Do we embody second language? Evidence for 'partial' simulation during processing of a second language

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Francesco Foroni [*]

SISSA – Trieste, Italy

ABSTRACT

The present paper investigates whether the processing of emotion language in the context of a second language (L2) entails motor simulations and whether simulation models extend to negation also for L2. Participants were exposed to sentences in L2 describing emotional expressions while facial muscle activity was continuously measured. Sentences mapped either directly upon the *zygomatic* muscle (e.g., "I am smiling") or did not (e.g., "I am frowning"), and were presented in the affirmative and negative form. Similarly to studies involving first language (L1), the zygomatic muscle was activated when reading affirmative sentences relevant to the muscle. In contrast, and differently from what previously observed in L1, reading sentences in the negative form ("I am not smiling") did not lead to relaxation/inhibition of the zygomatic muscle. These results extend the simulation models to the comprehension of L2 but they also provide important constraints and contribute to the debate about grounding of the abstract and concrete concepts.

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1. Introduction

The ability to share, to communicate, and to understand emotions is fundamental for our social life (Dewaele, 2008; Fussell, 2002; Rimé, 2007). Language is a powerful emotion elicitor (Velten, 1968), it can affect judgments (Johnson & Tversky, 1983) and, therefore, have important implications for face-to-face communication (Kawakami, Phills, Steele, & Dovidio, 2007). However, research on emotion language (i.e., emotion words, emotion-loaded words, descriptions of emotion-related events and emotion discourse) has characteristically focused on native language (L1). According to different theories, second language (L2) either uses the same or different mechanisms and neural substrates as L1. In order to advance our understanding of L2 processing and, as a result, also of L1 processing, the present paper investigates motor simulations during the comprehension of emotion language in the context of L2 (see Zwaan & Taylor, 2006).

1.1. Simulation during language comprehension

A fundamental question in cognitive neuroscience concerns the role of sensory and motor information in representing conceptual knowledge in the brain and in understanding objects, actions and words (see Tomasino & Rumiati, 2013).

The investigation of the neural system underpinning language processing has identified a network of brain areas including frontal and temporal left-hemisphere regions that, together with subcortical structures, are differentially involved in specific aspects of linguistic computation, from word level to sentence processing (Friederici, 2002; Ojemann, 1991; Poeppel & Hickok, 2004). The neurobiological models suggesting that these areas operate autonomously from other brain areas (e.g., modality-specific ones; Pylyshyn, 1980) largely fall into the traditional linguistic notions that language operates on abstract representations via formal rules (cf. Vukovic & Shtyrov, 2014) and does not benefit from the functional contributions of the sensorimotor system (e.g., Fodor, 1983).

However, recent theoretical arguments and an increasingly rich set of converging research findings together suggest that the processing of language may entail also the automatic recruitment of sensorimotor systems (Baumeister, Rumiati, & Foroni, 2015; Boulenger et al., 2006; Buccino, Riggio, Melli, Gallese, & Rizzolatti, 2005; De Grauwe, Willems, Rueschemeyer, Lemhöfer, & Schriefers, 2014; Filimon, Nelson, Hagler, & Sereno, 2007; Fischer & Zwaan, 2008; Foroni & Semin, 2009; Gentilucci & Gangitano, 1998; Glenberg & Kaschak, 2002; Glover & Dixon, 2002; Hauk, Shtyrov, & Pulvermüller, 2008; Quené, Semin, & Foroni, 2012; Meteyard, Cuadrado, Bahrami, & Vigliocco, 2012; Moseley, Carota, Hauk, Mohr, & Pulvermüller, 2011; Pulvermuller, 2005;

* Address: SISSA – Trieste, Neuroscience Area, Via Bonomea, 265, 34136 Trieste, Italy.

E-mail address: francesco.foroni@sissa.it

Winkielman, Niedenthal, & Oberman, 2008; Zwaan & Taylor, 2006). In general, neuroimaging research shows the involvement of the primary motor cortex (BA 4) in the processing of action verbs (e.g. Hauk, Johnsrude, & Pulvermuller, 2004; Kemmerer, Castillo, Talavage, Patterson, & Wiley, 2008; Pulvermüller, Hauk, Nikulin, & Ilmoniemi, 2005; Pulvermüller, Shtyrov, & Ilmoniemi, 2005). Studies using transcranial magnetic stimulation (TMS) find that motor-evoked potentials (MEPs) recorded from hand muscles change when stimulation is applied on the hand motor area following action language presentation (e.g., Buccino et al., 2005). Additionally, several studies report involvement of the premotor cortex (BA 6) in action language comprehension (Aziz-Zadeh, Wilson, Rizzolatti, & Iacoboni, 2006; Hauk et al., 2004; Tettamanti et al., 2005).

These findings are regarded as evidence in support of embodiment theories, which claim that conceptual knowledge is grounded in sensory–motor systems (Barsalou, 1999, 2008; Gallese & Lakoff, 2005; but see Mahon & Caramazza, 2008). Researchers holding this opinion claim that language processing is mediated by implicit motor simulations (Barsalou, 1999, 2008; Simmons, Hamann, Harenski, Hu, & Barsalou, 2008; Willems & Casasanto, 2011) and shares a common neural substrate with actual motor processing (Gallese & Lakoff, 2005). Namely, understanding a sentence like "I am smiling" entails in the comprehender the embodied sensorimotor simulations of the content described by linguistic utterances (e.g., de Zubicaray, Arciuli, & McMahon, 2013). That is, the re-enactment of a smile (i.e., simulation: activation of the zygomatic muscle; Foroni & Semin, 2009; Winkielman et al., 2008).

Related to the question whether language comprehension recruits motor simulations, an extension of this research investigates how negation is represented. Negation is of paramount importance for human reasoning because it refers to an abstract aspect of reality, namely the absence of a concept (e.g., Hasson & Glucksberg, 2006; Horn, 2001) and it allows us to reason by contradiction and to cope with false and contradictory statements. Thus, understanding how we comprehend negation can also contribute toward a more general understanding of how people construct and evaluate alternatives (cf. Hasson & Glucksberg, 2006). However, negation of action is a largely unexamined proposition so far (see Kaup, Yaxley, Madden, Zwaan, & Lüdtke, 2007; Liuzza, Candidi, & Aglioti, 2011; Tettamanti et al., 2008; Tomasino, Weiss, & Fink, 2010) and presents a challenge for models suggesting that the motor system drives action processing.

The few studies that did investigate this topic using functional magnetic resonance imaging (fMRI) found a partial deactivation in action-related areas during comprehension of negative sentences (e.g., Tettamanti et al., 2008; Tomasino et al., 2010). However, the brain imaging literature on this topic so far does not reveal – due to fMRI's poor temporal resolution, the large variability of experimental designs and procedures, and the presence of conflicting results (cf. Tomasino et al., 2010) – the actual causes of neural activation or deactivation in motor systems (Kemmerer & Gonzalez-Castillo, 2010). Therefore, it cannot be ruled out that such changes in brain activation are epiphenomenal and may only reflect secondary post-comprehension processes such as imagery or covert simulation (Lotto, Hickok, & Holt, 2009). Aravena et al. (2012), for instance, using 'grip-force' measurement to investigate negation found that action words in negative sentences had no significant effect on force-grip. However, this result it is open to multiple interpretations. In fact, even the lack of effect on force-grip by action words in negative sentences could be potentially compatible with evidence of reduced motor system activations in Tettamanti et al. (2008) and in Tomasino et al. (2010).

Recently, Foroni and Semin (2013) investigated the somatic correlates of negation in L1 and showed that reading sentences involving the affirmative form ("I am smiling") leads, indeed, to the activation of the zygomatic muscle, while reading sentences involving the negation ("I am not smiling") leads to the relaxation/inhibition of the same muscle. Importantly, because these effects occurred early (within 200 ms post-stimulus), they do suggest that motor simulation co-occurs with lexico-semantic processing. Furthermore, these results (but see also Bartoli et al., 2013) are in line with the simulation argument and recent fMRI studies (e.g., Tettamanti et al., 2008; Tomasino, Maieron, Guatto, Fabbro, & Rumiati, 2013; Tomasino et al., 2010).

In summary, while fMRI evidence mostly included action-related language (e.g., kick) suggesting the possible involvement of motor-area in the comprehension of negative sentences as they report a partial deactivation in action-related areas during comprehension of negative sentences (e.g., Tettamanti et al., 2008; Tomasino et al., 2010), Foroni and Semin (2013) went further and investigated the involvement of motor simulations during processing of L1 in the case of emotion language.

Thus, there is some empirical evidence suggesting that processing affirmative emotion language in L1 recruits the motor simulation of emotional states (e.g., activation of the corresponding facial muscles), while negative emotion language leads to relaxation/inhibition of motor simulation. Motor simulations, together with its subsequent bodily feedback, likely plays a major role during social interactions (e.g., Foroni & Semin, 2009, 2011a, 2011b; Hess & Bourgeois, 2010; Kawakami et al., 2007; Niedenthal, Mermillod, Maringer, & Hess, 2010; Oberman & Ramachandran, 2007; Winkielman et al., 2008). However, due to the scarcity of research on processing emotion language in L2, it is currently unknown whether L2 processing also requires motor simulations. In line with this possibility, Dudschig, de la Vega, and Kaup (2014) suggested that not only L1 but also L2 words "become automatically interconnected with sensory–motor processes" (p. 19). In the same vein, some authors have also argued that L2 comprehension requires motor simulations but in different degree (Vukovic & Shtyrov, 2014). These results suggest that the comprehension of emotion language in L2 should entail motor simulations (see Zwaan & Taylor, 2006) and they challenge the idea that L2 processing takes place in a fully amodal manner (cf. Dudschig et al., 2014).

Investigating motor simulation in L2 is of paramount importance because comprehension of L2 is a critical challenge for models suggesting that the motor system drives action-language processing. It has been argued that L2 is acquired and processed through the same neural structures responsible for L1 (Abutalebi, 2008) suggesting that simulations should be involved in L2 processing (Dudschig et al., 2014) as they are in L1 processing. Due to the overlapping between acquisition and processing of L1 and L2, if simulations are involved in L1 but not in L2, one could also question the suggestion that motor involvement is a necessary condition for language processing.

In the following, evidence about the neural mechanisms underlying the acquisition and processing of L1 and L2 will be reviewed. Subsequently, hypotheses underlying the present work will be described.

1.2. Neural mechanisms underlying acquisition and processing of L1 vs. L2

A basic issue in the study of L1 and L2 comprehension is whether a L2 learnt later in life can be processed through the same neural mechanisms underlying L1 acquisition and processing. Considering that L1 is acquired implicitly and is mediated by innate learning mechanisms triggered during a critical period, it remains unclear whether the same mechanisms underlie the acquisition of L2 (Perani & Abutalebi, 2005).

The socialization histories for L1 and late L2 are very different (Dewaele & Pavlenko, 2002; Harris & Ayçiçeĝi, 2009; Pavlenko,

2005). Moreover, the literature on bilingual aphasics reports selective recovery of one language, suggesting a differential neural representation of L1 and L2 (Albert, Obler, & Obler, 1978). However, there are limitations to the generalization of such lesion evidence to healthy individuals (Abutalebi, Cappa, & Perani, 2001; Green & Price, 2001).

Thus, it might be argued that while the experience of a native speaker promotes the establishment of strong action–perception links as described in the embodied cognition literature (Pulvermüller & Fadiga, 2010), a typical L2 speaker might not rely on the same mechanisms to understand action language (Pavlenko, 2005; but see Dudschig et al., 2014). The reason for this discrepancy is that native-language learning generally co-occurs with bodily movements and actions to which the word refers. The conceptual development includes information received from all sensory modalities including kinesthetic and visceral (Pavlenko, 2005) while formal L2 learning usually occurs in an artificial environment without significant involvement of the majority of sensory modalities (Perani & Abutalebi, 2005). Through action–perception wiring, L1 action words may thus become directly linked to motor codes and programs. L1 comprehension and use will, therefore, include also physiological and sensory simulations (cf. Semin & Smith, 2008) while L2 might not result in such rich and direct associations (Perani & Abutalebi, 2005).

In line with this argument, recently it was suggested that the processing of L2 acquired late in life depends on different cognitive mechanisms and cerebral structures from L1 (Ullman, 2001, 2004). From this perspective, while lexical knowledge is represented in the declarative memory system for both L1 and L2, grammatical knowledge is declarative for L2 and implicit for L1. Thus, since the neural systems that mediate implicit and declarative knowledge are distinct (respectively, a left frontal–basal ganglia circuit and left temporal language areas), this theory suggests that L2 acquisition in adulthood does not depend on the same brain mechanisms that are used to process L1 (Ullman, 2001). It follows that for late L2 speakers emotional language in L2 will not acquire the full emotional connotations as in L1 (cf. Bond & Lai, 1986; Dewaele, 2004, 2008; Gonzalez-Reigosa, Spielberger, & Diaz-Guerrero, 1976; Harris & Ayçiçeĝi, 2009; Sutton, Altarriba, Gianico, & Basnight-Brown, 2007). An alternative account hypothesizes instead that the acquisition of the L2 emerges in the context of an already specified language system, and that L2 will receive convergent neural representation within the L1 representations. According to this view, possible differences between L1 and L2 speakers may disappear as L2 proficiency increases (Green, 2003).

Ullman's hypothesis of separate neural structures for L1 and L2 did not receive large confirmation so far (Briellmann et al., 2004; Sakai, Miura, Narafu, & Muraishi, 2004; Wartenburger et al., 2003). In particular, the available evidence concerning language acquisition suggests that L2 is acquired through the same neural structures responsible for L1 acquisition (see Abutalebi, 2008). The brain structures traditionally associated with grammatical processing (e.g., Broca's regions, basal ganglia) were involved at a comparable level when bilinguals perform grammatical tasks in both L1 and L2 (e.g., Rüschemeyer, Zysset, & Friederici, 2006; Suh et al., 2007). However, recent functional connectivity analysis in low proficient bilinguals suggests that these brain regions may be differentially engaged by L1 and L2 (Dodel et al., 2005). Moreover, Wartenburger et al. (2003) observed differences in brain activations for grammatical tasks between L1 and L2 acquired late. Highly proficient bilinguals were in need of additional neural resources to achieve a comparable native-like performance.

These neural differences between L1 and L2, for both grammatical processing and lexico-semantic processing, are particularly prominent at the initial stages of L2 acquisition. Reaching native-like proficiency in L2 should reduce these differences (for a review see Abutalebi, 2008) but may not cancel them completely.

No investigation so far tested whether L2 is somatically grounded implementing sentence processing (instead of word processing) and testing this hypothesis measuring directly muscle simulation instead of inferring from compatibility paradigms (e.g., Dudschig et al., 2014). The present work tries to fill this gap by focusing on the somatic muscle correlates of emotion language processing in L2, and testing directly whether the comprehension of emotion language in a L2 entails the same somatic simulations as in L1.

1.3. Overview

In the present experiment it was examined whether the processing of a L2 (i.e., English for Dutch native speakers) in its affirmative and negative forms relies on the same somatic bases as that of L1 (Foroni & Semin, 2009, 2013). When participants read affirmative sentences in L1 (e.g., 'I am smiling') the relevant muscle (i.e., zygomatic major) activates; however, when they read negative sentences in L1 (e.g., 'I am not smiling'), the relevant muscle is inhibited. These results demonstrate the somatic base for L1 and a distinct grounding of linguistic markers such as negation (Foroni & Semin, 2013).

Stimulus material consisted of English sentences (participants' L2) either relevant (e.g., I am smiling) or irrelevant (e.g., I am frowning) to the target muscle under examination (zygomatic major). Sentences were constructed both in their affirmative (e.g., 'I am smiling') or negative form (e.g., 'I am not smiling'), and shown on a computer screen. Activation of facial muscles was measured throughout using facial electromyography (EMG; see also Stins & Beek, 2013).

If the simulation argument of language processing generalizes to L2, then one could expect L2 affirmative sentences (e.g., I am smiling) to induce zygomatic activation, and their sentential negation (e.g., I am not smiling) to induce reduce activation as was reported for L1 (see Foroni & Semin, 2013; cf. Dudschig et al., 2014; Tettamanti et al., 2008; Tomasino et al., 2010).

However, if the simulation hypothesis does not fully apply to L2, then a different pattern of data should be found. The absence of any muscle activation for negative sentences is also conceivable, similarly to the one reported by Aravena et al. (2012). However, previous research suggests that words in L2 do not simply inherit the semantic representation of their L1 translation equivalent: rather, words seem to be associated with the aspects of semantics afforded by the learning situations (Williams & Cheung, 2011), which can lead to different semantic representations in L2 compared to L1 (Eilola & Havelka, 2010).

Firstly, based on the idea that L1 engages the motor cortex more strongly than L2 (Vukovic & Shtyrov, 2014) and on recent evidence reviewed above (e.g., Dudschig et al., 2014; Foroni & Semin, 2013), the main hypothesis here is that L2 processing would result in weaker motor simulations compared to L1 (see also Bond & Lai, 1986; Dewaele, 2004; Gonzalez-Reigosa et al., 1976). To test this hypothesis, the strength of the muscle activation of L2 and L1 will be confronted.

In relation to the somatic reaction to negative relevant sentences, the neural differences between L1 and L2, for both grammatical processing and lexico-semantic processing, may be relevant (for a review see Abutalebi, 2008). While emotion language in L1 is embodied and simulated in its aspects (Foroni & Semin, 2013), in L2 emotion language this conclusion is still unknown. The processing of L2 could be simulated in all the aspects as L1 or the results could show a different pattern (e.g., non-significant relaxation/inhibition after negative sentences).

Finally, irrelevant sentences that do not refer to zygomatic activity (in affirmative or negative form; e.g., I am [not] frowning) should not show muscle reactions.

2. Method

2.1. Participants

Twenty-six native Dutch-speaker university students (9 females; 22 right-handed; mean age: 22.3) with good fluency in English language (L2 learnt after the age of 12 through scholastic programs) as assessed through self-report (cf. Marian & Neisser, 2000; Pavlenko, 2005), took part of the experiment (for monetary compensation: circa US $20.00) after signing informed consent.

2.2. Stimulus material

Stimulus sentences were verbal representations of emotional expressions that mapped either directly upon the *relevant* facial muscle (e.g., 'I am smiling'-zygomaticus major muscle) or did not do so – *irrelevant* (e.g., 'I am frowning'). *Relevant predicates* were: to smile, to laugh, to grin. *Irrelevant Predicates* were: to frown, to cry, to whine. Each relevant or irrelevant predicate was presented in the affirmative and negative form using the first person singular conjugation (12 target sentences in total). An example of affirmative sentence is "I am smiling" while an example of negative sentence is "I am not grinning". The target English sentences presented here were intermixed with 12 Dutch sentences. Results relative to the L1 sentences are reported in Foroni and Semin (2013).[1]

2.3. Procedure, apparatus and data acquisition

Procedure, apparatus and data acquisition were as reported by Foroni and Semin (2013). Participants were tested individually in a soundproofed experimental chamber. The experiment was presented as investigating the interference between reading and the performance at a simple spatial-classification task and the mediating role of skin conductance. Participant's task was to classify images of arrows according to where the arrow was pointing (left or right) after reading short sentences while their skin conductance was *supposedly* measured.

The trial structure was: fixation point (500 ms), baseline interval (3000 ms), stimulus sentence presentation (4000 ms). After stimulus presentation and 500 ms interval the image of an arrow appeared in the center of the screen and stayed until the participant responded whether the arrow was pointing toward left or right. In order to create variation in the classification task, each arrow-type (left-pointing and right-pointing) was presented in different visual forms (e.g., pointing toward bottom-right portion of the screen or top-right portion of the screen; with or without an oval circling the arrow). After participants responded to the arrow the trial ended. After an inter-trial interval (3000 ms) the next trial started. The sentence-arrow matching was randomly determined for each participant.

Participants were presented with 8 practice trials presenting affirmative and negative sentences different from the test sen-

tences (e.g., 'I am jumping', 'I am not hitting'). After the practice session participants received 5 blocks consisting of 24 trials each (12 L2 test sentences and 12 L1 sentences). Within each block the order of presentation was randomized for each participant. The repetition of the stimulus material was necessary in order to compensate the reduced number of stimuli and the high variability of physiological measurement (see Fridlund & Cacioppo, 1986). During the performance of the task, facial muscle activity over the left zygomatic major was measured continuously via electromyography (EMG) at a sample rate of 1000 Hz and referenced to an electrode placed on the left mastoid. Two miniature Ag/AgCl electrodes and Coulbourn-Isolated-Bioamplifier (Coulbourn Inc., Whitehall, USA) were placed on the left zygomatic major muscle following the guidelines and indications provided by Fridlund and Cacioppo (1986) with a mastoid ground. Namely, 'one electrode is placed midway along an imaginary line joining the cheilion and the preauricular depression (the bony dimple above the posterior edge of the zygomatic arch), and the second electrode is placed 1 cm inferior and medial to the first (i.e., toward the mouth) along the same imaginary line" (p. 571). The skin was cleaned and prepared to reduce electrode-site impedance to less than 11 kV.

The digitized signal was bandpass filtered from 10 to 450 Hz and then full-wave rectified offline using MATLAB (The Mathworks, Natick, NA). Based on previous investigations (e.g., Foroni & Semin, 2009, 2013), we focus our analyses on the EMG response of the first 1000 ms after stimulus presentation. EMG responses were expressed in microvolts as change in activity from baseline level (pre-stimulus level). *Baseline level* was considered the mean activity over a 500 ms period before stimulus presentation. As the baseline was supposed to reflect the muscle activity during resting/relaxing state, for each trial a 500 ms period of steady activity (i.e., without artifacts and/or extreme variations) was identified within the last second before stimulus presentation (see Foroni & Semin, 2013). Following guidelines for psychophysiological measurement (Cacioppo, Tassinary, & Berntson, 2007; Fridlund & Cacioppo, 1986), baseline was considered suitable when no artifacts were present (i.e., no peak-to-peak change of over 70 µV in the period). Change in activity compared to baseline was averaged over intervals of 200 ms giving rise to 5 *periods* of 200 ms each during the time interval considered. Trials were excluded when artifacts were present (i.e., when a peak of over 70 µV was present) or no steady baseline was present (excluded trials: 6.7%).

2.4. Design and statistical analysis

The data were analyzed in a three factorial design with *predicate relevance* (relevant vs. irrelevant) × *linguistic form* (affirmative vs. negative) × *period* (5 time intervals of 200 ms each) repeated-measure variables. Dependent variable was the mean activation level of the zygomatic major muscle (baseline-corrected) for each time-period by predicate relevance and linguistic form.

The results section will first report the results of the omnibus analyses of variance (Section 3.1). Geisser–Greenhouse conservative F tests were used to reduce likelihood of positively biased tests (see Dimberg, Thunberg, & Grunedal, 2002; Kirk, 1968). The results for relevant and irrelevant predicates will be, then, described separately (Sections 3.2 and 3.3 respectively). For each type of sentence a priori comparisons between the activation level and the zero-level are reported to determine if there is a significant activation (or relaxation/inhibition) for each time period. Additionally, within relevant and irrelevant predicates, a priori comparisons between means for the affirmative and negative form are also reported (e.g., activation of 'relevant, affirmative sentences' vs.

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[1] When targeting a single/specific muscle and the somatic correlates of language comprehension one faces the problem of a limited number of predicates to use as stimuli. In fact, few stimuli are similarly mapped onto the same muscle but are also matched for length and frequency with the 'control' sentences. Here we have found 3 for the zygomatic muscle. Other research has successfully investigated language comprehension with a similarly-limited set of stimuli (e.g., Aziz-Zadeh et al., 2006; Foroni & Semin, 2009, 2013). Thus, this limited number does not preclude the implementation of this approach. Dutch sentences presented in Foroni and Semin (2013) and English sentences are the exact linguistic counterpart/translation).

activation of 'relevant, negative sentences' in each time period after stimulus onset). A priori comparisons between means were evaluated by t-tests. Positive values of the muscle activation after baseline correction indicate the activation of the zygomaticus compared to pre-stimulus baseline, and negative values indicate inhibition compared to pre-stimulus baseline. Then, the results of the classification task performed by the participants after being exposed to each stimulus will be reported (Section 3.4). Finally, because of the perfect parallel between the present experiment and the one reported for L1 a comparison between Foroni and Semin's data (2013) and the present data is reported (Section 3.5).

3. Results

3.1. Omnibus analyses

Fig. 1 (Panel A) shows the outcomes for the *zygomatic major* muscle for the present experiment investigating L2 together with the results for L1 reported by Foroni and Semin (2013). Our main hypothesis was confirmed by the significant 2-way interaction between predicate relevance *over time*, $F(2,53) = 7.82$, $p = .001$.

Participants showed a significant increase of activation of the zygomatic major muscle over time when presented with sentences relevant to the muscle compared to the sentence irrelevant to the muscle. The higher order 3-way interaction involving also linguistic form did not reach statistical significance, $F(3,67) = 1.28$, $p = .287$.[2] In addition, there were two main effects of less theoretical interest that, nevertheless, support the orderly of the data. First, relevant sentences produced a larger activation than irrelevant sentences as shown by the main effect of predicate relevance, $F(1,25) = 5.65$, $p = .025$. Finally, the activation of the zygomatic increased in general over time, $F(2,49) = 4.14$, $p = .022$.

3.2. Relevant sentences

Affirmative sentences show a significant activation of the zygomatic muscle when relevant to the muscle in the last 2 intervals, ($p = .94, .52, .19, .05, .02$) while negative relevant sentences show no significant relaxation/inhibition ($p = .12, .20, .42, .44, .13$).

Affirmative relevant sentences show larger mean activation of the zygomatic muscle compared to negative relevant sentences not reaching, however, standard levels of significance ($p = .18, .12, .08, .06, .19$ (one-tailed)).

3.3. Irrelevant sentences

The sentences that are irrelevant to the muscle produced a relaxation/inhibition of the zygomatic muscle activity when in the affirmative form on the last 2 intervals ($p = .70, .10, .14, .06, .004$) while no systematic effect when in the negative form (all $ps > .26$). These last effects are consistent to the one reported previously (e.g., Foroni & Semin, 2013). Affirmative irrelevant sentences show generally no larger activation of the zygomatic muscle compared to negative irrelevant sentences except for the last interval ($p = .55, .77, .31, .28, .03$).

3.4. Classification task

To check the performance (RTs and accuracy) on the arrow-classification task reaction times and error percentage were analyzed separately in two 3-way analyses of variance with

predicate relevance (relevant vs. irrelevant) × *linguistic form* (affirmative vs. negative) × *arrow direction* (left vs. right) as within subject factors. There was no significant effect of any one of the factors as main effect or in interaction on RTs or errors (all $ps > 0.2$).

3.5. L2 vs. L1: cross studies analysis

Considering only the sample of participants that had sufficient number of trials that did not present movement artifact for both L1 and L2 ($N = 26$) it was possible to compare L1 and L2 on the same sample of participants. The data were analyzed in a four factorial design with *language* (L1 vs. L2) × *predicate relevance* (relevant vs. irrelevant) × *linguistic form* (affirmative vs. negative) × *period* (5 time intervals of 200 ms each) as repeated-measure variables. This analysis confirmed the hypothesis. The four-way interaction between *language*, *predicate relevance*, *linguistic form*, and *period* was significant, $F(3,75) = 2.84$, $p < .05$.

There were also lower order effects: The main effect of *predicate relevance* was significant ($F(1,25) = 10.32$, $p = .004$) as well as the main effect of *linguistic form* ($F(1,25) = 6.25$, $p = .019$) and of *period*, ($F(1,36) = 6.68$, $p = .007$). The interaction *predicate relevance* by *period* was also significant ($F(2,46) = 7.25$, $p = .002$), as well as the interaction between *predicate relevance*, *period*, and *linguistic form* ($F(2,55) = 4.07$, $p = .019$). I move now to report the a priori comparisons between means evaluated by uncorrected t-tests.

The first key comparison for the present argument relates to affirmative relevant sentences. While L1 is not different from L2 at 200 ms and 400 ms periods, L1 shows larger activation compared to L2 at 600 ms and 1000 ms period with the 800 ms period showing a marginal significant difference ($ps = .77, .21, .03, .07, .05$). A second key comparison between L1 and L2 is on the negative relevant sentences that showed significant relaxation/inhibition in L1 and no effect in L2. This comparison confirmed the visual inspection: L1 shows more inhibition (larger negative value) than L2. This difference is significant at 400 ms ($t(25) = 2.25$, $p = .03$) and at 600 ms period ($t(25) = 2.05$, $p = .05$) but not at 200 ms ($t(25) < 1$, $p = .47$), 800 ms ($t(25) = 1.2$, $p = .24$) and 1000 ms period ($t(25) < 1$, $p = .82$). Finally and as expected, no comparison on the irrelevant sentences (affirmative or negative) show any significant difference between L2 and L1 ($ts(25) < 1.1$, $ps > .24$).

Visual inspection highlighted for L1 and L2 an apparent different pattern of activation of the zygomatic major muscle in the last two periods (Fig. 1A and B) that is worth investigating. Separately for L1 and L2, follow-up ANOVAs were carried out with a three factorial design with *predicate relevance* (relevant vs. irrelevant) × *linguistic form* (affirmative vs. negative) × *period* (800 ms vs. 1000 ms) as repeated-measure variables. The results on L1 showed the following results: a main effect of *sentence relevance* ($F(1,29) = 6.79$, $p = .014$), a significant main effect of *linguistic form* ($F(1,29) = 5.48$, $p = .026$), a significant main effect of *period* ($F(1,29) = 6.20$, $p = .019$), a significant interaction between *sentence relevance* and *linguistic form* ($F(1,29) = 6.87$, $p = .014$). No other effects were significant ($ps > .39$). The same analysis on L2 showed a main effect of *sentence relevance* ($F(1,25) = 11.62$, $p = .002$), a significant main effect of *period* ($F(1,25) = 5.68$, $p = .025$), a significant interaction between *sentence relevance* and *linguistic form* ($F(1,25) = 5.18$, $p = .032$). No other effects were significant ($ps > .23$).

The results of L2 parallel those of L1. However, in this respect this interaction between *sentence relevance* and *linguistic form* is of interest as visual inspection suggests that the interaction in L2 could be driven by both an activation induced by relevant affirmative sentences and by a relaxation induced by irrelevant affirmative sentences. To investigate this possibility pairwise Bonferroni-corrected comparisons were implemented to compare

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[2] Interestingly, this effect was found significant in L1 (see Fig. 1, Panel B from Foroni & Semin, 2013). A comparison between L1 and L2 is reported later and the reasons for such differences are elaborated in the discussion section.
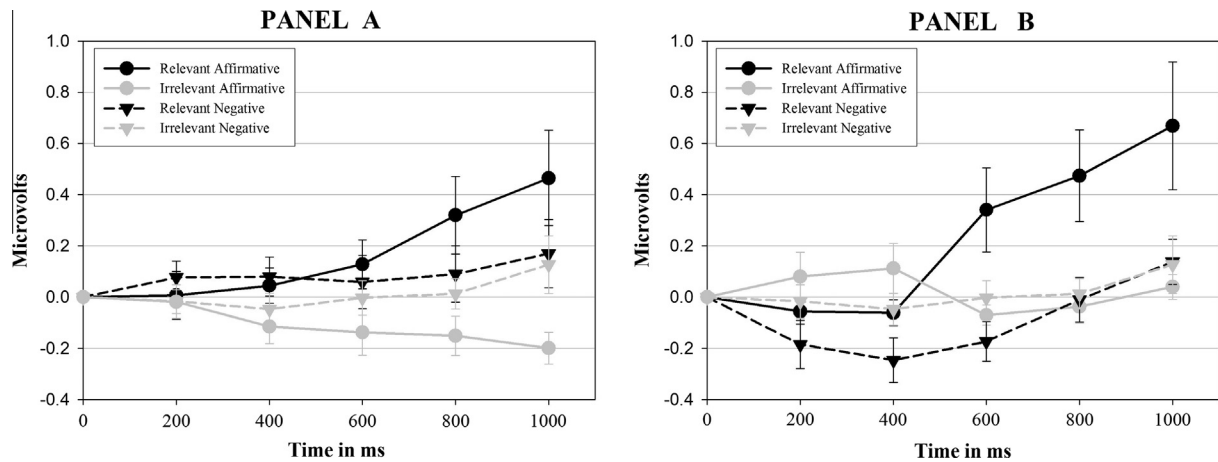
PANEL A

PANEL B

Fig. 1. Mean facial electromyographic response for the zygomatic major muscle (and Standard error of means), plotted in intervals of 200 ms, during the first second of exposure to stimulus sentences. Results are shown separately for each category of L2 sentences (Panel A) and of L1 sentences from Foroni and Semin (2013; Panel B).

condition means within *sentence relevance* by *linguistic form* interaction separately for L1 and L2. In L1, comparisons revealed that relevant affirmative sentences ($M = .573$, $SD = .204$) activate significantly more the zygomatic than affirmative irrelevant sentences ($M = .002$, $SD = .052$; $p = .004$) and than relevant negative sentences ($M = .064$, $SD = .078$; $p = .012$). Parallel to L1, the results on L2 comparisons showed that relevant affirmative sentences ($M = .392$, $SD = .157$) activate significantly more the zygomatic than irrelevant affirmative sentences ($M = -.175$, $SD = .065$; $p = .002$) and than relevant negative sentences ($M = .167$, $SD = .114$) in this case not significantly ($p = .19$). Finally, for L2 irrelevant affirmative sentences ($M = -.175$, $SD = .065$) appear to activate less the zygomatic than irrelevant negative sentences ($M = .055$, $SD = .119$), however, only marginally so ($p = .077$).

4. Discussion and conclusions

In the present experiment Dutch native speakers were presented with sentences in English (L2) in the affirmative and negative form while their facial EMG was measured. Stimulus sentences were either relevant ('I am smiling') or irrelevant ('I am frowning') to the zygomatic muscle.

The goal of the experiment was to test whether the processing of L2 has any somatic bases (i.e., muscle simulation) and whether they were similar or different from the ones reported for L1 (e.g., Foroni & Semin, 2009, 2013). The present approach importantly deviates from previous research on embodiment of concepts because it goes beyond simple words or sentence in L1, investigating more complex and abstract forms of reasoning (i.e., negation) in L2 (see Foroni & Semin, 2013; Hasson & Glucksberg, 2006; Horn, 2001).

The processing of affirmative emotion sentences in L2 involved the simulation of the state of the affair described by the text; namely, when we read sentences like 'I am smiling' in L2 our smiling muscles contract. This result nicely parallels the one obtained for L1 (Foroni & Semin, 2009, 2013) and support the claim that also the processing of L2 has somatic bases and correlates (Vukovic & Shtyrov, 2014). However, and differently from L1, when we process negative sentences we do not see any significant relaxation of the relevant muscle. If we take the muscle activation as an index of somatic correlates of language processing, then this supports the interpretation that while emotional language processing in L1 relies on simulations of the meaning described by the utterances, in L2 such simulations is only partial.

Although numerous studies have reported the involvement of premotor cortex and primary motor cortex in action language

comprehension, the nature of these motor effects is still a controversy. On one hand, some researchers suggest that these effects reflect an early simulation of motor processing, and that these cortical areas play functional roles in language comprehension (e.g., Barsalou, 1999, 2008; Hauk & Pulvermüller, 2004; Willems & Casasanto, 2011). On the other hand, other researchers claim that the motor effects reflect post-comprehension mental imagery or strategy (e.g., Papeo, Vallesi, Isaja, & Rumiati, 2009; Tomasino, Fink, Sparing, Dafotakis, & Weiss, 2008; Vukovic & Shtyrov, 2014). Motor-related effects occurring in an early time window is necessary if the primary motor cortex and the premotor cortex play a functional role in action language comprehension (cf. Vukovic & Shtyrov, 2014). At least in L1, the emergence of these effects within 200 ms post-stimulus (Foroni & Semin, 2013) suggests the co-occurrence of motor simulation with lexico-semantic processing. However, the emergence of these effect appears slower in L2 leaving open this issue for L2 processing.

In general, the magnitude of the somatic reaction in L2 is smaller than the one reported for L1 (see Fig. 1, Panels A and B). In fact, when presented with affirmative sentences here participants display a significant activation of the zygomatic muscle in the last 2 intervals (compared to the last 3 reported for L1, see Foroni & Semin, 2013, p. 4) and they produce a smaller absolute activation than the one reported for L1. The weaker magnitude of the somatic simulation for L2 compared to the one reported for L1 is generally in line with the argument that the different socialization histories of L1 and L2 are reflected in different degree of embodiment (cf. Semin & Smith, 2008; e.g., Dewaele, 2008; Harris & Ayçiçegi, 2009; Pavlenko, 2005; Sutton et al., 2007). This difference is also in line with imaging studies (e.g., Tettamanti et al., 2008; Tomasino et al., 2010, 2013; Vukovic & Shtyrov, 2014) and functional connectivity analysis suggesting that these brain regions may be differentially engaged by L1 and L2 (Dodel et al., 2005; Wartenburger et al., 2003). A neurobiological explanation for this asymmetry is readily available in theories suggesting that L1 is used in interactive and diverse real-world contexts promoting the formation of strong action–perception links. In fact, these theories posit that the meaning of words/verbs is embodied in strongly-integrated neural networks formed through associative learning mechanisms. The motor activation involved in processing a late L2, instead, is suggested to be lower, because the corresponding representation is less rich and weaker (Pulvermüller, 2012).

Also for negative sentences there are important differences. When presented with negative sentences in L1, participants show a significant relaxation of the target muscle starting in the first 200 ms of exposure (see Foroni & Semin, 2013) while in L2 here

they do not produce any similar effects. The lack of relaxation/inhibition induced by negative sentences in L2 could be interpreted as the result of a qualitatively different processing of linguistic negation in L2 compared to L1 (Ullman, 2001, 2004).

Based on visual inspection of the results, additional analyses were carried out on the last two periods in L1 and L2. The main analyses show similar pattern of results in L1 and L2. However, it is interesting to look within the significant *sentence relevance* by *linguistic form* interaction: In L2 the irrelevant affirmative sentences seem to induce more relaxation than irrelevant negative sentences (albeit not significantly so), while in L1 the corresponding same sentences do not show any muscle response. These partially inconsistent results may be due to noise in the aggregated data as well as due to other factors. One possibility, not supported by the clear-cut data in L1 and the lack of statistical significant in the additional analyses, is that the relaxation induced by irrelevant affirmative sentences in L2 is meaningful and, thus, could call into question the hypothesized specificity of the muscle response. The present data cannot rule out this possibility even though there is no clear statistical support for it. Thus, this issue should be further investigated in the future.

Neural differences between L1 and L2 may exist, for both grammatical processing and lexico-semantic processing. These differences are particularly prominent for L2 system processed with a non-native-like proficiency (Abutalebi, 2008). A possible exception is given by grammatical processing since evidence suggests that, despite native-like L2 proficiency, more extensive brain activity is necessary for L2, localized near the areas mediating L1 grammar (Wartenburger et al., 2003). Recently, Kaup and colleagues advanced a theoretical model of the processing of negation (Kaup et al., 2007), which implies that the understanding a negative sentence (e.g. "John has not left") is achieved by a process of deviation–detection between two simulations (i.e., affirmative and negative form: 'John has left' and 'John has not left') with the simulation of the negated sentence occurring after the simulation of the affirmative one. The finding of L1 reported by Foroni and Semin (2013) do not seem to be in line with this model's expectation as relevant negative sentences produce first a fast reduction in muscle activation (i.e., simulation of the negated sentence) and then a return to baseline and a concurrent small activation of the relevant muscle (i.e., simulation of the affirmative one). Namely, the simulation of the negated sentence seems to occur before and not after the simulation of the affirmative one. The results of L2 do not show any indication of multiple and temporally distinct simulations of the negative sentence or of its affirmative meaning. Foroni and Semin's results, together with the findings reported here, may provide potential boundary conditions useful in refining the model proposed by Kaup et al. (2007).

Theoretically, the present results extend the somatic base of language processing from L1 onto L2 and, thus, have important implications for models of human cognition (e.g., Barsalou, 2008; Glenberg, 1997; Lakoff & Johnson, 1999), neural mapping of language, and language processing (e.g., Buccino et al., 2005; Hauk et al., 2004; Tettamanti et al., 2005, 2008; for a review Abutalebi, 2008). However, the present results constitute also a critical constraint for embodied approaches on language learning and have significant theoretical implications for the embodiment debate. For instance, one possible interpretation for the lack of simulation of negation in L2 is also that simulation is not necessary for understanding sentences (see e.g., de Vega et al., 2014; Ferguson, Sanford, & Leuthold, 2008). Since several authors have suggested that L2 is acquired and processes through the same neural structures responsible for L1 (Abutalebi, 2008), then if L2 can be processed and understood without motor cortex involvement and without somatic correlates, then motor involvement may not be functionally necessary for L1 processing either.

Even though the present results do not directly speak to the causal role of sensory and motor activation/simulations in conceptual processing (see e.g., Mahon & Caramazza, 2008) this study constitutes an important step forward in understanding how abstract concepts such as negation as well as concrete ones can be accommodated within embodied theories (cf. Barsalou, 2008; Boroditsky & Prinz, 2008; see also e.g., Glenberg & Kaschak, 2002; Kiefer & Pulvermüller, 2012; Kousta, Vigliocco, Vinson, Andrews, & Del Campo, 2011) and how these theories can also accommodate the acquisition of L1 vs. L2.

The mechanism responsible for systematic differences between L1 and L2 in perceived or experienced emotionality remained an open issue. Future research should investigate the possibility that the difference in somatic bases of L1 vs. L2 could be responsible for it. Language learned in the process of intense childhood socialization seems to have a strong somatic base that is not present or evoked by language learned later in life, in classroom settings or through limited socialization (Pavlenko, 2005). Lamendella (1977) and Paradis (1994) argue that L1 and L2 acquisition differ in the involvement of the amygdala, the limbic system, and other brain structure engaged in processing of emotion, drives and motivation. While in L1 acquisition the above structures are fully involved in production and perception, in L2 acquisition such structures are involved to a lesser degree. In adult, facial motor resonance to emotional content has been correlated to activations in the limbic regions and in the amygdala, which are known to be involved in experiencing and in processing emotional content (e.g., Wild, Erb, Eyb, Bartels, & Grodd, 2003; see Dalgleish, 2004 for a review). In agreement with the embodied accounts, when facial muscles are blocked, the activity in the amygdala is attenuated (Hennenlotter et al., 2009). Thus, this difference in the degree of involvement of these neural structures during acquisition of L1 and L2 could be responsible for the stronger affective connotation of L1. The present research does not speak to this issue, but build a further bridge between these literatures.

The present results have also implications in general for intercultural communication (e.g., Bond & Lai, 1986; Dewaele, 2004; Gonzalez-Reigosa et al., 1976) where the differences in embodied histories will differentiate emotional communication between L1 and L2. Weaker somatic correlates in L2 may contribute to language barriers for L2 speakers in the emotional domain, undermining the possibility of reaching reciprocal understanding and common ground, which are considered key aspects of effective communication (e.g., Clark, 1996).

At the practical level, this difference between L1 and L2 may well result in important behavioral differences. Foroni and Semin showed that these somatic simulations shape participants' evaluation of novel stimuli (Foroni & Semin, 2009, 2011a) but this effect is only present for activations that reach a certain threshold (cf. Foroni & Semin, 2009). It is possible that L2 simply does not have 'strong enough' somatic bases to guide evaluative judgments. Considering that such somatic simulations have been found responsible for driving not only explicit judgment (e.g., Foroni & Semin, 2009, 2011a; Niedenthal et al., 2010), but also affective processes (Foroni & Semin, 2011b; Winkielman et al., 2008) and even implicit reactions to social stimuli (Foroni & Semin, 2012; Vanman, Paul, Ito, & Miller, 1997) the difference between somatic bases between L1 and L2 may have much larger consequences.

In line with such claim, recent research reveals potentially significant implications of such differences in a marketing context (Puntoni, De Langhe, & van Osselaer, 2009); namely, marketing slogans in the consumers' native language were perceived as more emotional than in L2, an effect that was not due to a lack of comprehension. On the other hand, the reduced somatic response to L2 could have beneficial effect as well inducing a weaker bias in those

cases where emotions tend to impair or mislead our judgments (e.g., Johnson & Tversky, 1983; Keysar, Hayakawa, & An, 2012).

Acknowledgements

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