Neuroscience Letters 471 (2010) 48–52

Contents lists available at ScienceDirect

Neuroscience Letters

journal homepage: www.elsevier.com/locate/neulet

Gesture influences the processing of figurative language in non-native speakers: ERP evidence

Agustín Ibáñez[a,b,c,*], Facundo Manes[b], Josefina Escobar[a,e], Natalia Trujillo[d], Paola Andreucci[a,e], Esteban Hurtado[a,e]

[a] Neuroscience Laboratory, University Diego Portales, Santiago, Chile
[b] Laboratory of Experimental Psychology and Neurosciences, Institute of Cognitive Neurology (INECO) & Institute of Neuroscience, Favaloro University, Buenos Aires, Argentina[1]
[c] National Scientific and Technical Research Council (CONICET), Buenos Aires, Argentina
[d] Neuroscience Group, University of Antioquia, Medellín, Colombia
[e] P. Catholic University of Chile, Santiago, Chile

ARTICLE INFO

Article history:
Received 8 September 2009
Received in revised form
14 December 2009
Accepted 7 January 2010

Keywords:
ERP
N400
LPC
Gesture
Metaphor
Contextual modulation
Second language

ABSTRACT

Gestures should play a role in second language comprehension, given their importance in conveying contextual information. In this study, the N400 and the LPC were evaluated in a task involving the observation of videos showing utterances accompanied by gestures. Students studying advanced (G-High participants) and basic German (G-Low participants) as a second language were investigated. The utterance–gesture congruence and metaphoric meaning of content were manipulated during the task. As in previous ERP reports with native speakers, metaphorical expressions were sensitive to gestures. In G-Low participants, no modulation in the 300–500 ms window was observed, and only a modest effect was observed for the 500–700 ms window. More subtle differences of verbal expression were not processed in this group. Consistent with previous reports of the same paradigm with native speakers, the N400 from G-High group discriminated both congruent and incongruent gestures as well as literal and metaphorical sentences. Our results suggest that semantic processing is robust in the learning of a second language, although the amplitude modulation and latency of ERPs might depend on the speaker's proficiency level.

It has been argued that a thorough comprehension of a second language (L2 hereafter) requires not only a command of the linguistic structures but also the ability to employ such structures in an appropriate context [23]. The gestures of multilingual speakers show an influence of L2, as they differ from the gestures of monolingual speakers in their gesture execution [1]. Gestures represent common concepts that are frequently accessible even to non-native speakers. Verbal utterances are related to the information conveyed by gestures. This aspect of language is particularly evident in figurative speech, where a considerable amount of contextual information is required for understanding [6]. For example, studies show that contextual information (i.e., previous information at sentence or relevant scheme levels) beyond lexical content is crucial to understanding metaphorical expressions [5]. These gestures could represent an aspect of communicative competence for the person learning a second language [23,12] and may even produce stronger neural markers of language learning [13].

The purpose of our research is to determine whether electrophysiological correlates of literal and metaphoric semantic processing are modulated by gestural information conveyed to participants with either high or low L2 proficiency.

Event related potentials (ERPs) can be consistently measured using electroencephalography (EEG). ERPs are the ongoing electrophysiological activity resulting from the synchronous activation of several neural subpopulations that occur in response to sensory, motor or cognitive events. ERPs reflect the summed activity of excitatory postsynaptic potential (EPSP) and inhibitory postsynaptic potential (IPSP) activated in response to each new stimulus. This technique has an excellent temporal resolution in the order of milliseconds (ms); but the ERPs are less precise for the anatomical localization of the neural generators than the neuroimaging techniques. Two electrophysiological components have been studied in relation to the semantic processing of L2. The N400 is an ERP component characterized by a negative deflection peaking

* Corresponding author at: Laboratory of Experimental Psychology and Neurosciences, Institute of Cognitive Neurology (INECO) & Institute of Neuroscience, Favaloro University, Buenos Aires, Argentina. Tel.: +54 11 4807 4748.
E-mail addresses: aibanez@neurologiaconitiva.org, agmabaib@gmail.com (A. Ibáñez).

[1] http://www.neurologiacognitiva.org/.

0304-3940/$ – see front matter © 2010 Elsevier Ireland Ltd. All rights reserved.
doi:10.1016/j.neulet.2010.01.009

about 400 ms after the presentation of anomalous linguistic stimuli [16,8]. It is highly sensitive to contextual semantic modulation [10]. The second component, the late positive complex (LPC), has been related to a process of re-analysis of the incongruent situation produced by inconsistent meaning [22].

Current studies have suggested that multimodal and co-occurring speech and gestures are integrated by the brain simultaneously into the context of a preceding sentence [20]. In particular, the stroke phase of a gesture conveys the meaning of a gesture [17], a meaningful property of gesture stroke that has been used in neuroscience. Studies using fMRI have shown that unimodal (gesture only) and multimodal integration of gestures and speech increase activation in the classical left hemispheric language areas [15]. Recent ERPs studies have triggered the N400 and LPC with the gesture stroke onset. For example, Ozyüreck et al. [20] assessed the integration of speech and gesture simultaneously triggered by word onset and static gesture stroke onset. The latency, amplitude, and topographical distribution of both word and gesture onset mismatches were found to be similar, despite the difference in modality and in the specificity of meaning conveyed by spoken words and gestures, indicating that the brain integrates both types of information similarly and simultaneously. Time-locking ERPs by gesture strokes allow the investigation of relevant semantic coordination processes drawn from a temporally dynamic event stroke gesture. Previous reports of co-gesture speech paradigms ([3,11] show N400 and LPC components elicited by gesture stroke onset strongly modulated in terms of congruent vs. incongruent stimuli compared to the N400/LPC component elicited by word onset. Since the stroke occurs 200–400 ms after the relevant word onset, it constitutes a better temporal window compared with word onset because it implies the temporal integration between sentence meaning and gesture meaning.

Previous ERP studies on semantic processing show that ERPs are normally elicited by L2 speakers during lexical-semantic processing during a sentence comprehension task [7,19,25]. To our knowledge, however, there are no prior ERP studies exploring how L2 speakers integrate the gesture information and figurative language. We employed a previously described co-speech gesture paradigm with native Spanish [3] and German [11] speakers. This paradigm consisted of four different video clips conveying a combination of literal or metaphorical expressions accompanied by congruent or incongruent gestures. The ERPs were recorded while participants viewed the short video clips. This allowed us to observe the effects of the gesture congruency and expression type on the semantic processing of the L2 learners.

Fig. 1. Examples of expressions uttered with gestures. The figure shows four examples of German expressions uttered with gestures (literal expression with congruent gesture; literal expression with incongruent gesture; metaphoric expression with congruent gesture; and metaphoric expression with incongruent gesture). Those expressions consisted of the following German sentences: (A) Diese Telefone sind Handys; those telephones are mobile phones (literal expression with congruent gesture); (B) Diese Werkzeuge sind Hämmer; those tools are hammers (literal expression with incongruent gesture); (C) Diese Kämpfer sind Löwen; those warriors are lions (metaphoric expression with congruent gesture); (D) Diese Tugenden sind Diamanten; those virtues are diamonds (metaphoric expression with incongruent gesture). An ocular fixation cross ("+") was displayed centered on the screen at the beginning of each trial, followed by the presentation of the main stimulus in a short video clip. Then the subject had to classify the stimulus by pressing either button 1 (congruent) or button 2 (incongruent) with the right hand as soon as the utterance was comprehended.

Thirty adult Spanish speakers participated in this experiment for monetary compensation. They were recruited from the Goethe Institute and divided into two groups based on their German language proficiency (G-High and G-Low). The proficiency level was determined by examinations from the Goethe Institute, and was confirmed by performance measures from a translation test. The High German language proficiency group (G-High) consisted of 15 subjects (7 males, age 23.4 ± 4.38 years; 1 participant was excluded due to excessive movement artifacts during the EEG recording). All the participants passed the Kleines Deutsches Sprachdiplom (KDS) or the Zentrale Oberstufenprüfung (ZOP) test. Both of these tests require a high proficiency in German. They correspond to the highest level of language mastery on the Common European Framework of Reference for Languages. Only participants with perfect translation on an ad hoc, self-assessed German proficiency questionnaire were included. A second group (G-Low) consisted of 15 subjects (8 males, age 21.1 ± 5.15 years; two participants were excluded due to excessive movement artifacts during the EEG recording). They had developed their L2 skills up to the Goethe-Zertifikat B1 level (Zertifikat Deutsch), which requires basic knowledge of colloquial German language. At this proficiency level, they could communicate effectively in everyday life situations, corresponding to the fourth level (B2) on the Common European Framework of Reference for Languages. The final sample consisted of 27 subjects (14 from the G-High group and 13 from the G-Low group). All participants signed a written consent form in agreement with the Declaration of Helsinki after being given a complete description of the study. The experiment was approved by the Ethics Committee of the Neuroscience Laboratory. All participants had normal or corrected vision and hearing, and none of them had any personal history of neurological or psychiatric disease.

The aforementioned expression–gesture paradigm with 176 different video streams (44 clips for each expression–gesture combination) was used in this study [11]. Half of the video streams contained gestures that were congruent with the spoken expressions (literal or metaphoric) and the other half contained incongruent gestures. All expressions had the basic structure: "Diese X sind Y" (Those X are Y). The participants' task was to watch the video clips and indicate whether they were congruent (if the gesture and verbal expression conveyed the same meaning), or incongruent (the gesture and verbal expression were unrelated). The gesture strokes appeared in all clips immediately after the onset

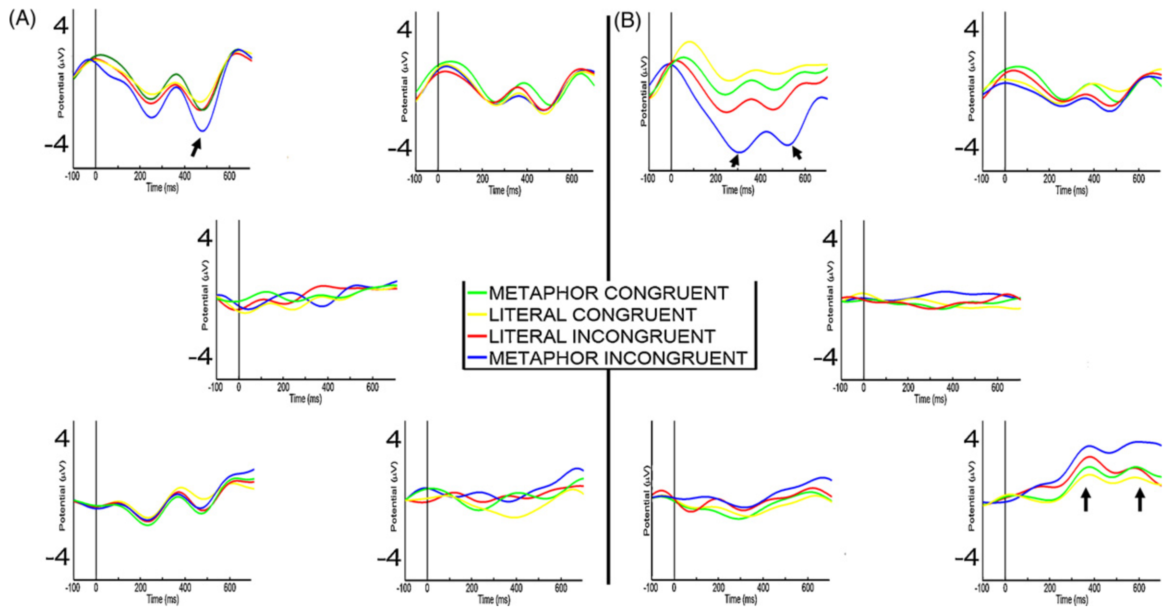

Fig. 2. ERPs of gesture congruency and type of expression. The figure shows waveforms for the four categories from five ROIs (left anterior, left posterior, Cz, right anterior and right posterior). The arrows indicate an ROI and window that had significant differences between categories. (A) G-Low participants. In this group no modulation in the 300–500 ms window was observed, and only a modest effect was observed for the 500–700 ms window. Over the anterior left ROI, only the incongruent metaphorical expression was significantly different from the other categories in the latter time frame. (B) G-High participants. Note that Left Anterior N400 was the most relevant component since it showed the biggest observed negativity, specifically for the metaphorical/incongruent condition. It also showed clear modulation for metaphorical expressions in terms of congruency, while congruent expressions showed the same behavior whether they were metaphorical or literal.

of the final word. However, the preparatory phase of the gestures anticipated the corresponding verbal expression [11]. Fig. 1 shows four examples of German expressions uttered with gestures: (a) a literal expression with a congruent gesture; (b) a literal expression with an incongruent gesture; (c) a metaphoric expression with a congruent gesture; and (d) a metaphoric expression with an incongruent gesture). The task involved the classification of the video clips and began with a brief explanation of how each category should be assigned to each response key (congruent or incongruent). After a brief practice (5 video clips), the trials were presented pseudo-randomly (the sequence was counterbalanced, controlling for not more than two trials of the same category based on the type of gesture or type of word). Each trial began with a "+" at the center of the screen for ocular fixation (250 ms), followed by the video stream ($M = 5.4 \pm 1.3$) and subsequent classification task. In this task participants had to press key 1 or 2 (congruent or incongruent) with the right hand once they comprehended the utterance. After the response, an interval of 1500 ms preceded the next trial. There were no breaks during the task. More details about the experimental design can be found in the supplementary data.

The electrophysiological signals were recorded on-line using a GES300, 129-channel system with HydroCel Sensors from Electrical Geodesic Inc. The ERP data was recorded with a 0.1–100 Hz analog bandpass filter. A digital bandpass filter between 0.5 and 30 Hz was applied off-line to remove unwanted frequency components. The signals were sampled at 500 Hz. During the recordings, the reference was set by default to vertex, but it was then re-referenced off-line to link the mastoids. All the epochs with eye movement artifacts were removed from the data using automatic and visual procedures before further analysis. The artifact-free epochs were averaged to obtain the ERPs. The waveforms were averaged separately for each experimental condition: (a) congruent gesture with literal expression; (b) congruent gesture with metaphorical expression; (c) incongruent gesture with literal expression; (d) incongruent gesture with metaphorical expression. We triggered the onset of the stroke of the accompanying gesture [3,11,26]. The time frames when the gesture stroke occurred were further analyzed in a frame-by-frame edition of the video stream [11]. The EEG Lab Matlab toolbox and T-BESP software (http://neuro.udp.cl/software) were used for EEG off-line processing and analysis.

Five regions of interest (ROIs) were used to represent and analyze the scalp topography of the ERP components, as recommended for dense arrays based on the N400/LPC scalp topography reported in previous studies [3,11]. Each ROI comprised six adjacent electrodes centered on the following sites: left anterior (LA, over F3), right anterior (RA, over F4), central-midline (Cz, over Vertex), left posterior (LP, over P3) and right posterior (RP, over P4). Two ERP windows (N400 window: 300–500 ms; and LPC window: 500–700 ms) were selected for all conditions. This time windows analysis has been selected in following both previous reports of this paradigm, in order to make the effects comparable. An additional analysis of the mean amplitude around the peaks (280–430 ms for N400; 430–580 ms for LPC) yielded the same effects as the current analysis (See supplementary data analysis, Section 2). For each comparison, a repeated measures ANOVA was performed with the following within-subject factors: (1) gesture (congruent vs. incongruent); (2) expression (literal vs. metaphoric); and (3) ROI (LA, RA, CM, LP or RP). Unvaried comparisons were done when necessary. The results were corrected with the Greenhouse–Geisser and Bonferroni methods to adjust the unvaried output of the repeated-measures ANOVA for violations of the compound symmetry assumption.

For the 300–500 ms window, no main effect of gesture, expression or interaction between the factors was observed. Only an ROI effect ($F(4, 48) = 10.56$, $p < 0.01$) was observed.

For the 500–700 ms window, Fig. 2A shows the grand average ERPs from all ROIs (LA, RA, Cz, LP and RP). No main effect of gesture or expression was observed. An interaction between the ROI, expression and gesture was obtained ($F(4, 48) = 3.23$, $p = 0.01$). A small difference at the anterior left ROI was observed. Post hoc comparisons performed on this last interaction (Tukey HSD test; MS = 0.16, df = 48.000) revealed that in the anterior left ROI, the incongruent metaphorical expression was significantly different from the congruent literal expression clip ($p < 0.01$), the incongruent literal expression clip ($p < 0.01$), and the congruent metaphorical expression clip ($p < 0.01$). No other relevant pair-wise comparisons were statistically significant.

For the 300–500 ms window, Fig. 2B shows the grand average ERPs from all ROIs (LA, RA, Cz, LP and RP). The main differences between the expression–gesture video clips can be observed in a bipolar voltage pattern in the anterior left and posterior right ROIs. The ANOVA revealed the significant main effects for ROI ($F(4, 52) = 24.71$, $p < 0.01$) and gesture ($F(1, 13) = 19.23$, $p < 0.01$). In addition, an interaction between the gesture, expression and ROI was obtained ($F(4, 52) = 7.07$, $p < 0.01$). In the anterior left ROI, the incongruent metaphorical clip produced the greatest ERP negativity ($-2.87 \pm 0.33\,\mu v$), followed by the incongruent literal clip ($-0.79 \pm 0.14\,\mu v$), the congruent metaphorical clip ($-0.02 \pm 0.13\,\mu v$), and the congruent literal clip ($0.43 \pm 0.09\,\mu v$). The post hoc comparisons done on this last interaction (Tukey HSD test; MS = 0.38, df = 52.000) showed that in the left anterior region, most of the categories were significantly different [metaphor congruent with respect to literal congruent ($p < 0.5$), literal incongruent ($p < 0.01$) and metaphor congruent; as well as literal congruent with respect to literal incongruent ($p < 0.5$)]; with the exception of the literal congruent category versus the metaphorical congruent category ($p = 0.90$). In the posterior right ROI, the incongruent metaphorical clip produced the greatest ERP positivity ($2.42 \pm 0.33\,\mu v$), followed by the incongruent literal clip ($1.74 \pm 0.21\,\mu v$), the congruent metaphorical clip ($1.42 \pm 0.21\,\mu v$), and the congruent literal clip ($1.17 \pm 0.23\,\mu v$). This is consistent with a bipolar inversion pattern. Post hoc comparisons (Tukey HSD test; Bonferroni corrected, MS = 0.41, df = 52.000) yielded significant differences between metaphor incongruent category with respect to literal congruent ($p < 0.5$) and metaphor congruent ($p < 0.05$). No differences were obtained for the literal congruent clip versus the metaphorical congruent clip comparison ($p = 0.34$), and the congruent metaphorical clip versus the literal incongruent clip comparison ($p = 0.99$). No significant differences were observed in this temporal window for the other ROIs.

For the 500–700 ms temporal window, a pattern similar to that described above was observed. The ANOVA revealed a significant main effect for the type of verbal expression (literal vs. congruent; $F(1, 13) = 10.93$, $p < 0.01$) as well as for the ROI ($F(4, 52) = 33.07$, $p < 0.01$). In addition, an interaction between the type of gesture, type of verbal expression, and ROI was observed ($F(4, 52) = 10.33$, $p < 0.01$). The post hoc comparisons of this interaction (Tukey HSD test; Bonferroni corrected, MS = 0.32, df = 52.000) showed the same effect as previously reported in the left anterior region. Again, all the gesture–expression categories showed significant differences except for the literal congruent versus the metaphorical comparison ($p = 1.3$). In the right posterior ROI, the incongruent metaphorical clip induced significantly greater ERP positivity than the congruent metaphorical clip ($p < 0.01$), the literal congruent clip ($p < 0.01$) and the literal incongruent clip ($p < 0.01$). Significant differences were not observed for the other ROIs.

The results of our research suggest that gesture information modulates the processing of figurative and literal language to the similar extent in G-Low subjects as in G-High subjects. In G-Low participants, no modulation in the 300–500 ms window was observed, and only a modest effect was observed for the 500–700 ms window. Over the anterior left ROI, only the incongruent metaphorical expression was significantly different from the other categories in the latter time frame. This suggests that G-Low participants only discriminated between the more contextual (metaphorical) and incongruent multimodal information. More subtle differences of verbal expression were not processed in this group.

The 500–700 ms LPC effects from the G-High group strongly resemble the same waveform modulation, as well as the scalp and bipolar voltage pattern, reported previously for German native speakers using the same study paradigm [11]. The greatest negativity was that of Left Anterior N400 component produced for incongruent gestures with metaphorical expressions in our sample of native German speakers. Metaphorical expressions were subject to the biggest N400 modulation in terms of congruence (e.g., N400 amplitude difference between congruent and incongruent gestures) in the left at the same region, where literal expressions showed a similar, but smaller, modulation. The literal/congruent group did not show differences with metaphorical/congruent condition in any region. The same findings were present in the G-High group.

These results demonstrate that highly proficient L2 speakers have neuronal responses that are similar in time and morphology to those of native speakers. This challenges the idea that there are fundamental differences in language processing between native speakers and advanced L2 speakers [21]. Our research confirms that semantic stimuli significantly affect ERP responses in L2 speakers [7,19,25] and shows brain activation time delays in L2 low proficiency participants [18]. Similar delays in processing have been reported as a response to morphosyntactic anomalies [24]. A decreased amplitude and delayed latency in other components have also been reported for low proficiency L2 speakers [21], suggesting a weaker or slower mechanism in semantic processing when L2 learners are at the basic level. Overall, these results suggest that semantic processing is robust from the beginning levels of L2 acquisition, although amplitude modulation and latency might depend on the proficiency level. Our research shows that the distinct pattern in semantic processing between G-Low versus G-High participants is present even when complex stimuli (videos) and highly abstract expressions (metaphors) are used.

The integration of visual and semantic clues requires multimodal processing based on meaningful actions [4,9]. Some studies suggest that speech perception is enhanced when the observed speaker performs gestures congruent in meaning to the verbal expression [2]. In addition, other research has shown that visual information (articulated gestures) presented with spoken language increases the sound perception of L2 through multi-sensory integration [14]. Our results confirm the neuronal integration of visual cues and semantic processing in L2 learners.

Our research also corroborates earlier results of N400 and LPC modulation by both incongruent [22] and congruent gestures [14] presented with metaphorical or literal verbal expressions [3,11]. This adds further evidence of a neuronal interaction between the auditory and visual inputs during semantic processing, showing that a metaphor is a linguistic construction that is highly sensitive to the context in which it is used, even for L2 speakers.

From the ERP extraction results, it is important to note that we used gesture stroke onset time as a reference for time-locked component estimation. This allowed us to obtain relevant information from a temporally dynamic process [3,11]. Since stimuli presentation lacks discrete transient visual events separated by time [22,27], early visual components such as P1/N1 are reduced, but N400 and LPC seem to be preserved [22,3]. An observed waveform flatness and bipolar voltage pattern (e.g., opposite effects at frontal and posterior regions) have been previously reported in co-speech gesture video studies [3,11]. Since multimodal and complex stimuli seem to elicit left frontal N400 effects as well as bipolar voltage patterns [3,11], and multimodal integration of gestures and speech increases activation in the left frontal language areas [15], an N400 component is expected to be present at frontal regions.

Our results confirm prior research showing that co-gesture figurative language is a highly contextualized part of semantic processing. To our knowledge, this is the first study exploring the context sensitivity of gestures paired with verbal expressions using video clips and ERPs in L2 speakers. Contextual information is crucial in acquiring L2 competence, as the domain of language involves not only understanding literal components of speech, but also figurative components in relation to their integration with other sources of contextual paralinguistic information (i.e., gestures). Our report shows that the level of L2 proficiency affects the neuronal processing of semantic meaning constructed from the gesture type (congruent or incongruent) and the type of expression (literal or metaphoric). This paves a new path for studying the electrophysiological correlates of multimodal, paralinguistic cues and figurative language in L2 learners.

Acknowledgements

This research was partially supported by a CONICET and DAAD/CONICYT postdoctoral grants and by a Neuroscience Grant CG090325006 (Diego Portales University). We wish to thank Christopher Srepel for his recordings support and three anonymous reviewers for their helpful criticism in earlier versions of the manuscript. We wish to thank Goethe Institute from Santiago for his support.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.neulet.2010.01.009.

References

[1] A. Brown, Crosslinguistic Influences in First and Second Languages. Convergence in Speech and Gesture, Boston University and Max Planck Institute for Psycholinguistics, Boston, 2007.
[2] D. Callan, J. Jones, K. Munhall, A. Callan, C. Cross, E. Vatikiotis-Bateson, Neural processes underlying perceptual enhancement by visual speech gestures, Neuroreport 14 (2003) 2213–2218.
[3] C. Cornejo, F. Simonetti, A. Ibañez, N. Aldunate, F. Ceric, V. Lopez, R. Núñez, Gesture and metaphor comprehension: electrophysiological evidence of cross-modal coordination by audiovisual stimulation, Brain Cogn. 70 (1) (2009) 42–52.
[4] D. Cosmelli, A. Ibanez, Human cognition in context: on the biologic. cognitive and social reconsideration of meaning as making sense of action, Integr. Psychol. Behav. Sci. 42 (2008) 233–244.
[5] S. Coulson, C. Van Petten, Conceptual integration and metaphor: an event-related potential study, Mem. Cognit. 30 (2002) 958–968.
[6] R. Giora, On our Mind: Salience, Context and, Figurative Language, Oxford University Press, Oxford, 2003.
[7] A. Hahne, What's different in second-language processing? Evidence from event-related brain potentials, J. Psycholinguist. Res. 30 (2001) 251–266.
[8] A. Ibañez, R. San Martin, E. Hurtado, V. Lopez, ERP studies of cognitive processing during sleep, Int. J. Psychol. 44 (2008) 290–304, doi:10.1080/00207590802194234.
[9] A. Ibáñez, D. Cosmelli, Moving beyond computational cognitivism: understanding intentionality. Intersubjectivity and ecology of mind, Integr. Psychol. Behav. Sci. 42 (2008) 129–136.
[10] A. Ibáñez, V. Lopez, C. Cornejo, ERPs and contextual semantic discrimination: Evidence of degrees of congruency in wakefulness and sleep, Brain Lang. 98 (2006) 264–275.
[11] A. Ibáñez, P. Toro, C. Cornejo, M. Weisbrod, J. Schröder, High contextual sensitivity of metaphorical expressions and gesture blending: a video ERP design. Psychiatry Res., submitted for publication.
[12] E. Kellerman, Crosslinguistic influence: transfer to nowhere? Annual Rev. Appl. Linguist. 15 (1995) 125–150.
[13] S. Kelly, S. Manning, S. Rodak, Gesture gives a hand to language and learning: perspectives from cognitive neuroscience, developmental psychology and education, Lang. Linguist. Compass (2008), doi:10.1111/j.1749-818x.2008.00067.x.
[14] S. Kelly, S. Ward, P. Creigh, J. Bartolotti, An intentional stance modulates the integration of gesture and speech during comprehension, Brain Lang. 101 (2007) 222–233.
[15] T. Kircher, B. Straube, D. Leube, S. Weis, O. Sachs, K. Willmes, K. Konrad, A. Green, Neural interaction of speech and gesture: differential activations of metaphoric coverbal gestures, Neuropsychologia 1 (2009) 169–179.
[16] M. Kutas, S. Hillyard, Reading senseless sentences: brain potentials reflect semantic incongruity, Science 207 (1980) 203–205.
[17] D. McNeill, Language and Gesture, The University of Chicago Press, Chicago, 1992.
[18] S. Ojima, H. Nakata, R. Kakigi, An ERP study of second language learning after childhood: effects of proficiency, J. Cogn. Neurosci. 17 (2005) 1212–1228.
[19] L. Osterhout, J. McLaughlin, I. Pitkanen, C. Frenck-Mestre, N. Molinaro, Novice learners, longitudinal designs, and event-related potentials: a means for exploring the neurocognition of second language processing, Lang. Learn. 56 (2006) 199–230.
[20] A. Özyüreck, R. Willems, S. Kita, P. Hagoort, On-line integration of semantic information from speech and gesture: insights from event-related brain potentials, J. Cogn. Neurosci. 19 (2007) 605–616.
[21] S. Rossi, M. Gugler, A. Friederici, A. Hahne, The impact of proficiency on syntactic second-language processing of German and Italian: evidence from event-related potentials, J. Cogn. Neurosci. 18 (2006) 2030–2048.
[22] T. Sitnikova, G. Kuperberg, P. Holcomb, Semantic integration in videos of real-world events: an electrophysiological investigation, Psychophysiology 40 (2003) 160–164.
[23] G. Stam, Lexical failure and gesture in second language development, in: C. Cavé, I. Guaïtella, S. Santi (Eds.), Oralité at Gestualité: Interactions et Comportements Multimodaux Dans La Communication, L'Harmattan, Paris, 2001, pp. 271–275.
[24] K. Weber, Syntactic anomaly elicits a lexico semantic (N400) ERP effect in second language but not the first, Psychophysiology 45 (2008) 920–925.
[25] C. Weber-Fox, H. Neville, Maturational constraints on functional specializations for language processing: ERP and behavioral evidence in bilingual speakers, J. Cogn. Neurosci. 8 (1996) 231–256.
[26] R. Willems, A. Özyürek, P. Hagoort, When language meets action: the neural integration of gesture and speech, Cereb. Cortex 17 (2007) 2322–2333.
[27] Y.C. Wu, S. Coulson, Meaningful gestures: electrophysiological indices of iconic gesture comprehension, Psychophysiology 6 (2005) 654–667.