Brain and Cognition 70 (2009) 42–52

Contents lists available at ScienceDirect

Brain and Cognition

journal homepage: www.elsevier.com/locate/b&c

Gesture and metaphor comprehension: Electrophysiological evidence of cross-modal coordination by audiovisual stimulation

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ARTICLE INFO

Article history:
Accepted 7 December 2008
Available online 5 February 2009

Keywords:
Gesture
Metaphor
Stroke
Video
N400
LPC
Multimodal integration

ABSTRACT

In recent years, studies have suggested that gestures influence comprehension of linguistic expressions, for example, eliciting an N400 component in response to a speech/gesture mismatch. In this paper, we investigate the role of gestural information in the understanding of metaphors. Event related potentials (ERPs) were recorded while participants viewed video clips of an actor uttering metaphorical expressions and producing bodily gestures that were congruent or incongruent with the metaphorical meaning of such expressions. This modality of stimuli presentation allows a more ecological approach to meaning integration. When ERPs were calculated using gesture stroke as time-lock event, gesture incongruity with metaphorical expression modulated the amplitude of the N400 and of the late positive complex (LPC). This suggests that gestural and speech information are combined online to make sense of the interlocutor's linguistic production in an early stage of metaphor comprehension. Our data favor the idea that meaning construction is globally integrative and highly context-sensitive.

1. Introduction

Ordinary language demands the integration of multiple elements other than speech in real time, such as contextual information, gestures, and bodily postures (Clark, 1996; Kelly, Barr, Church, & Lynch, 1999; Krauss, 1998; Krauss, Morrel-Samuels, & Colasante, 1991; McNeill, 1992). Although this applies to most linguistic exchanges, such integration should be more evident when highly contextualized forms of language are used. One of these cases is figurative language, where bodily expressions – particularly facial and hand gestures – seem to play an important role in comprehension (McNeill, 2000). Production and comprehension of metaphor, for example, appears to be a strongly contextualized linguistic phenomenon (Cornejo, 2007; Leezenberg, 2001; Shanon, 1993). In the neuroscience field the contextualized approach to metaphorical comprehension has recently emerged as a topic of interest (e.g., Coulson & Van Petten, 2002; Pynte, Besson, Robichon, & Poli, 1996). Following this line of thought, the question we intend to address in this paper is whether bodily information influences the comprehension of abstract expressions such as those involved in metaphorical understanding. Particularly, we investigate the electrophysiological correlates of cross-modal semantic integration of gesture and speech in the comprehension of metaphorical expressions.

Some studies have used event related potentials (ERPs) to investigate particular aspects of metaphorical language processing. For example, in a pioneer study, Pynte et al. (1996) compared familiar and unfamiliar metaphors with literal sentences, showing enhanced N400 amplitude for metaphors in comparison to those in literal sentences. Interestingly, the authors also found an effect of the preceding context (irrelevant or relevant sentences added to the target sentences), suggesting that meaning construction of a metaphorical expression is sensitive to the sentence context. Later studies have confirmed that metaphors produce a larger N400. For example, it is known that the N400 elicited by metaphorical expressions is also modulated by familiarity of the expression (Coulson & Van Petten, 2002; Coulson & Van Petten, 2007; Tartter, Gomes, Dubrovsky, Molholm, & Stewart, 2002) and by individual differences (Kazmerski, Blasko, & Dessalegn, 2003; Kazmerski, Blasko, & Marroquin, 2003).

It is important to note that these studies have been carried out using written and unimodal stimuli. This approach, although experimentally useful, is less ecologically valid and has the disadvantage of ignoring non-linguistic cues. In fact, co-speech gestures seem to improve language comprehension, for example, directing attention (Goodwin, 2000), modulating speech acts (Kendon, 2000), and illustrating elements of the speaker's conceptual world

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doi:10.1016/j.bandc.2008.12.005

(McNeill, 1992). Gesture also plays an important role during the critical period of language development (Bates & Dick, 2002; Goldin-Meadow, Nusbaum, Kelly, & Wagner, 2001; Hadar, Wenkert-Olenik, Krauss, & Soroker, 1998; Iverson & Goldin-Meadow, 1998; McNeill, 1992; Morrel-Samuels & Krauss, 1992; Rauscher, Krauss, & Chen, 1996).

So-called non-linguistic cues are also co-produced with metaphorical language. For example, several observational and ethnographic studies show that people produce relevant spontaneous gestures accompanying speech when talking about mathematics (Núñez, 2004), time (Núñez & Sweetser, 2006), kinship (Enfield, 2005), and other abstract concepts across cultures (Cienki, 1998; Kita, Danziger, & Stolz, 2001; McNeill, 1992). Gestural and emotional information appear to be present during the production of metaphorical utterances, manifesting themselves quite clearly in figurative language (Gibbs, Leggitt, & Turner, 2002). For a comprehensive review on gesture and metaphor see Cienki and Müller (2008).

In order to address bodily dimensions of human communication, some studies have begun to introduce non-verbal stimuli in their experimental designs (Coulson, 2004). A more natural approach to the study of everyday language comprehension can be achieved using video clips. Videos elicit experiences similar to the perception of events in the real world (Levin & Simons, 2000) and they can be used to obtain ERPs during their exposure. Sitnikova, Kuperberg, and Holcomb (2003) reported that observing incongruent actions during a video exposition elicit a negative trend in the ERP that can be associated to the N400. Similarly, ERPs registration during video presentation has been used to study integration of speech and hand-gesture (Kelly, Kravitz, & Hopkins, 2004; Kelly, Ward, Creigh, & Bartolotti, 2007; Wu & Coulson, 2005; Özyüreck, Willems, Kita, & Hagoort, 2007). Kelly et al. (2004) showed short videos displaying sentences with co-occurring gestures, and found that gesture modulates ERPs, specifically the N400 component. Mismatched gestures produced amplitude differences at earlier and later periods compared to matching gestures. They concluded that gestural information is integrated into discourse at a very early stage of language processing. In addition, Kelly et al. (2007) found different patterns for the gesture-speech integration, modulated by pragmatic knowledge about the accidental or purposeful nature of the mismatch.

In summary, the N400 has been classically reported as a reflection of semantic expectancy violation (Kutas, Van Petten, & Kluender, 2006). There is evidence of N400 modulation by gesture incongruity with literal expressions and by sentential context incongruity with metaphorical meaning. In real life, gesture information should also be integrated online in the process of making sense of metaphors. In this line, incongruity between co-occurring gestures with metaphorical expressions should also modulate the amplitude of N400 and should, therefore, be considered as important as linguistic contextual data (see for example, Pynte et al., 1996).

The present study intends to present electrophysiological evidence of the integration of gestural information during the comprehension of metaphors. We hypothesized that gestural information is processed and integrated at very early stages of metaphorical comprehension. We recorded ERPs while participants viewed short video streams of a person uttering metaphorical expressions co-produced with bodily gestures that were either congruent or incongruent with the metaphorical meaning of such expressions. If gestures were incongruent with the metaphor, it would create a conflict that may be electrophysiologically identifiable by means of a modulation of the N400 component.

2. Methods

2.1. Participants

Eighteen undergraduates (10 men, 8 women) voluntarily agreed to participate in the study, signing a written consent. They were all right-handed according to the Edinburgh Handedness Inventory (Oldfield, 1971). The mean age of the participants was 23 years (SD 2 years). All of them were monolingual, native Spanish speakers. None of them had personal or family histories of neurological or psychiatric disease. For the electrophysiological analysis we considered 15 participants. Three participants were excluded due to an excessive number of artifacts in the EEG.

2.2. Stimuli construction

2.2.1. Frequency use

The terminal words of an initial list of metaphorical and literal sentences were tested for frequency use by means of the Lifcach software (Sadowsky & Martínez, 2003). We selected words with a moderate-high frequency level.

2.2.2. Metaphoricity of the linguistic stimuli

In order to measure the degree of metaphoricity of the stimuli, 50 undergraduate students rated 136 sentences according to their degree of metaphoricity. Half of the sentences were literal expressions. Students rated the sentences on a 0–100 scale from literal to metaphoric (0 = maximal literality; 100 = maximal metaphoricity). The sentences were pseudo-randomly assigned into four subgroups (Literal 1 and Literal 2; Metaphoric 1 and Metaphoric 2). The average score with metaphorical sentences (82.05 ±, 13.74) was clearly different than with the literal ones (10.11 ±, 12.17) ($F\,(1,49) = 1768.7$, $p = <0.01$). The two subgroups of metaphorical expressions, however, did not present a significant differences in their rating averages (metaphor list 1: 81.44 ± 13.74; versus metaphor list 2: 82.49 ± 11.08) ($F\,(1,49) = 0.16$, $p > .05$).

2.2.3. Materials

Sixty-eight metaphors were used to record the video clips of an actor uttering them with congruent and incongruent gestures. The actor was instructed to sit on a chair and utter verbal expressions co-produced with specific gestures involving only hands and arms. He was also instructed to suppress salient facial gestures, to maintain eye contact with the camera, and to keep the body centered, keeping irrelevant or additional movements to a minimum. In order to maintain a constant speech rhythm he used a small metronome behind his right ear. The metronome's pulse was kept constant throughout the recordings.

Half of the video streams contained gestures congruent with the metaphorical meaning of the expression and the other half contained incongruent gestures. All expressions had the same basic syntactic structure: "THOSE X ARE Y" where "Y" corresponded to a tri- or bi-syllabic word accompanying the gesture stroke.

The production of the gesture usually began in the middle of the first word of the metaphorical expression, with the stroke coinciding with the pronunciation of the second and final word. In order to obtain a sense of congruity with the whole utterance, gestures always referred to the metaphorical meaning of the expression, that is, they were not related to the literal meaning of the last word ("Y"). We excluded from the study iconic gestures that referred to the second word. For instance, when the actor uttered *Esos hombres son luces* ("Those men are lights"), he moved his right hand, opening his fingers from head upwards, indicating mind openness (see Fig. 1A). Although this is valid for most of the stimuli, in some cases a certain iconic similarity still remained (see for example

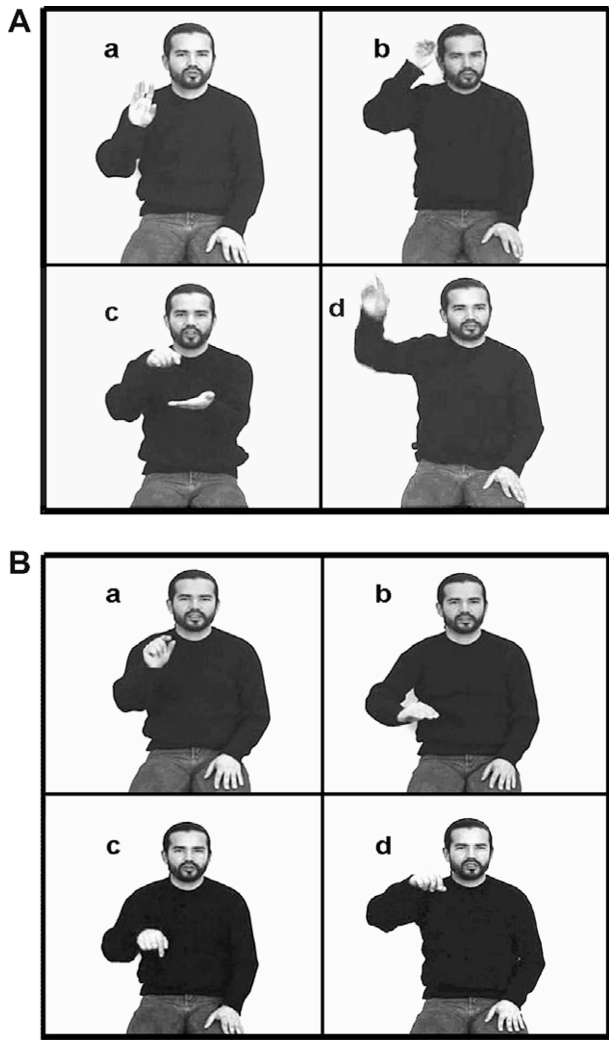

Fig. 1. (A) Examples of metaphorical expressions uttered with congruent gestures. Co-produced with the Spanish sentence (a) *Esos vendedores son loros* ("Those salesmen are parrots"), the right hand moves upwards to the level of the shoulder (palm facing out) while repeatedly closing and opening fingers and opposed thumb, evoking the idea of a mouth speaking too much; (b) *Esos hombres son luces* ("Those men are lights"), the right hand moves upwards, touches the right temple and projects a diagonal upward and outward movement. At the same time the hand opens to indicate open-mindedness; (c) *Esas secretarias son relojes* ("Those secretaries are clocks"), with both arms relatively extended the right index finger moves straight down until it touches the upward-facing open palm of the left hand, indicating punctuality; (d) *Esas jóvenes son aviones* ("Those young women are airplanes"), with the hand in a standard pointing position, the right index finger moves rapidly from the center up toward the right, indicating speed. (B) Examples of metaphorical expressions uttered with incongruent gestures. (a) *Esos pies son lanchas* ("Those feet are motorboats"), thumb and index finger come closer together, indicating something tiny; (b) *Esos jóvenes son jirafas* ("Those young people are giraffes"), right hand open palm facing down is placed slightly above the waist, indicating short height; (c) *Esos proyectos son historia* ("Those projects are history"), index finger moving straight downwards, indicating present time; (d) *Esos puños son acero* ("Those fists are steel"), right thumb delicately rubs the tip of index and middle fingers, indicating softness.

expression d in Fig. 1A). Regarding the incongruent gestures, they had the same timing as the congruent ones, but they suggested the opposite meaning from the metaphorical sense of the expression. For example, while the actor said *Esos proyectos son historia* ("Those projects are history"), his index finger moved straight downwards at the center, indicating present time. The sense of "present, now" is clearly contradictory with the metaphorical meaning of "Those projects are history", which in Spanish means roughly "Those projects are obsolete" (see Fig. 1B(c)). Appendix A shows examples in the original Spanish version with the corresponding approximate English translation with gesture descriptions (congruent and incongruent).

The videos were recorded with a digital Mini-DV Panasonic camera and were later displayed with the software Presentation (Neurobehavioral Systems) on a PC. The duration of the stimuli was controlled in each one of the videos reaching an average of 4 s. The average duration of the auditory sentences was 1.647 ms; SD 0.150; final words had an average duration of 0.695; SD 0.106. For all video clips relevant features of the stimuli were controlled considering four different dimensions: the moment when the gesture starts (on average 1.59 s; SD 0.34); the time at which the stroke appears (on average 2.47 s; SD 0.39); the time point when the last word begins (on average 2.06 s; SD 0.33); and the temporal difference between the beginning of the word and the gesture stroke (on average 0.41 s; SD 0.21). Gesture strokes appeared in all clips immediately after the word onset. However, when the starting time of gestures is considered, the preparatory phase of the gestures anticipated the corresponding co-expressive speech. This anticipation of gesture has been previously documented (Krauss, 1998; McNeill, 1992).

Finally, additional analyses ensured that there were no major differences across relevant dimensions between the list of metaphors that appeared with congruent gestures and the list that appeared with incongruent gestures (last word frequency (t (66) = 0.33; $p > 0.5$); gesture starting time (t (66) = 1.03; $p > .05$); stroke timing (t (66) = 0.53; $p > 05$), last word starting time (t (66) = 1.59; $p > .05$); temporal difference between the beginning of the word and the stroke (t (66) = 1.52; $p > .05$)).

2.3. Stimuli validation

To validate the final stimulus set, we conducted a validation study in which participants were instructed to classify the gesture accompanying the metaphorical expression as congruent or incongruent pressing two different keys. The accuracy of the responses and reaction times (RTs) were measured (see Fig. 2A). Observations lying outside the normal time limit parameters (i.e, those lying beyond 2.7 SD from average for both conditions) were rejected for any further analysis. They represented less than 3% of the original sample.

One hundred twelve undergraduate students from the Pontificia Universidad Católica de Chile voluntarily participated in this validation process (55 men and 57 women, average age 19.8 years, ±1.6). They agreed to collaborate by signing an informed consent form. They were all right-handed according to the Edinburgh Handiness Inventory (Oldfield, 1971). All of them were monolingual, native Spanish speakers. None of them had personal or family history of neurological, psychiatric diseases, or hearing deficits.

Participants were highly accurate when classifying the metaphorical expressions according to congruent and incongruent gestures. The mean accuracy percentage was 91.75% (SD 7.04) for congruent gestures and 89.93% (SD 8.42) for incongruent gestures. In addition, metaphorical expressions uttered along with incongruent gestures resulted in slower RTs than with congruent ones. Table 1 shows mean RTs, standard deviation and accuracy by type of gesture. According to a repeated measures ANOVA, no difference was found between congruent or incongruent gestures with respect to the accuracy of the responses ($p < .01$). Congruent gestures, however, elicited significantly faster RTs than incongruent ones ($F(1,110) = 77.1$, $p < .01$). These results assured the quality of the stimuli for the electrophysiological study.

In the experiment, participants were instructed to only observe the video clips. They were not asked to classify them (see Fig. 2B). In order to ensure that participants were paying attention to the videos, they were informed that at the end of the experiment they

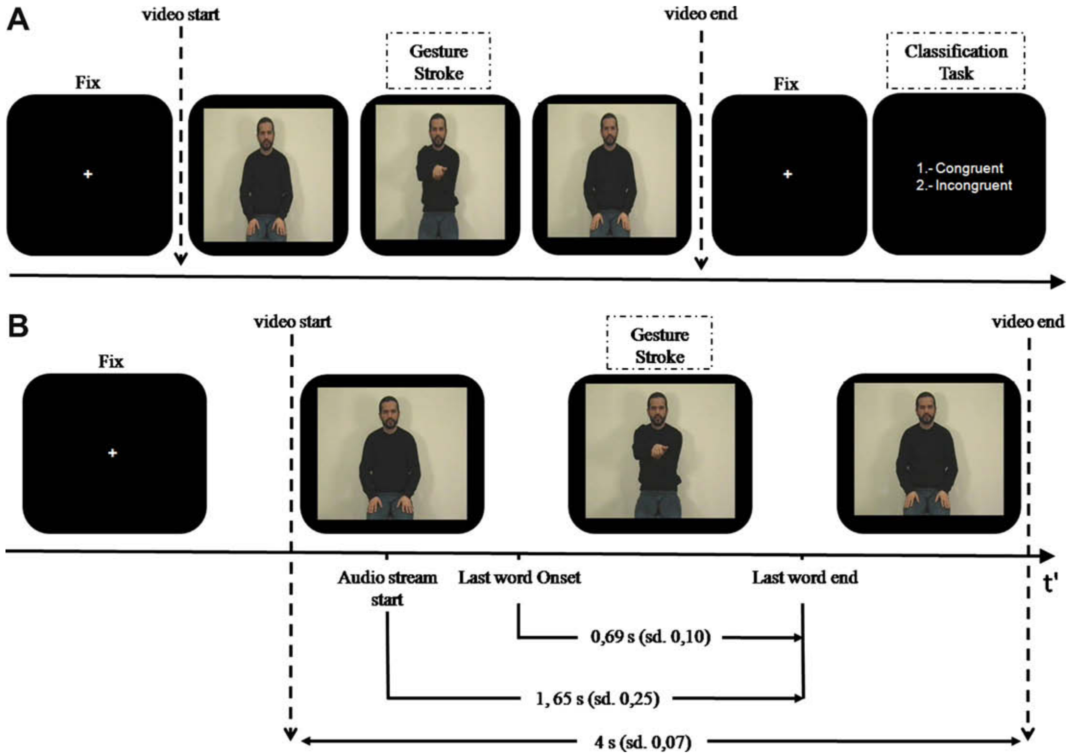

Fig. 2. (A) Example of a trial used in the stimuli validation study. Immediately after the visualization of the stimulus participants had to classify the gestures as congruent or incongruent. (B) Example of a trial used during EEG recording. Participants only had to watch the clips without making any classification judgments for congruent or incongruent gestures.

Table 1
Reaction times (RTs) and accuracy in the validation study. The table shows the RTs average in ms and the percentages of accurate responses, standard deviations (SD) and percentile range (5–95) for both type of gestures (congruent and incongruent) co-occurring with metaphorical expressions.

	RT (ms)		Accuracy		
	Mean	SD	%	SD	Percentile range (5–95)
Congruent	1822	618	91.75	7.04	71.85–97.00
Incongruent	2148	869	89.93	8.42	65.85–96.00

would be asked several questions about the contents of the video clips.

2.4. Electrophysiological recording

Signals were recorded on-line using a 64-channel system from Electrical Geodesic Inc (see Fig. 3) with a 16-bit A/D converter and the NetStationTM software. Analog filters were 0.1 and 100 Hz. A band pass digital filter between 0.5 and 30 Hz was later applied to remove unwanted frequency components. Signals were sampled at 1000 Hz and then re-sampled at 250 Hz to reduce file size. During recordings the reference was set by default to vertex but later we calculated and applied a linked mastoid reference. Two bipolar derivations were used to monitor vertical and horizontal ocular movements (EOG). Continuous EEG data were segmented from 200 ms prior to the time-locked event to 800 ms after it. All segments with eye movement contamination, or any other artifact, were excluded from further analysis. Segments were rejected if they met one of the following criteria: the signal amplitude exceeding 250 mV; running average exceeding 150 mV; EOG artifact occurred. The average number of artifact-free trials was 29 ± 3.4 in the congruent condition and 28.3 ± 4.2 in the incongruent condition. Data were corrected with a 200 ms baseline. The

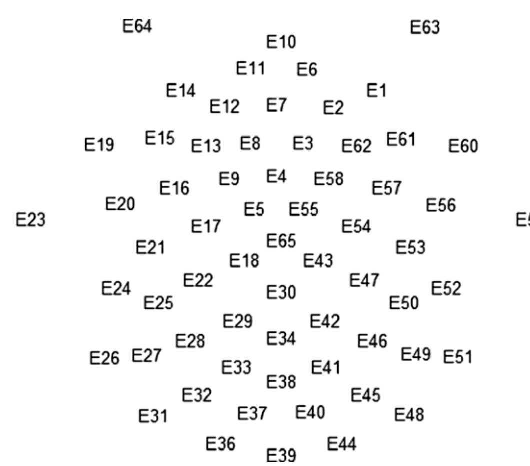

Fig. 3. Electrode location for 64-channels.

EEGLab Matlab toolbox was used for EEG off-line processing and analysis (Delorme and Makeig, 2004).

2.5. Data analysis

We compared the pattern of electrophysiological activity recorded while participants observed the selected video clips. ERPs were analyzed using two different time-locking events: (a) the onset of the critical word (the final word of the metaphorical expression); and (b) the onset of the stroke of the accompanying gesture. Three ERP components were identified: early negativity, N400, and late positive complex (LPC). The amplitude of each component was measured for each experimental condition. Time windows around the maximum amplitude difference between conditions were selected and the mean value was calculated in the segments: 170–350 ms, for the early negativity; 350–650 ms, for the N400; and 650–900 ms, for the LPC.

Regions of interest (ROI) were used to represent the scalp topography of the ERP components when necessary. Groups of electrodes were collapsed into these regions in order to avoid loss of statistical power (Oken & Chiappa, 1986). Five ROIs were selected to conduct this analysis: left anterior ROI (LA: E8, E9, E11, E12, E13, E14, E15, E16, E19); right anterior ROI (RA: E3, E58, E6, E2, E62, E1, E61, E57, E60); central midline ROI (CM: E5, E17, E18, E22, E30, E43, E47, E54, E55); left posterior ROI (LP: E37, E33, E29, E36, E32, E28, E22, E31, E27); and right posterior ROI (RP: E40, E41, E42, E44, E45, E46, E47, E48, E49). Although the figures show the ERPs grand averages for each group, all statistical calculations were done using individual waveforms. Several ANOVAs of repeated measures were performed. For N400 and LPC window and for both onsets (word and stroke) univariate comparisons were done for two factors: gesture category (congruent and incongruent) and electrode position (ROIs). Results were corrected with the Greenhouse-Geisser and Bonferroni's methods to adjust the univariate output of repeated measures ANOVA for violations of the compound symmetry assumption. After ANOVA, post hoc comparisons (LSD test, Bonferroni corrected) were performed for relevant comparisons (these post-hoc tests were performed only on variables with significant univariate *F*-values).

3. Results

3.1. Word onset ERPs

When word onset was selected as the time-locked event sentences with congruent and incongruent gestures elicited very similar ERPs waveforms (see Fig. 4). No differences were found in the time window of N400 (350–650 ms). A small difference was observed at a late latency (700–900 ms). A repeated measures ANOVA (Condition × ROIs) was performed to compare the late negativity amplitude across conditions. Although an interaction effect was obtained (F (2,28) = 4.61, p = .034), no significant main effect was found for the factor "Condition" (F (1,13) = 1.39; p < .15). Post hoc comparisons (LSD test, Bonferroni corrected, MS = 0.29214, df = 14.000) revealed no statistical differences between the congruent and incongruent categories.

3.2. Gesture stroke ERPs

When the onset of gesture stroke was selected as the time-locked event, the expressions with congruent and incongruent gestures elicited different ERPs waveforms (see Fig. 5). The largest effect concentrated on the left-frontal and right-posterior ROIs. A bilateral frontal negativity was associated with incongruent gestures. A clear dipolar voltage pattern was identifiable displaying negativity at left anterior sites and a positivity at right posterior sites. This effect is inverted for the congruent gesture condition, showing an interaction between gesture congruity and topography.

A two factors repeated measures ANOVA (Congruity X Topography) was conducted at the three temporal windows previously described. The levels of gesture congruity were Incongruent Gesture and Congruent Gesture, while the levels for topography were Left Anterior, Central Midline, and Right Posterior ROIs. Table 2 shows the mean amplitude (and SD) for the early negativity, N400, and LPC in the congruent and incongruent conditions.

In the 170–350 ms epoch the ERPs appeared to be more negative at the left-anterior sites in the incongruent than in the congruent gesture condition. The reversed occurred at right-posterior sites. These differences, however, yielded no statistical significance (F (2,28) = 1.41, p > .05).

In the epoch of 350–650 ms, incongruent gestures elicited a large negativity at the left-frontal ROI and a moderate positivity at the right-posterior ROI in comparison with the waveform elicited by congruent gestures. The interaction between congruity and topography was statistically significant (F (2,28) = 6.83, p < .01). Post-hoc comparisons (LSD test, Bonferroni corrected, MS = 3.38102, df = 28.000) revealed statistical differences between

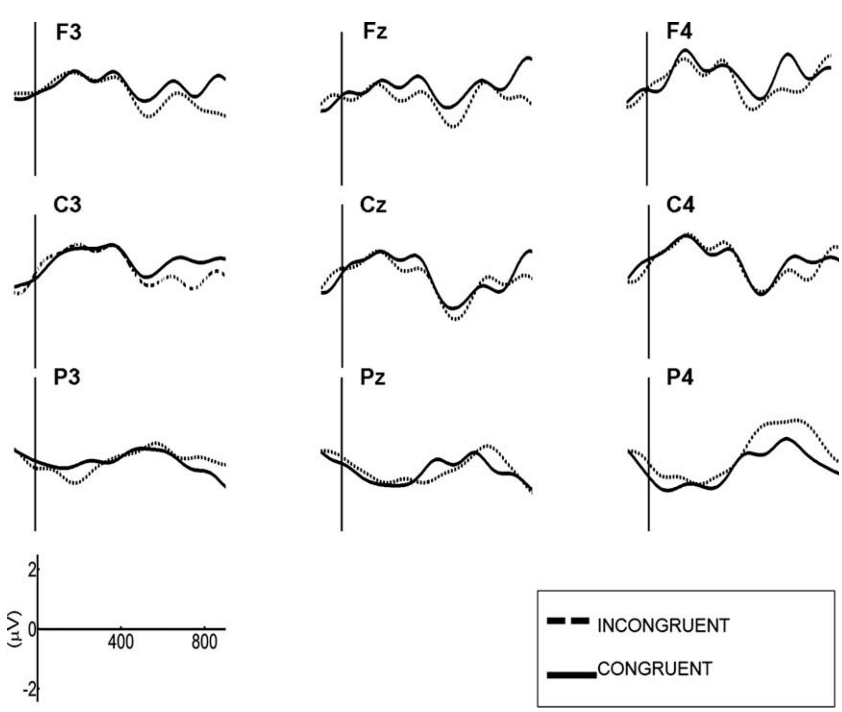

Fig. 4. Word onset ERP waveforms elicited by congruent (continuous line) and incongruent gestures (dashed line), at six electrode sites. The regions of interest (ROI) selected were: left and right frontal, left central and right posterior. There were no significant differences between the congruent and incongruent conditions.

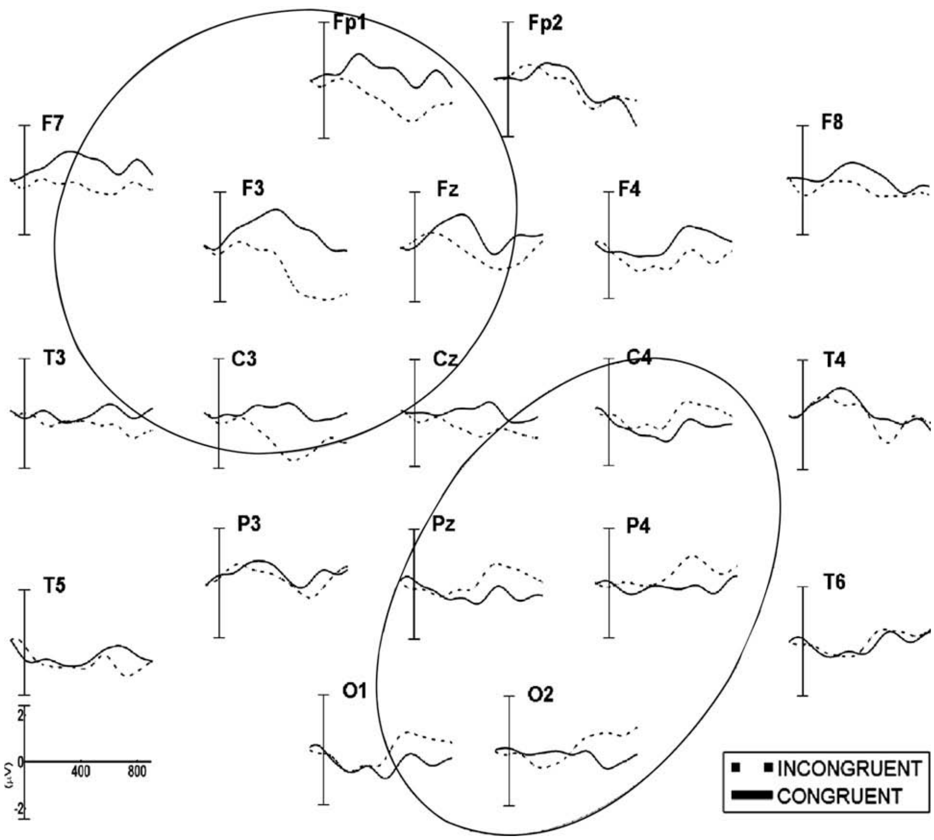

Fig. 5. Gesture stroke ERP waveforms elicited by congruent (continuous line) and incongruent (dashed line) gestures. There is a negative waveform at the more anterior left sites, and a positive waveform at the posterior right sites. Ellipses indicate the scalp sites where the largest effect of gesture congruency was obtained. Only a subset of the 10–20 standard electrode locations is shown.

Table 2
Mean amplitude (in μV) and standard deviation (SD) for congruent and incongruent conditions in regions of interest (ROIs: left-anterior, central midline and right-posterior). The time windows were 170–350 ms (early negativity), 350–650 ms (N400), and 650–900 ms (LPC).

	Electrode sites	170350 ms (Early negativity)		350–650 ms (N400)		650–900 ms (LPC)	
		Mean	SD	Mean	SD	Mean	SD
Congruent Gesture	Anterior-left	0.30	0.28	0.83	0.54	0.79	0.59
	Central-midline	0.20	0.29	0.25	0.28	0.12	0.36
	Posterior-right	0.14	0.21	−0.49	0.39	−0.88	0.31
Incongruent Gesture	Anterior-left	0.10	0.20	−1.91	0.22	−0.91	0.42
	Central-midline	−0.11	0.19	−0.09	0.48	−0.09	0.48
	Posterior-right	0.37	0.27	−1.35	0.39	0.89	0.45

congruent and incongruent gestures, at left-anterior ($p < .01$) and at right-posterior ROIs ($p < .05$). In agreement with the dipolar voltage pattern inversion, no differences were obtained in central-midline electrode sites ($p > 0.5$).

In the 650–900 ms epoch, the ERP was more positive at the right-posterior ROI in the incongruent gesture condition than in the congruent one. This effect was mirrored by a moderate negative waveform in left-anterior sites. A statistically significant interaction was observed between the congruity of gesture and topography ($F(2,28) = 6.17$, $p < .01$). Post hoc comparisons showed statistically significant differences for gesture congruity at left-anterior ($p < .01$) and right-posterior ROIs ($p < .05$). No statistical differences were observed at midline-central ROI ($p > .05$).

Fig. 6a shows the waveform differences obtained by subtracting the congruent gesture condition from the incongruent one at the left-anterior and right-posterior ROIs. A temporally extended negativity can be seen at more anterior sites accompanied by a right positivity at posterior sites. Fig. 6b shows the scalp topography for both gesture conditions at 400 and 600 ms time windows. A frontal–central negativity, lateralized to the left, can be clearly observed.

An additional analysis was performed using a more extended time window (400–900 ms). Significant differences between the two congruency levels were found at the left-frontal ROI (Bonferroni corrected, $F(1,13) = 17.9$, $p < .01$) and at the right-posterior ROI (Bonferroni corrected, $F(1,13) = 15.2$, $p < .01$). No significant differences were observed at the midline-central ROI (Bonferroni corrected, $F(1,13) = 0.04$, $p > .05$). Fig. 7 shows the ERPs at left-frontal, midline-central, and right-posterior ROIs.

4. Discussion

In this study we compared the electrophysiological patterns generated by metaphorical expressions co-occurring with congruent and incongruent gestures. We did not find differences in ERPs elicited by congruent and incongruent gestures when the time-

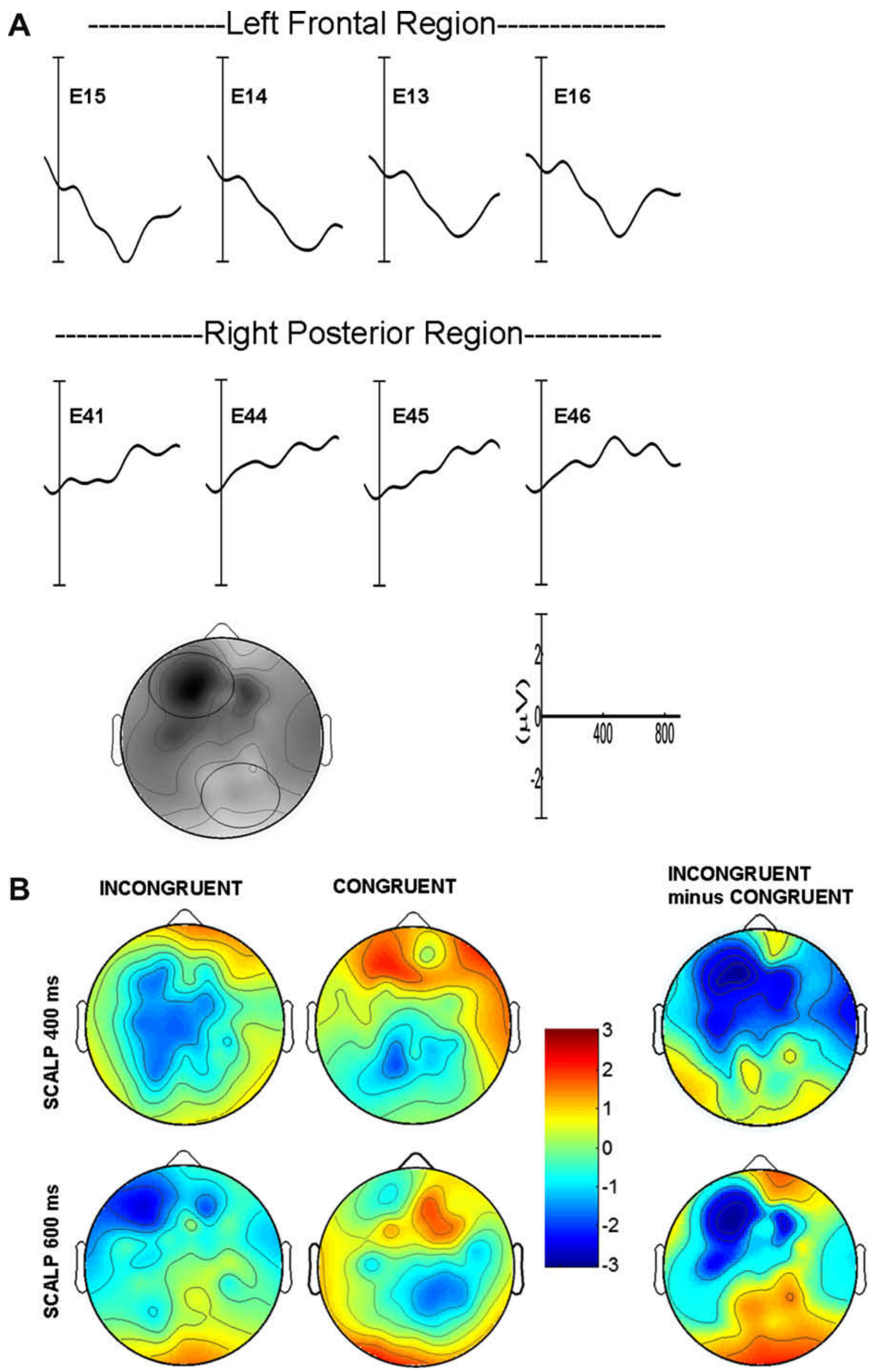

Fig. 6. (a) Difference waveforms in µV obtained by calculating incongruent minus congruent gesture conditions at selected left anterior and right posterior sites. The gray topographic scalp shows, for the latency range of 600 ms after the stroke onset, the area corresponding to the selected electrodes. (b) Voltage maps at 400 and 600 ms for both the incongruent and congruent conditions. The subtraction of both conditions (incongruent minus congruent) at the same latencies is displayed on the right.

locked event was the word onset. However, when the time-locked event was the onset of the stroke of the gesture, we observed differences in 350–650 ms and 650–900 ms epochs. This suggests that integration of gestural information might be relevant for the comprehension of metaphorical expressions, as reflected by the differences observed at behavioral and electrophysiological levels. In the 350–650 ms epoch, incongruent gestures elicited greater negativity than congruent ones at the left-frontal electrode sites as well as a moderate positivity at right-posterior electrode sites. Considering that this negativity shares many characteristics with the N400 component, we interpret it as indicating the semantic weight that gestures carry in the processing of metaphorical meaning. In the 650–900 ms epoch (LPC) potentials at the posterior-right electrode sites were more positive in the incongruent gesture condition than in the congruent gesture condition. In both windows the interaction between gesture congruence and electrode position was statistically significant, suggesting a dipolar voltage pattern (frontal-left vs. occipital-right). These electrophysiological correlates show a modulation based on the cross-modal meaning integration that is required for the processing of the kind of stimuli used in this study (see Wu & Coulson, 2007a). Both gesture and linguistic expression appear to be spontaneously integrated to construct metaphorical meanings. In this sense, our results suggest that metaphor may be a linguistic construction that is highly sen-

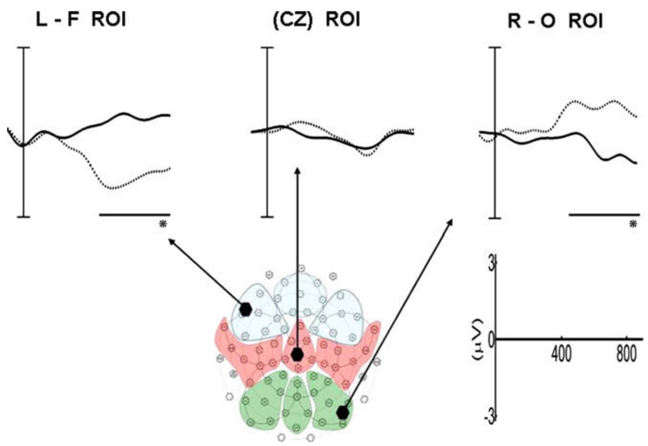

Fig. 7. ERP waveforms for three selected ROIs at left-frontal, Cz and right-occipital sites. The horizontal bar with an asterisk at the bottom right of the graphs indicates statistically significant differences ($p < .001$).

sitive to the context in which it is manifested (Cornejo, 2004, 2007).

There are some differences between the classical N400 pattern and the significant negativity we observed in the 350–650 ms window. Whereas the N400 component has been usually described as a negativity with central–parietal topography when verbal stimuli are presented (Kutas & Hillyard, 1980; Kutas & Van Petten, 1994; Kutas et al., 2006), the negativity elicited by nonverbal stimuli that we observed is more distributed, with a left-anterior lateralization. Recent studies indicate that the topographic distribution of this negativity could be very wide, reaching even the whole anterior half of the scalp. That in turn suggests that the N400 is a polymodal context-dependent component consisting of different processes and with multiple generating sources (Kutas & Federmeier, 2000; Van Petten & Luka, 2006; Zhou, Zhou, & Chen, 2004). Previous studies of the N400 component involving co-speech gestures have shown that the scalp topography varies depending on the nature of the task. For example, Kelly et al. (2007) found that the same experimental paradigm could elicit N400 at different scalp sites. A larger bilateral frontal and central (but more left pronounced) N400 effect was obtained when participants believed the gesture and speech were intentionally coupled. When participants believed that the gesture and speech were not intentionally coupled the result was a right frontal N400 effect. These results indicate that this kind of negativity strongly depends on the task that is performed (see Bernardis, Salillas, & Caramelli, 2008).

Several factors can be invoked to explain the scalp distribution found in our study. First, it has been observed that non-linguistic visual stimuli (such as pictures, videos and gestures) present an anterior distribution of the negativity (Barrett & Rugg, 1990; Holle & Gunter, 2007; Kelly et al., 2004; Sitnikova et al., 2003; West & Holcomb, 2002; Wu & Coulson, 2005, 2007a, 2007b; Özyüreck et al., 2007). Second, it is known that an early N400 with a more frontal distribution is elicited by early contextual anticipation (Van den Brink, Brown, & Hagoort, 2001). Third, a left lateralization has been reported in several N400 studies using auditory and multimodal stimuli (for a review, e.g., Cornejo et al., 2007; Hahne & Friederici, 2002; Holcomb & Neville, 1990; Van Petten & Luka, 2006). Finally, and in a somewhat more speculative line of reasoning, the hemispheric differences may be additionally explained by the fact that in some models the semantic processing of the left hemisphere is more predictive and more sensitive to the semantic expectations of the upcoming linguistic input (Federmeir & Kutas, 1999). It is very likely that the formal structure of our stimuli (i.e., *Those X are Y*) generated similar expectations, especially given that explicit instructions regarding attention to gestures were involved (Kelly et al., 2007). Interestingly, a N400 left anterior negativity has been previously reported in response to formally similar sentences (Ibáñez, López, & Cornejo, 2006). Taken together, these facts may account for the left-anterior topography of N400 reported in the present study, in which complex and composite semantic stimuli (metaphorical sentences and video gestures that generate semantic expectations) are presented via cross-modal stimulation.

Another difference between the negativity observed in the present study and the classically reported N400 is the extended time-course of the negativity we found in the 350–650 ms epoch. This could be explained by the characteristics of the stimuli, which are continuous rather than discrete. Moreover, they demand a global sense-making process for each gesture which distinguishes from the more precise identification process present in classical linguistic studies. The prolongation of the N400 component has been described by Sitnikova et al. (2003), who implemented an experimental incongruent condition with video clips of real life situations.

In addition to the N400 component, our results also show that incongruent gestures elicited a posterior positive deflection in the waveform observed 500–900 ms after the onset of the stroke of the gesture. This late positivity has been typically linked to memory processes (Rugg & Yonelinas, 2003). Although N400 and LPC have been experimentally dissociated, suggesting that each component reflects different aspects of memory (Van Petten, Kutas, Kluender, Mitchiner, & McIsaac, 1991), both effects often co-occur (Sitnikova et al., 2003; Wu & Coulson, 2005). The posterior-positivity effect we found in this study strongly resembles the one reported by Sitnikova et al. (2003). To explain the effect, it is important to consider some features that are common to both studies. On the one hand, neither study asked participants to make a decision. Therefore, the idea that this late positivity would express a variant of decision P3 (Donchin & Coles, 1988) does not apply in this case. On the other hand, both studies used video clips displaying a contextually inappropriate action in an otherwise coherent real-world situation. This fact suggests that the late positivity effect expresses a process of reanalysis of the inconsistent situation produced by the incongruent gesture (Münte, Heinze, Matzke, Wieringa, & Johannes, 1998; Sitnikova et al., 2003). What is special about our results is that the gestures are inconsistent not with any contextually inappropriate action, but with the *metaphorical meaning* of linguistic expressions. Thus, the hypothesized reanalysis is triggered when a non-literal reading is unsatisfied.

As mentioned earlier, another interesting finding in this study is the very different ERPs elicited by variations in time-locked events—the onset of the word and of the stroke of the gesture. We found that ERPs evoked by expressions with congruent and incongruent gestures presented no statistically significant difference when the word onset was selected as the time-locked event. However, we observed important differences in the electrophysiological patterns when the time-locked event was the onset of the stroke of the gesture. To our knowledge, no study has reported results using the onset of the stroke as the time-locking event.

Three factors may explain the difference between word-locked and gesture-locked ERPs, as operationalized in this study. First, the two time windows are not completely separated. Indeed, the two 400 ms windows after onset partially overlap, but this is not directly visible due to the fact that the two ERPs waveforms have different baselines. Since the baseline modifies the ERP waveform, two baselines at different time points yield ERPs with reduced correspondences. Second, although usually a gesture and the critical word partially overlap in time, in our experiment the stroke onset was about 400 ms later than the word onset. Finally, in our study the latency between word onset and stroke onset was not constant throughout the trials. Although on average the stroke occurred 400 ms after word onset, the standard deviation was 200 ms. For this reason, the timing of word and stroke onset trials produced ERPs that do not have exact temporal correspondence. They must, therefore, be analyzed accordingly. These facts might explain why no effect is detected when the signals are time-locked to the word onset. Whatever theoretical interpretation we may invoke, these results indicate that serious attention must be paid to the rapid integration of bodily cues and speech, even when it occurs in highly abstract linguistic constructions such as metaphors.

With respect to the stroke onset as the time-locked event, it is important to note that ERP waveforms had early divergences at time zero, and that they presented different morphological patterns. This, however, is expected since spontaneous gestures have temporal dynamics that are not restricted to the stroke onset. Although the stroke usually conveys an important dimension of the meaning of a gesture (Kendon, 2004; Kita & Özyürek, 2003; McNeill, 2000; Willems, Özyürek, & Hagoort, 2007), its visuo-kinesthetic representation begins earlier. Moreover, unlike the speech stream, spontaneous gestures are synthetic and present a considerable variability in the timing of global meaning identification. Crucially, they do not manifest themselves as a clearly distinct and discrete visual event in time. In brief, stroke gesture as time-locking event results in a different electrophysiological pattern because of its comparatively different salience within the ongoing gesture compared to, for example, the critical word onset in speech stream. These fundamental properties of gestures may explain the heterogeneity of the morphological patterns we observed in this study (for a similar methodology – frame by frame edition of each onset of video clips of dynamic events – see Sitnikova et al., 2003). In any case, we endorse the idea of using the stroke of the gesture as a time-locking event because it allows the investigation of relevant sense-making processes drawn from a temporally dynamic event. Besides, we can take advantage of the fact that the stroke can be marked precisely with a specific video frame, allowing the analysis of a dynamic event by means of a well-defined static reference point – even though early components of the visual ERP (i.e., N1) could not be clearly seen. This was an expected result due mostly to the lack of discrete transient visual events separated by time (i.e., the early components were likely refractory due to the continuous stimulus presentation format) (Davis, Mast, Yoshie, & Zerlin, 1966; Sitnikova et al., 2003; Wu & Coulson, 2005).

As reported in the methods section, the gestures of the stimuli referred to the metaphorical meaning of the expression. However, in some cases it was difficult to avoid the iconic resemblance between gesture and the literal meaning of the final word. There are several reasons to think that this fact does not affect our results. First, considering that this situation occurred in very few cases, it is improbable that the observed ERP can be explained by iconic similarity. Second, congruence of gesture with metaphorical meaning was previously validated. If gestures had been massively iconic with the literal meaning of the last word, they would be either categorized as incongruent or they would show low congruence levels in the validation study, since literal meaning is inconsistent with the metaphorical interpretation. Third, there are several reports of N400 modulation based on contextual effects from the immediately previous sentence (Nieuwland & Van Berkum, 2006; for review see: Hagoort, 2008; Van Petten & Luka, 2006). The eventual iconicity effect would only mean an additional effect, probably independent on the previous linguistic context, but not a non-effect of context (i.e., "girls") and gesture (i.e., "hand moving quickly upward"), which is our main point. Further studies may show if there is an overall or partial meaning construction based on sentence/gesture blending.

In sum, the results presented in this study provide important elements for the understanding of the role gestures play in the global and contextualized process of metaphorical comprehension. However, further research would be desirable to fully account for the role of gesture in the comprehension of literal speech and other forms of daily linguistic constructions. Previous studies have reported N400 and LPC amplitude modulation by gestures that are incongruent with literal expressions (i.e., Kelly et al., 2004, 2007; Wu & Coulson, 2005; Wu & Coulson, 2007a; Wu & Coulson, 2007b). There is also evidence that the final word of metaphorical expressions elicits larger N400 components than the final word of literal ones (Pynte et al., 1996). Future research will hopefully expand the search for electrophysiological correlates underlying cross-modal integration needed for metaphor comprehension.

In a more flexible conceptualization of language comprehension, our data suggest that meaning construction is globally integrative and highly context sensitive (Cornejo, 2008; Cosmelli & Ibáñez, 2008; Coulson, 2006; Ibáñez & Cosmelli, 2008; Ibáñez, Haye, González, Hurtado, & Henríquez, In press). Gesture information is early integrated during ongoing linguistic comprehension with the figurative meaning of the expression. Gesture is part of the global sense of the metaphorical expression. This integration process seems to be from the very start a unitary global construction. Keeping in mind methodological constraints, meaning construction and human cognition should be approached, theoretically and empirically, as ecological and contextualized.

Acknowledgments

This study was supported by Grant 1030473 from the FONDECYT (CHILE) (Fondo para el Desarrollo de la Ciencia y Tecnología) to Carlos Cornejo and Franco Simonetti. We thank María Teresa Muñoz, Diego Carrasco, David Carré, Roberto Musa, Boris Lucero and Francisco Pizarro for helping with data collection. We would also like to thank the reviewers of Brain and Cognition for their valuable comments on previous versions of this article.

Appendix A

Examples taken from the stimulus set in the original Spanish version, with their English literal translation and the descriptions of the corresponding gestures.

Sentence	Literal translation	Gesture description
Congruent condition		
Esos cirujanos son artistas	*Those surgeons are artists*	Right index finger and thumb touching at the tip and moving downward, indicating precision
Esos vendedores son loros	*Those salesmen are parrots*	Right hand with palm facing frontwards, fingers stretched out, opening and closing repeatedly in center-right space

Appendix A (*continued*)

Sentence	Literal translation	Gesture description
Esos jóvenes son cerdos	*Those young people are pigs*	Right hand moving from left shoulder to top left space, as if dusting off something from shoulder
Esos hombres son robles	*Those men are oaks*	Right hand to chin, indicating some kind of elegant beard.
Esas mujeres son avispas	*Those women are wasps*	Right hand moving backwards, tossing something over the shoulder
Esos hombres son luces	*Those men are lights*	Right close hand opening from head upwards, to indicate mind openness
Esas secretarias son relojes	*Those secretaries are clocks*	Open left hand with palm up and right index finger pointing downwards on left hand
Esas jóvenes son aviones	Those young women are airplanes	Right index finger moves rapidly from center to top right space, indicating speed
Esos bailarines son chuzos	*Those dancers are sticks*	Both flat hands stretched out with palms facing each other, in parallel, indicating rigidity
Esos hombres son parásitos	*Those men are parasites*	Right hand with palm down, moves to front and slightly flips upwards, indicating disdain
Esos médicos son dioses	*Those doctors are gods*	Right open hand with palm up, moving upwards, indicating elevation
Esos licores son venenos	*Those liquors are poisons*	Both index fingers cross in front of speaker at the face level, indicating rejection
Esos niños son gansos	*Those children are gooses*	Right index finger hits side of the head twice, indicating low intellectual ability
Esos barrios son tumbas	*Those neighborhoods are tombs*	Both hands with palm down crossing at center level in front and moving outwards, indicating stillness
Incongruent condition		
Esos puños son acero	*Those fists are steel*	Right thumb rubs all other fingers, indicating softness
Esos pies son lanchas	*Those feet are motorboats*	Right index and thumb come together, indicating small size
Esos jóvenes son gallos	*Those young people are roosters*	Middle and index finger move forward from the chest, indicating irrelevance
Esas motos son flechas	*Those motorcycles are arrows*	Right hand open palm facing front, indicating "stop"
Esas manos son regalos	*Those hands are gifts*	Both hands closed are held tight against the chest
Esos jóvenes son jirafas	*Those young people are giraffes*	Open hand slightly above the waist with palm facing down, showing low height
Esos zapatos son tanques	*Those shoes are tanks*	Closed hand with pinky finger stretched out pointing upwards, indicating thinness
Esos proyectos son historia	*Those projects are history*	Right index finger pointing down moves downward indicating present time
Esos relatos son desgarros	*Those stories are tears*	Both index fingers join in the middle at the fingertips
Esos cabellos son sedas	*Those hairs are silks*	The pointing index finger of the right hand zigzags while moving downward
Esas niñas son palomas	*Those girls are doves*	Loose open hands, palms facing each other at shoulder level, indicating a big volume
Esos ingenieros son cuadrados	*Those engineers are squares*	Both hands are closed at the side of the head. They open while moving outwards.
Esas bailarinas son gacelas	*Those dancers are antelopes*	Both palms, one facing up and the other one facing down, are joined horizontally with fingertips pointing forward. Top hand slides toward the chest
Esos niños son bestias	*Those children are beasts*	Right hand delicately rubs side of the face

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