental probe recognition afterward. If gestures activate stored knowledge about the phenomena they depict, evidence of word priming is expected in the form of reduced response latencies and reduced amplitude of the N400 elicited by related relative to unrelated probe words.

EXPERIMENT 1

Method

Participants. Sixteen volunteers were compensated for their participation. The data of 4 individuals were excluded because of excessive artifacts in their EEGs. Data from the 12 remaining volunteers (5 females, 7 males) were included in the final analysis. All were healthy, English-speaking adults with no history of neurological impairment.

Materials and Procedure. One hundred sixty gesture video clips were paired with related or unrelated probe words. Gesture clips were constructed by videotaping a naive individual as he described segments of cartoons (e.g., *Tom & Jerry*). He was told that the video would be utilized in a memory experiment, and was instructed to describe each clip in as much detail as possible. Iconic gestures digitized for experimental use typically either reenacted actions performed in the cartoon (e.g., turning a doorknob) or depicted salient features of objects or events (e.g., the path of a careening rock).

Twelve volunteers (none of whom participated in the ERP experiment) rated the degree of relatedness between probe words and counterpart gestures on a 5-point scale. Related words were consistently rated as more related than unrelated ones, yielding a mean rating of 3.34 ($SE = .2$) as compared with 1.55 ($SE = .13$) [$F(1,11) = 255$, $p < .0001$].

Four lists were constructed, each containing 40 related gesture–word pairs, 40 unrelated pairs, and 80 unrelated fillers. No gesture clip or word was repeated on any list, but across lists, each word appeared once as a related and once as an unrelated stimulus. Trials began with a fixation cross, presented in the center of a 17-in. color monitor screen. Gesture clips were presented at a rate of 48 msec per frame (48 frames total for each trial). One second after gesture offset, a probe word appeared for 1 sec. This relatively long interstimulus interval allowed participants to refocus their gaze on the center of the screen. All of the frames were centered on a black background, subtending approximately 11º of visual angle.

The participants were told that they would view soundless video clips showing a man describing cartoons, followed by probe words. They were asked to press either YES or NO on a button box as soon as they felt confident that the word either matched or did not match the preceding video. Because it was unclear whether decontextualized gestures contained enough information for the relatedness judgment task, the participants were told that they might find a large proportion of probes unrelated. Response hand was counterbalanced across subjects. Four additional trials made up a practice block.

EEG recording. The EEG was recorded using tin electrodes at 29 standard sites, using the international 10–20 system (Nuwer et al., 1999; for further explanation of electrode placement, see Wu & Coulson, 2005). Electrodes were also placed on the right mastoid for offline re-referencing, and below the right eye and at the outer canthi for monitoring blinks and eye movements. All electrodes were referenced online to the left mastoid, and impedances were maintained below 5 kΩ. EEG was amplified with an SA Instrumentation isolated bioelectric amplifier and digitized online at 250 Hz (bandpass, 0.01 to 40 Hz).

Offline re-referencing to averages of the right and left mastoids was performed after artifact removal. ERPs were time-locked to the onset of probe words, spanning a window from 100 msec before stimulus onset to 920 msec after. Only trials accurately categorized by participants were included in the averages. The mean artifact rejection rate was 17% ($SD = 10\%$) for related trials and 18% ($SD = 14\%$) for unrelated trials. On average, related bins contained 24 trials ($SD = 5$), and unrelated bins contained 27 trials ($SD = 7$).

Data analysis. Behavioral data were assessed with repeated measures ANOVA. With subjects as a random variable, response latencies were trimmed within 2 *SD*s of each subject's mean latency for both conditions (4% of related trials and 5% of unrelated trials were lost due to trimming); an additional analysis, with items (F2) as the random variable, was also conducted.

EEG analysis. Mean amplitude and peak latencies of probe words were measured from 300 to 500 msec, and from 500 to 900 msec poststimulus onset. Measurements underwent repeated measures ANOVA with the factors of word relatedness and electrode site. Scalp distribution of ERP effects was investigated as in Wu (2005). The p values were subjected to Greenhouse–Geisser correction (Greenhouse & Geisser, 1959) where appropriate, though original degrees of freedom are reported.

Results and Discussion

Behavioral responses. The participants accurately classified 71% of related words (SE = 2%) and 85% of unrelated words (SE = 3%). Greater accuracy for unrelated words [$F(1,11) = 5.4$, $p < .04$] reflects participants' bias toward the unrelated response. The mean classification time for related items was 967.2 msec (SE = 51), and 1,024 msec (SE = 77) for unrelated items. No effect of word relatedness was observed in either the subjects (F = 2) or items ($F < 1.5$, n.s.) analysis.

ERPs. ERPs to related and unrelated probe words are shown in Figure 1. Between 300 and 500 msec poststimulus, the amplitude of the negative component (N400) was considerably more negative in response to unrelated items, as indicated by a main effect of word relatedness (see Table 1). The N400 effect was maximal over central and centroparietal midline electrode sites (Cz and CPz), and was larger over posterior right hemisphere lateral electrode sites relative to corresponding ones over the left hemisphere (see Figure 2). From 500 msec to the end of the epoch (900 msec), unrelated words continued to elicit reliably more-negative ERPs with a similar centroparietal midline maximum.

Words related to preceding gestures elicited less N400 than unrelated ones, in keeping with the view that gestures activate information that facilitates lexical integration. However, ERPs to related words are also more positive-going than their unrelated counterparts in the latter portion of the epoch. This positivity likely means that such ERPs are members of the P300 family of potentials, which tend to be enhanced in response to targets presented in binary decision paradigms (for a review, see Kok, 2001). It is unclear to what degree the observed relatedness effect was driven by the binary word classification task, and to what degree it genuinely reflects facilitation of processes sensitive to the meaningful content of gestures.

EXPERIMENT 2

To eliminate ERP effects attributable to the classification task, we conducted a second experiment. A new group of volunteers was presented with the same gesture–word pairs, but was instructed only to attend to stimuli. Afterward, the participants received a surprise memory test assessing words recognized from the experiment. This test provided an indirect measure of attention to probes. We predicted that if gestures aid word comprehension, unrelated words would elicit a larger N400 than related ones.

Method

Fourteen volunteers participated in Experiment 2. Two individuals were excluded because of excessive artifacts in their EEGs. Twelve remaining volunteers (7 females, 5 males) were included in the final data set. Materials and presentation parameters were identical to those used in Experiment 1, with the exception that filler trials were omitted, yielding a stimulus set of 80 items. The volunteers were instructed to attend to video clips and words. The incidental memory test administered afterward contained all of the probe words presented during the experiment, along with 80 distractors. The EEG recording and analysis were carried out exactly as in Experiment 1. Critical bins contained an average of 34 trials (SD = 5). The mean artifact rejection rate was 14% (SD = 12%).

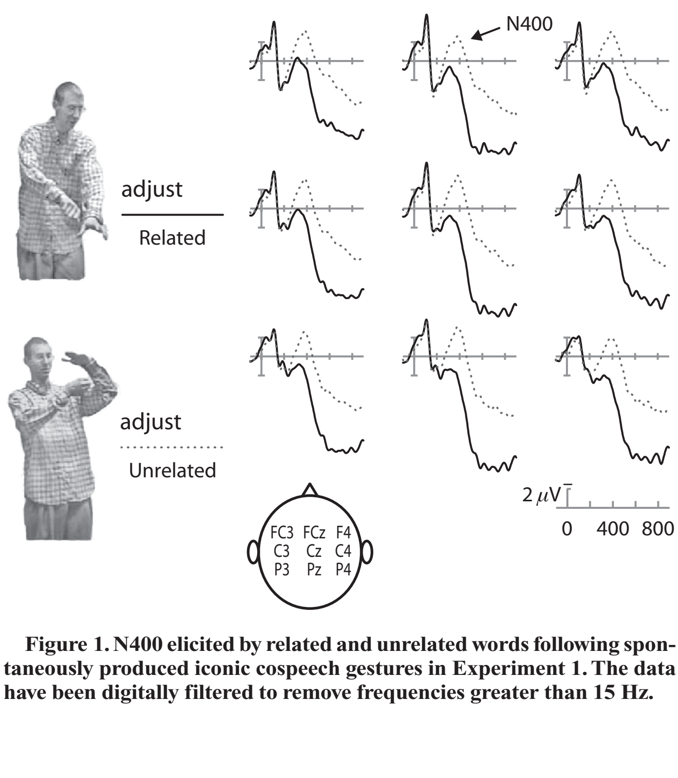

Figure 1. N400 elicited by related and unrelated words following spontaneously produced iconic cospeech gestures in Experiment 1. The data have been digitally filtered to remove frequencies greater than 15 Hz.

Table 1
Experiment 1: Analyses of Mean Amplitudes of ERPs Elicited by Probe Words

Time	Relatedness (R)			R × Posteriority (P)			R × Hemisphere (H)		R × H × P	
Interval (msec)	Midline $F(1,11)$	Medial $F(1,11)$	Lateral $F(1,11)$	Midline $F(6,66)$	Medial $F(6,66)$	Lateral $F(3,33)$	Medial $F(1,11)$	Lateral $F(1,11)$	Medial $F(6,66)$	Lateral $F(3,33)$
300–500	24.7***	26***	27.2***	2.9	1.1	1.1	1.9	4.5†	1.6	7.6**
500–900	35.8***	29.7***	15.5**	7.6**	4.4*	1.5	2.5	2.3	0.4	2.5

*$p < .05$. **$p < .005$. ***$p < .0005$. †$p = .06$.

Results and Discussion

Accuracy. On average, the participants accurately recognized 50% of probe words (*SD* = 17%): 27.5% of related words (*SD* = 9%) and 22.5% of unrelated ones (*SD* = 11%). This difference approached significance in a two-tailed matched pairs *t* test [$t(11) = -1.9$, $p = .09$].

ERPs. As shown in Figure 3, unrelated words consistently elicited more-negative ERPs than related ones between 300 and 500 msec, and 500 to 900 msec poststimulus (see Table 2). These outcomes demonstrate that even without explicit analysis, the visuospatial cues provided by gestures make the comprehension of related words easier.

GENERAL DISCUSSION

To assess priming by spontaneous iconic gestures, we recorded ERPs while healthy adults watched soundless gesture clips followed by related and unrelated probe words, in two experiments. In Experiment 1, the participants judged the relatedness between gestures and probe words. When collapsed across lists, the same probes appeared in both related and unrelated trials; however, related words were classified less accurately than unrelated ones (71% vs. 85% for unrelated words), indicating that in the absence of supporting context, the intended meaning of gestures was apprehended with difficulty, though at an above-chance rate.

Moreover, ERPs to related and unrelated probe words differed approximately 350 msec after stimulus onset. This effect exhibited a centroparietal, right-hemisphere-lateralized distribution, which is typical of the N400 effects reported in other studies of visually presented words (Kutas, Van Petten, & Besson, 1988). Unrelated words elicited larger-amplitude N400 than related ones. In Experiment 2, the participants were instructed simply to attend to gestures and words; recognition of incidentally encoded words was measured after the EEG recording session. As expected, unrelated words elicited larger N400 than related ones. Although more broadly distributed than in Experiment 1, this effect also appeared larger over right hemisphere electrode sites. Differences in topography of N400 effects observed in the two experiments may be attributed to different demands of the categorization and recognition tasks.

Outcomes from Experiment 2 demonstrate that even when no explicit relatedness judgment is required, gestures nevertheless benefit the processing of words. This result is consistent with numerous other studies reporting N400 context effects, regardless of whether participants are asked to make explicit semantic judgments. N400 effects have been observed for targets in masked priming paradigms in which participants are unable to report the

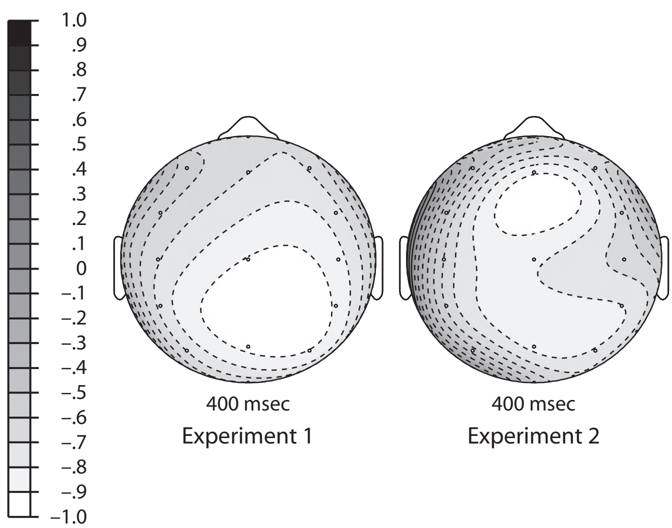

Figure 2. Topography of the N400 effect in Experiments 1 and 2.

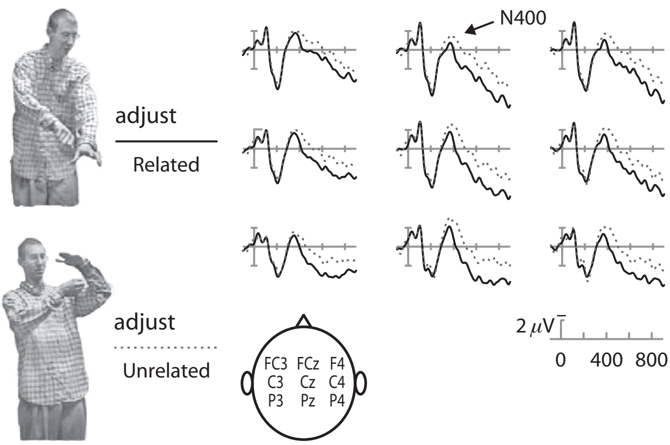

Figure 3. N400 elicited by related and unrelated words following spontaneously produced iconic cospeech gestures in Experiment 2.

prime (Deacon, Hewitt, Yang, & Nagata, 2000), and in attentional blink paradigms in which participants are unable to report the target (Luck, Vogel, & Shapiro, 1996). Indeed, with sufficient contextual support, N400 effects begin before word recognition is complete (Van Petten, Coulson, Rubin, Plante, & Parks, 1999).

Response latencies also reflected sensitivity to word relatedness. On average, individuals classified related words 57 msec faster than unrelated ones, though this effect did not exceed the threshold of conventional significance. Nonsignificant effects here may be due to the relatively small sample size.

In the present study, gestures may have activated semantic or associative information related to referents whose visuospatial properties were consistent with the gestures' semiotic features. We suggest that these activations were sufficient to reliably facilitate the integration processes indexed by the N400, but not those required for the relatedness judgment task. This pattern is similar to that reported in a study investigating semantic priming by words whose referents bear visuoperceptual resemblances to the referent denoted by the target word (e.g., *button–coin*), in which an N400 effect was reported, but behavioral effects were nonsignificant (Kellenbach, Wijers, & Mulder, 2000). Similarly, Pecher, Zeelenberg, and Raaijmakers (1998) report that RTs revealed evidence of visuoperceptual semantic priming only in cases in which participants were induced to process perceptual properties associated with words, and to avoid relatedness-checking strategies. Thus, it is possible that some behavioral tasks may not be sensitive to the preactivation of visuosemantic features of words.

The iconic gestures studied here fall midway between pointing gestures (Kelly et al., 2004) and symbolic hand signs (Gunter & Bach, 2004) studied previously, in terms of their similarity to linguistic systems such as English or ASL. Like linguistic symbols, emblematic hand signs such as the "thumbs up" gesture are conventionalized and arbitrarily[1] related to their referents. In contrast, the link between iconic gestures and their referents is based on fairly abstract perceptual similarities. Moreover, although an essential property of language is displacement, or the capacity to communicate things that are not currently present, pointing gestures, as studied in Kelly et al., 2004, are meaningful because their referent is copresent. By contrast, the iconic gestures we used were presented in the absence of their referents. Further, in contrast to methods used in previous research on the brain response to gestures, our gesture stimuli were not artificially generated by actors, but emerged naturally from speakers in the course of authentic communicative situations.

What does the finding of lexical priming by iconic gestures reveal about comprehension in natural conversation, in which talk and gesture unfold together across both visual and auditory modalities? Our findings suggest that iconic gestures activate meaning-based representations that are compatible with linguistic surface forms, in keeping with other studies showing cross-modal priming of words by pictures (Carr, Sperber, McCauley, & Parmalee, 1982; Hines, 1993; Pratarelli, 1994; Vander-

Table 2
Experiment 2: Analyses of Mean Amplitudes of ERPs Elicited by Probe Words

Time	Relatedness (R)			R × Posteriority (P)			R × Hemisphere (H)		R × H × P	
Interval (msec)	Midline *F*(1,11)	Medial *F*(1,11)	Lateral *F*(1,11)	Midline *F*(6,66)	Medial *F*(6,66)	Lateral *F*(3,33)	Medial *F*(1,11)	Lateral *F*(1,11)	Medial *F*(6,66)	Lateral *F*(3,33)
300–500	6.7*	5.8*	2.9	0.8	0.4	0.4	2.7	6.3*	1.5	1.3
500–900	5.6*	5.2*	3.5	1.0	0.5	1.1	1.2	3.1	1.2	0.6

*$p < .05$.

wart, 1984), and lexical priming on the basis of visuoperceptual similarities between the referents of two words (Kellenbach et al., 2000). Comprehension processes prompted by iconic gestures may not dramatically differ from those prompted by other contentful representations, such as words and pictures. Whether iconic gestures facilitate speech comprehension is a matter for further investigation.

This study enhances the current field of gesture research in two important ways. First, it investigates real-time processes mediating multimodal discourse comprehension, complementing previous behavioral research on the communicative value of iconic gestures. Second, it provides evidence that body movements that are neither conventionally meaningful nor copresent with their referent can affect the processing of related words. Our finding that spontaneously produced iconic gestures prime related concepts suggests commonalities in the processing induced by iconic gestures with that prompted by entrenched hand signs (Gunter & Bach, 2004) as well as pointing gestures made in the presence of their referents (Kelly et al., 2004). The findings reported here indicate that the abstract interpretation of human biological movement can affect the comprehension of linguistic surface forms.

AUTHOR NOTE

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REFERENCES

Alibali, M. W., Flevares, L. M., & Goldin-Meadow, S. (1997). Assessing knowledge conveyed in gesture: Do teachers have the upper hand? *Journal of Educational Psychology*, **89**, 183-193.

Barrett, S. E., & Rugg, M. D. (1990). Event-related potentials and the semantic matching of pictures. *Brain & Cognition*, **14**, 201-212.

Bavelier, D., Corina, D., Jezzard, P., Clark, V., Karni, A., Lalwani, A., et al. (1998). Hemispheric specialization for English and ASL: Left invariance–right variability. *NeuroReport*, **9**, 1537-1542.

Beattie, G., & Shovelton, H. (1999). Mapping the range of information contained in the iconic hand gestures that accompany spontaneous speech. *Journal of Language & Social Psychology*, **18**, 438-462.

Beattie, G., & Shovelton, H. (2002). An experimental investigation of some properties of individual iconic gestures that mediate their communicative power. *British Journal of Psychology*, **93**, 179-192.

Carr, T. H., Sperber, R. D., McCauley, C., & Parmalee, C. M. (1982). Words, pictures, and priming: On semantic activation, conscious identification, and the automaticity of information processing. *Journal of Experimental Psychology: Human Perception & Performance*, **8**, 757-777.

Cassell, J., McNeill, D., & McCullough, K.-E. (1999). Speech–gesture mismatches: Evidence for one underlying representation of linguistic and nonlinguistic information. *Pragmatics & Cognition*, **7**, 1-34.

Deacon, D., Hewitt, S., Yang, C.-M., & Nagata, M. (2000). Event-related potential indices of semantic priming using masked and unmasked words: Evidence that the N400 does not reflect a post-lexical process. *Cognitive Brain Research*, **9**, 137-146.

Ganis, G., Kutas, M., & Sereno, M. I. (1996). The search for "common sense": An electrophysiological study of the comprehension of words and pictures in reading. *Journal of Cognitive Neuroscience*, **8**, 89-106.

Goldin-Meadow, S., & Sandhofer, C. M. (1999). Gesture conveys substantive information about a child's thoughts to ordinary listeners. *Developmental Science*, **2**, 67-74.

Greenhouse, S. W., & Geisser, S. (1959). On methods in the analysis of profile data. *Psychometrika*, **24**, 95-112.

Gunter, T. C., & Bach, P. (2004). Communicating hands: ERPs elicited by meaningful symbolic hand postures. *Neuroscience Letters*, **372**, 52-56.

Hines, D. (1993). Effect of masked picture primes on semantic priming for easy- and difficult-to-name words. *Journal of General Psychology*, **120**, 149-169.

Holcomb, P. J., & Neville, H. J. (1990). Auditory and visual semantic priming in lexical decision: A comparison using event-related brain potentials. *Language & Cognitive Processes*, **5**, 281-312.

Kellenbach, M. L., Wijers, A. A., & Mulder, G. (2000). Visual semantic features are activated during the processing of concrete words: Event-related potential evidence for perceptual semantic priming. *Cognitive Brain Research*, **10**, 67-75.

Kelly, S. D., Kravitz, C., & Hopkins, M. (2004). Neural correlates of bimodal speech and gesture comprehension. *Brain & Language*, **89**, 243-260.

Kok, A. (2001). On the utility of P3 amplitude as a measure of processing capacity. *Psychophysiology*, **38**, 557-577.

Krauss, R. M., Morell-Samuels, P., & Colasante, C. (1991). Do conversational hand gestures communicate? *Journal of Personality & Social Psychology*, **61**, 743-754.

Kutas, M., & Hillyard, S. A. (1980). Event-related potentials to semantically inappropriate and surprisingly large words. *Biological Psychology*, **11**, 99-116.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature*, **307**, 161-163.

Kutas, M., Van Petten, C. K., & Besson, M. (1988). Event-related potential asymmetries during the reading of sentences. *Electroencephalography & Clinical Neurophysiology*, **69**, 218-233.

Luck, S. J., Vogel, E. K., & Shapiro, K. L. (1996). Word meanings can be accessed but not reported during the attentional blink. *Nature*, **383**, 616-618.

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

McPherson, W. B., & Holcomb, P. J. (1999). An electrophysiological investigation of semantic priming with pictures of real objects. *Psychophysiology*, **36**, 53-65.

Neville, H. J., Coffey, S. A., Lawson, D. S., Fischer, A., Emmorey, K., & Bellugi, U. (1997). Neural systems mediating American Sign Language: Effects of sensory experience and age of acquisition. *Brain & Language*, **57**, 285-308.

Nuwer, M. R., Comi, G., Emerson, R., Fuglsang-Frederiksen, A., Guerit, J. M., Hinrichs, H., et al. (1999). IFCN standards for digital recording of clinical EEG. The International Federation of Clinical Neurophysiology. *Electroencephalography & Clinical Neurophysiology*, **52**(Suppl.), 11-14.

Pecher, D., Zeelenberg, R., & Raaijmakers, J. G. W. (1998). Does pizza prime coin? Perceptual priming in lexical decision and pronunciation. *Journal of Memory & Language*, **38**, 401-418.

Pratarelli, M. E. (1994). Semantic processing of pictures and spoken words: Evidence from event-related brain potentials. *Brain & Cognition*, **24**, 137-157.

Rogers, W. T. (1978). The contribution of kinesic illustrators toward the comprehension of verbal behavior within utterances. *Human Communication Research*, **5**, 54-62.

Sitnikova, T., Kuperberg, G., & Holcomb, P. J. (2003). Semantic integration in videos of real-world events: An electrophysiological investigation. *Psychophysiology*, **40**, 160-164.

Valenzeno, L., Alibali, M. W., & Klatzky, R. (2003). Teachers' gestures facilitate students' learning: A lesson in symmetry. *Contemporary Educational Psychology*, **28**, 187-204.

Vanderwart, M. (1984). Priming by pictures in lexical decision. *Journal of Verbal Learning & Verbal Behavior*, **23**, 67-83.

Van Petten, C., Coulson, S., Rubin, S., Plante, E., & Parks, M. (1999). Time course of word identification and semantic integration in spoken language. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, **25**, 394-417.

Van Petten, C., & Kutas, M. (1990). Interactions between sentence context and word frequency in event-related brain potentials. *Memory & Cognition*, **18**, 380-393.

Wu, Y. C. (2005, August). Meaning in gestures: What event-related potentials reveal about processes underlying the comprehension of iconic gestures. *Newsletter of the Center for Research in Language*, **17**(2). Retrieved January 31, 2007, from crl.ucsd.edu/newsletter/17-2/17-2.pdf.

Wu, Y. C., & Coulson, S. (2005). Meaningful gestures: Electrophysiological indices of iconic gesture comprehension. *Psychophysiology*, **42**, 654-667.

NOTE

1. Some analysts might argue that emblems exploit metaphoric iconicity; however, such mappings are even more abstract than those necessary for the interpretation of iconic gestures used in the present study.

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