Title: Invisible side of emotions: somato-motor responses to affective facial displays in alexithymia

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Abstract

According to recent theories, the detection of emotions involves somatic experiences. In this study, we investigated the relation between somatic responses to affective stimuli, emotion perception, and alexithymia. Variations in automatic rapid facial reactions (RFRs) were measured in a selected population of participants with high and low levels of alexithymia (HA and LA, respectively). Electromyographic activity was recorded from the *corrugator supercilii* and the *zygomaticus major*, while participants performed a gender classification task on faces expressing various emotional states. LA participants showed congruent RFRs in response to both fearful and happy stimuli. On the other hand, HA participants did not show congruent RFRs in response to fearful faces. They showed congruent, but delayed, RFRs in response to happy faces. These results provide evidence of a deficit in somato-motor emotional processing in people with high alexithymic personality traits, and thus support the hypothesis that alexithymia is associated with a deficit in emotional embodiment.

Keywords Alexithymia · Rapid facial reactions · Visceral responses · Hypo-arousal · Fear

Introduction

Emotions are complex mental and neurophysiological states pervasive to the functioning of the mind/brain at almost every level. Experiencing affective states recruits specific patterns of somato-motor activity, a phenomenon referred to as the “emotional motor system” (Niedenthal 2007; Niedenthal et al. 2010; Gallese and Sinigaglia 2011). The experience of emotions is intimately linked with the production of emotion-related movements. Furthermore, the causal association between emotional experiences and corresponding motor behaviors is bi-directional. For example, the viscero-motor phenomenon of tachycardia is both a product and a cause of anxiety; similarly, the somato-motor phenomenon of a smile is both a product and a cause of happiness (Niedenthal et al. 2010; Frijda 2009).

The somato-motor component of an emotional response supports communication between individuals (Falkenberg et al. 2008; Wild et al. 2001; Hess and Fischer 2013). For example, expressions of fear, pain, and disgust communicate vital information about threats in the environment to conspecifics. Likewise, smiles are fundamental to survival because of their role in forming parental bonds. Recent theories have proposed that ascribing emotional states to others involves re-experiencing the same affective states in one’s own sensory and motor systems (Cacioppo et al. 1986; Larsen et al. 2003; McIntosh 1996; McIntosh et al. 2006; Moody et al. 2007; Hess and Bourgeois 2010; Foroni and Semin 2011; Hess and Fischer 2013). These embodied simulation theories posit that somato-motor reactions to others’ emotional expressions intrude upon the observer’s affective state to produce a matching emotion, thus providing a direct form of “emotion understanding” (Gallese and Sinigaglia 2011; Niedenthal et al. 2010; Bastiaansen et al. 2009; Oberman et al. 2007; Niedenthal 2007). Evidence in favor of such an embodied mechanism is given by phenomena of implicit production of emotional facial expressions in response to others’ emotional facial expressions (Dinmberg and Thunberg 1998; Cacioppo et al. 1986). Supporting the embodied simulation mechanism of emotion understanding, studies have found that adult humans exposed to the emotional expressions of conspecifics automatically produce stereotyped facial movements—known as rapid facial reactions (RFRs; for a review, see Cattaneo and Pavesi 2014)—that are specific to the observed facial expression (Dimberg and Thunberg 1998; Cacioppo et al. 1986). RFRs may be either mimetic (i.e., smiling in response to a smile) or reactive (i.e., expressing fear in response to an angry face; Dimberg 1982; McIntosh 2006). They are produced outside of awareness, with a sub-second onset latency in the 300–700-ms range (Dimberg et al. 2000). Moreover, they are not altered by superimposed voluntary movements.

RFRs are thought to either initiate or modulate affective states, and may, therefore, play a fundamental role in communicating emotions between individuals (McIntosh 1996, 2006). According to this idea, RFRs are a manifestation of emotion embodiment (Hatfield et al. 1992; Lundquist and Dimberg 1995; Vaughan and Lanzetta 1980) allowing one to perceive and recognize the emotional facial expressions of others (Niedenthal et al. 2001).

There is evidence that RFRs are impaired in neuropsychiatric disorders with severe affective symptoms, such as schizophrenia (Falkenberg et al. 2008) and unipolar depressive disorder (Wexler et al. 1994). Some authors have pinpointed a lack of embodied emotional expressions as a core element of such disorders. However, it is not yet known whether RFRs are similarly impaired in subclinical phenomena characterized by specific difficulties in processing emotional stimuli, such as alexithymia. Alexithymia is a relatively stable personality trait that is present to varying degrees in the general population (Luminet et al. 2004; Taylor 2000). Evidence suggests that alexithymia increases vulnerability to a broad range of psychiatric disorders (Taylor et al. 1996; Honkalampi et al. 2000; Henry et al. 2010; Yu et al. 2011; Todarello et al. 2005; van't Wout et al. 2007; Loas et al. 2000; Frewen et al. 2008). Individuals with high alexithymic trait (HA) constitute around the 10% of the normal population (Taylor et al. 1991). They experience difficulties in identifying and describing their own emotions, particularly when those emotions are negative (Sifneos 1973; Taylor et al. 1991). Expanding the classical construct of alexithymia, recent studies in HA individuals have also identified a difficulty in processing the emotions of others (see Grynberg et al. 2012 for a review; Scarpazza et al. 2014, 2015).

Research into the affective somato-motor systems of alexithymics is at an early stage. As of yet, the only two studies (Sonnby-Borgstrom 2009; Peasley-Miklus et al. 2016) that have investigated RFRs in HA individuals have obtained contrasting results. Sonnby-Borgstrom (2009) found impaired RFRs of the *corrugator supercilii* in response to angry faces in HA; on the other hand, Peasley-Miklus et al. (2016) found no differences in RFRs between individuals with high and low alexithymia levels. The latter study, however, used a mental imagery paradigm; thus, it investigated RFRs in response to auto-generated emotions, not RFRs produced in response to others' emotional expressions.

This topic is highly significant to embodied theories of affective states and affective communication, which hypothesize that automatic affective motor reactions play a causal role in understanding others' emotions. The present study was specifically designed to test that hypothesis. We investigated the degree to which participants with low (LA) and high (HA) alexithymia levels produce RFRs that are congruent with observed facial expressions in the *corrugator supercilii* and *zygomaticus major* muscles (Larsen et al. 2003), and whether those RFRs, if present, are associated with individual's empathy, measured using the Interpersonal Reactivity Index (Davis 1983). We predicted that participants with high alexithymia levels would show attenuated RFRs in response to observed emotional expressions, particularly negative ones, because of a deficit in emotion embodiment. Indeed, the previous studies have shown that individuals with HA have a specific difficulty in processing negatively valenced stimuli (e.g., Scarpazza et al. 2014, 2015; Pollatos and Gramann 2011; Borhani et al. 2016; Maier et al. 2016). On the contrary, we predicted that LA participants would show normal RFRs. We also predicted a positive association between RFR amplitude and empathy scores (Hussey and Safford 2009).

Methods

Participants

241 participants were screened to be enrolled in the current study. Participant inclusion criteria are reported in detail elsewhere (Scarpazza et al. 2014, 2015). Briefly, participants were included in the study if (1) they had no history of neurological, major medical or psychiatric disorders; (2) they did not show subclinical or clinical depression on the Italian version of the Structured Clinical Interview

for DSMIV Axis I Disorders (SCID-I; First et al. 1997); and (3) they were congruently classified as either HA or LA by two different alexithymia instruments. The two instruments used to asses alexithymia were the 20-item Toronto Alexithymia Scale (TAS-20; Taylor et al. 2003; cutoff for HA > 61; cutoff for LA < 39)—which comprises three subscales (difficulty identifying feelings—DIF; difficulty describing feelings—DDF; and externally oriented thinking—EOT)—and the alexithymia module of the structured interview for the Diagnostic Criteria for Psychosomatic Research (DCPR, Mangelli et al. 2006; cutoff for HA ≥ 3; cutoff for LA < 3). Participants in the LA group were chosen to be gendermatched with the HA participants to avoid possible effects of gender differences. Initial enrollment included 12 HA and 14 LA participants.

The study was approved by the ethical committee of the Department of Psychology of the University of Bologna and was conducted according to the principles of the Declaration of Helsinki.

Self-report questionnaires

Since the participant's emotional state during the experiment can influence RFRs (Moody et al. 2007; Niedenthal et al. 2001), all participants were asked to complete the positive and negative affect schedule prior to the experiment (PANAS, Crawford and Henry 2004), to exclude participants who showed low motivation to participate in the study. The PANAS consists of ten positive affect items and ten negative affect items. Participants rated the extent to which they experienced certain mood states on a five-point scale (1 = "very slightly or not at all," and 5 = "extremely"). Ratings of "enthusiastic" and "afraid" were of particular relevance to the present study, since these were the emotional expressions shown to participants. Moreover, ratings of "interested" and "attentive" ratings were also analyzed to estimate the participant's motivation level in the experiment. We excluded one participant from the HA group and two participants from the LA group, because they gave low ratings (1 = "not at all") of the "attentive" and "interested" items, and their inattention to the task may have negatively influenced the results.

A previous study found that RFRs in response to others' expressions were positively related to empathy (SonnbyBorgstrom 2009). Thus, we administered the Interpersonal Reactivity Index (IRI, Davis 1983), a self-report questionnaire frequently used to measure empathy, to our participants. The IRI consists of 28 items divided into four subscales measuring different dimensions of empathy: fantasy, empathic concern, perspective taking, and personal distress.

Visual stimuli

Participants were tested individually. They were seated in front of a 19-inch screen that was used to present the stimuli. All stimuli were displayed on a black background and resized to a visual angle of 8.23° high and 9.83° wide at a viewing distance of 50 cm. The black-and-white stimuli depicted 15 objects, which were used as catch trials, and 30 static pictures of facial expressions taken from the pictures of facial affect (PFA) database (P. Ekman and W.V. Friesen, Consulting Psychologists Press, Palo Alto, CA, 1976). The PFA stimuli were selected based on the previous studies, to facilitate the comparison between our results and those of the prior studies that used the same stimuli (e.g., Dimberg et al. 2000; Dimberg and Petterson 2000; McIntosh et al. 2006). The stimuli showed ten different actors (five male and five female), each demonstrating three facial expressions: fearful, happy, and neutral. E-Prime software was used to present the stimuli and to flag event onsets in the electromyography (EMG) recordings.

EMG recording

Facial EMG activity was recorded from the *corrugator supercilii* and *zygomaticus major* muscles using 6-mm diameter surface Ag/AgCl electrodes in a bipolar montage (see Cattaneo and Pavesi 2014 for an overview of the anatomy of facial muscles, and see Fridlund and Cacioppo 1986; Larsen et al. 2003 for surface EMG recordings of facial muscles). Ground electrodes were placed on the mastoids. We recorded EMG from the left side of the face, in accordance with studies reporting more left-sided facial movement in emotional expressions (Rinn 1984; Dimberg and Petterson 2000). Muscle activity was amplified 1000× with the Biopac MP150 System and sampled at 1000 Hz. A 50-Hz notch filter was applied to remove line noise. To hide the fact that facial muscle activity was the variable of interest, participants were told that activity from several muscles throughout the body would be measured. Fake electrodes were placed on the left leg, arm, and shoulder. When debriefed after the experiment, none of the participants reported that they were aware of the deception. Continuous EMG recordings were collected for two blocks of trials in each participant. Each block contained 45 trials (10 faces × 3 emotions—happy, fearful, and neutral—and 15 objects).

Trial structure and task

At the beginning of each trial, a white fixation cross was presented in the center of the screen. After 5 s, a randomly selected stimulus (i.e., a face or an object) replaced the fixation cross and remained on the screen for 2 s, followed by a 20-s inter-trial interval (Dimberg and Thunberg 1998; Dimberg et al. 2000, 2002). Participants were not aware that the purpose of the experiment was to assess emotional processing; they were asked to perform a task irrelevant to emotion in which they categorized the gender of the face or object as male or female (please note that the Italian language does not have a neutral form. Therefore, every object is either masculine or feminine). Participants pressed a key to respond. All 45 stimuli were presented in each block in a randomized order. Therefore, each stimulus was presented twice in the course of the entire experiment.

EMG data processing

Two participants in the LA group and one in the HA group were excluded from data processing and analysis because of massive movement artifacts in their EMG recordings. Thus, the data of 10 LA and 10 HA participants were processed and analyzed. We identified a time window of interest from − 500 to + 1250 ms relative to the onset of each visual stimulus. Our pre-processing pipeline consisted of the following five steps: (1) the digitized EMG signals were filtered offline with a 30-Hz high-pass filter; (2) all recordings were rectified; (3) trials with baseline (pre-stimulus) EMG activity more than 2 standard deviations from the mean baseline EMG amplitude across all 90 trials were excluded from further analyses (fewer than 5% of trials overall); (4) baseline correction was performed trial-by-trial by subtracting the mean pre-stimulus activity (− 500 to 0 ms) from each data point post-stimulus onset; and (5) the rectified EMG traces were simplified by averaging data into bins of 250 ms. Using 250-ms bins corresponds to a sampling frequency of 4 Hz. According to the Nyquist–Shannon sampling theorem, the sampling frequency has to be at least twice of the maximal frequency of interest to be sampled. Raw EMG recordings contain fast frequencies that require high sampling rates (for example, we used a sampling rate of 1000 Hz to digitize the raw signal). However, once the EMG recording is rectified, the frequency of the signal becomes much slower. In the case of RFRs, the fluctuation of the rectified EMG has not been quantified in the literature, but it can be qualitatively determined by observing the time courses of RFRs in the previous studies. Responses from the *corrugator supercilii* muscle seem to evolve in time at frequencies of 1.5 Hz or less, while responses in the *zygomatici* muscles vary at even slower frequencies (e.g., Dimberg and Thunberg 1998; Dimberg and Petterson 2000). As a consequence, sampling frequencies of 3 Hz or higher are required to describe the time course of RFRs; hence, we chose to use 250-ms bins. EMG recordings from each trial were reduced to six timepoints corresponding to the 1–250-, 251–500-, 501–750-, 751–1000-, and 1001–1250-ms bins. EMG data associated with viewing the objects were not analyzed, since the objects were used as catch trials.

Explicit ratings

After the facial EMG experiment, participants were asked to rate the arousal and valence of each emotional facial expression and object used in the main experiment. Participants gave arousal and valence ratings on a nine-point Likert scale, with 1 meaning “not very arousing” or “very negative emotion” and 9 meaning “highly arousing” or “very positive emotion.”

Statistical analysis

Between-group differences in scores on the self-report questionnaires (PANAS and IRI) were investigated using two independent samples *t* tests. We used the Bonferroni method to correct for multiple comparisons.

To analyze the behavioral data, a mixed factor analysis of variance (ANOVA) was conducted on reaction times (RT) with group (two levels: LA and HA) as a betweensubject variable and stimulus (four levels: fearful, happy, neutral, and object) as a within-subject variable.

To analyze EMG activity, separate mixed factor ANOVAs were conducted for each muscle (i.e., *corrugator* and *zygomaticus*) using group (two levels: LA and HA) as a between-subject variable and stimulus (three levels: fearful, happy, and neutral) and time (five levels: 0–250, 250–500, 500–750, 750–1000, and 1000–1250 ms) as within-subject variables. This approach is in accordance with the previous literature (e.g., McIntosh 2006; Sonnby-Borgstrom 2009) and is justified by the fact that *Corrugator* and *Zygomaticus* are separate within-subject variables. As a confirmatory analysis of the validity of such approach, analyses were also repeated including muscle (two levels) as an additional within-subject variable (omnibus ANOVA).

Mean arousal and valence ratings from the LA group and the HA group were calculated separately for each of the four stimulus conditions (fear, happy, neutral, and objects) and submitted to mixed factor ANOVAs with group (two levels: LA and HA) as a between-subject variable and stimulus (four levels: fearful, happy, neutral, and objects) as a withinsubject variable.

Newman–Keuls test was used for post-hoc comparisons. Partial eta squared (η^2_{p}) is reported as an estimate of effect size. Note that 0.2 is considered a small effect, 0.5 a medium effect, and 0.8 a large effect (Cohen 1969). No outliers were identified in any of the analyses.

Finally, correlations were tested between EMG activity and explicit ratings of valence and arousal, and between EMG activity and IRI result in the LA and HA groups, separately.

Results

Table 1 gives demographic information, alexithymia scores as measured by the TAS-20 and the DCPR, and IRI scores fo LA ($n = 10$) and HA ($n = 10$) groups. A medium effect size ($\eta_p^2 = 0.54$) was expected based on a previous study (McIntos 2006). Based on our sample size and the effect size, the achieved power ($1 - \beta$) was approximately 0.90, as calculated G*Power 3 (Faul et al. 2007).

Self-report questionnaires

LA and HA participants did not differ in PANAS item ratings (please see Table S1 in the supplementary material). Importantly, the two groups also did not differ in their ratings of "afraid" (independent samples t test: $t = 0.709$, $df = 18$, $p = 0.48$), "enthusiastic" ($t = 0.871$, $df = 18$, $p = 0.39$), "attentive" ($t = 0.709$, $df = 18$, $p = 0.47$), and "interested" ($t = -0.87$, $df = 18$, $p = 0.39$) items.

Results of the IRI are reported in Table 1. LA and HA participants did not differ in the total IRI score ($t = 2.03$, $df = 18$, $p = 0.057$), in the empathic concern subscale score ($t = 1.46$, $df = 18$, $p = 0.16$) or in the personal distress subscale score ($t = -1.22$, $df = 18$, $p = 0.236$). However, the two groups differed in their scores on the fantasy subscale ($t = 2.33$, $df = 18$, $p = 0.032$) and the perspective taking subscale ($t = 4.65$, $df = 18$, $p < 0.001$). The between-group difference in perspective taking remained significant after applying a Bonferroni correction for multiple comparisons.

Reaction times

The ANOVA revealed main effects of group ($F[1,18] = 4.8$; $p = 0.04$; $\eta_p^2 = 0.21$) and stimulus ($F[3,54] = 7.6$; $p = 0.002$; $\eta_p^2 = 0.29$). The Group x Stimulus interaction was also significant ($F[3,54] = 3.34$; $p = 0.02$; $\eta_p^2 = 0.15$). Because of the the significant interaction, we analyzed LA and HA groups, separately. In the LA group, there was a significant main effect of stimulus ($F[3,27] = 6.74$; $p = 0.001$; $\eta_p^2 = 0.42$). Although participants were only required to respond to the gender of the face, post-hoc tests showed that they responded more quickly to fearful faces (704.2 ± 89.4) than to happy faces (729.2 ± 95.6 ms; $p = 0.04$) and neutral faces (trend toward significance: 732.3 ± 93.9 ms; $p = 0.06$). Moreover, they responded more quickly to objects (685.8 ± 102.4 ms) compared to happy faces (729.2 ± 95.6 ms; $p = 0.003$) and neutral faces (732.3 ± 93.9 ms; $p = 0.003$), but not compared to fearful faces (704.2 ± 89.4, $p = 0.13$). In the HA group, there was also a significant main effect of stimulus (F[3,27] = 5.37; $p = 0.004$; $\eta_p^2 = 0.37$). Post-hoc tests showed that, in contrast to LA participants, the RTs of HA participants were not modulated by emotional expressions. RTs to fearful faces (839.4 ± 107.8) did not differ from RTs to happy faces (822.9 ± 116.1 ms; $p = 0.65$) or to neutral faces (788.9 ± 40.1 ms; $p = 0.35$). Moreover, participants responded more quickly to objects (706.7 ± 84.8 ms) than to any of the facial expressions (all comparisons: $p < 0.03$).

Facial EMG

In the *corrugator supercilii*, the three-way Group × Stimulus × Time interaction was significant (F[8,144] = 2.66, $p = 0.009$; $\eta_p^2 = 0.22$). Post-hoc tests revealed that, in LA participants, the peak of activation at 625 ms in the *corrugator supercilii* was significantly higher when viewing a fearful face than when viewing a happy face ($p < 0.001$) or a neutral face ($p < 0.001$). In addition, in the fear condition, activation at 625 ms was significantly different from activation in all other time intervals (all comparisons: $p < 0.001$). On the contrary, no *corrugator supercilii* activity was detected in the HA group during observation of emotional faces. The graph showing each participant's *corrugator supercilii* activation in response to fearful faces is shown in the supplementary information, Figure S1.

In the *zygomaticus major*, the three-way Group × Stimulus × Time interaction was also significant ($F[8,144] = 5.92$, $p < 0.001$; $\eta_p^2 = 0.25$). Post-hoc tests revealed that, in LA participants, the peak of activation at 625 ms in the *zygomaticus major* was significantly higher when viewing a happy face than when viewing a fearful face ($p < 0.001$) or a neutral face ($p < 0.001$). In addition, in the happy condition, activation at 625 ms was significantly different from activation at all other time intervals (all comparisons: $p < 0.001$). In HA participants, activation in the *zygomaticus major* peaked at 825 ms, and was significantly higher when viewing a happy face than when viewing a fearful face ($p < 0.001$) or a neutral face ($p < 0.001$). In addition, in the happy condition, activation at 825 ms was significantly different from activation at all other time intervals (all comparisons: $p < 0.001$). The graph showing each participant's *zygomaticus major* activation in response to happy faces is shown in the supplementary information, Figure S2.

Results of group analyses are shown in Fig. 1.

The omnibus ANOVA revealed a significant Group × Muscle × Stimulus × Time interaction ($F[8,144] = 4.81$, $p < 0.001$; $\eta_p^2 = 0.26$), thus justifying the approach adopted.

In addition, we tested the correlation between the amplitude of the *corrugator supercilii* activation at 625 ms in response to fearful faces and IRI perspective taking scores in the LA and HA groups, separately. In the LA group, there was a strong correlation between the two measures ($r = 0.72$, $p = 0.004$), while no correlation emerged in the HA group ($r = -0.21$, $p = 0.54$). This indicates that, in LA participants only, the higher the perspective taking score, the bigger the *corrugator supercilii* activation in response to fearful faces. We also tested the correlation between IRI perspective taking scores and the amplitude of the *zygomaticus major* activation at 625 ms in LA participants and at 875 ms in HA participants. This correlation was not significant in either LA participants ($r = 0.24$, $p = 0.49$) or HA participants ($r = 0.32$, $p = 0.35$).

Explicit ratings

A significant main effect of stimulus ($F[3,54] = 135.2$; $p < 0.001$; $\eta_p^2 = 0.88$) was found on arousal ratings. Positive and negative faces were rated as more arousing than neutral faces and objects ($p < 0.001$ at post-hoc test). No differences between groups emerged. The explicit ratings of arousal strongly correlated with *corrugator supercilii* RFRs to fearful faces in LA participants (at 625 ms $r = 0.80$, $p = 0.004$) but not in HA participants (at 625 ms $r = -0.18$, $p = 0.60$; at 875 ms $r = 0.22$, $p = 0.27$). No correlation between arousal ratings and *zygomaticus major* RFRs to happy faces emerged (LA at 625 ms $r = -0.04$, $p = 0.89$; HA at 875 ms $r = 0.25$, $p = 0.47$).

There was also a significant effect of stimulus on valence ratings ($F[3,54] = 163.6$; $p < 0.001$; $\eta_p^2 = 0.90$). Post-hoc tests revealed that valence ratings of happy faces (mean: 7.23) were significantly more positive than valence ratings of fearful faces (mean 2.6, $p < 0.001$), neutral faces (mean 4.3 $p < 0.001$), and objects (mean 4.9 $p < 0.001$). Conversely, valence ratings of fearful faces were more negative than valence ratings of neutral faces and objects (all comparisons $p < 0.001$). Again, no differences between groups emerged. The explicit ratings of valence correlated with *corrugator supercilii* RFRs to fearful faces in LA participants (at 625 ms $r = -0.72$, $p = 0.02$) but not in HA participants (at 625 ms $r = 0.22$, $p = 0.53$; at 875 ms $r = 0.15$, $p = 0.37$). No correlation between valence ratings and *zygomaticus major* RFRs to happy faces emerged (LA at 625 ms $r = -0.15$, $p = 0.69$; HA at 875 ms $r = -0.23$, $p = 0.51$).

Discussion

The aim of this study was to investigate the relation between alexithymia and somato-motor responses to affective stimuli. The results showed distinct patterns of results in the reactions times and RFRs of LA and HA participants. Reaction times recorded during the EMG experiment showed that LA participants responded more quickly to fearful faces than to neutral or happy faces, even though we used an implicit emotion task—i.e., participants responded to the gender of the faces. In addition, the LA group showed RFRs to fearful and happy faces in congruent muscles at about 625 ms after stimulus presentation; the peak of activation at 625 ms in the *corrugator supercilii* was significantly higher when viewing a fearful face than when viewing a happy or a neutral face, whereas the peak of activation at 625 ms in the *zygomaticus major* was significantly higher when viewing a happy face than when viewing a fearful or a neutral face. These findings are in line with the previous results from the general population, thus supporting our use of the LA group to represent the general population (Moody et al. 2007; Niedenthal et al. 2001; Hatfield et al. 1992; Lundquist and Dimberg 1995; Vaughan and Lanzetta 1980).

In contrast, there was no fear facilitation effect in the gender categorization responses of HA participants. Furthermore, the somato-motor reactions of the HA group to affective facial expressions revealed a difficulty in processing emotions, especially fear. HA participants did not show congruent RFRs to fearful stimuli. They did show congruent RFRs to happy faces in the *zygomatici* muscles, but the RFRs were delayed (875-ms post-stimulus onset) relative to those of the LA participants (625-ms post-stimulus onset). The absence of RFRs to fear in the HA group suggests that those individuals do not embody the motor aspect of fear, corroborating the previous results (Scarpazza et al. 2014, 2015). The presence of congruent but delayed RFRs to happy faces likely indicates that the embodied communication system for positive affective states is dysfunctional in HA, but still present. Further research is needed to reveal the nature of this dysfunction, which could be arise from several processing differences, including different thresholds for emotional stimuli, longer processing times, or abnormally rapid habituation to affective expressions.

The dissociation between embodiment of fearful and happy facial expressions in HA is in accordance with the previous research suggesting that HA participants mainly experience a difficulty in processing negative emotions. Individuals with high alexithymia show altered responses to many types of negative stimuli, such as early auditoryrelated potentials in response to potentially dangerous acoustic stimuli (Schäfer et al. 2007), reduced electrodermal responses to negative pictures (Pollatos et al. 2008), impaired internal somatic simulation of fearful faces (Scarpazza et al. 2014), and decreased anticipation of the occurrence of a negative emotional event (Starita et al. 2016). On the other hand, an important body of the literature suggested that processing of positive emotions is spared in HA (see for instance: Borhani et al. 2016; Maier et al. 2016; SonnbyBorgstrom 2009; Pollatos et al. 2008).

The findings that HA participants do not automatically generate RFRs to fearful facial expressions or show fearrelated facilitation of RTs could be explained by hypo-functioning of the amygdala in alexithymia. The amygdala is an important brain region for emotional processing (LeDoux 2014;

Adolphs 2013), especially for fear (Vytal and Hamann 2010). Moreover, the amygdala is crucial to early processing stages of facial expressions (Liddell et al. 2005; LeDoux 2012). The central nucleus of the amygdala sends signals via both direct and indirect connections to numerous anatomical areas involved in producing somatic signs of fear (Davis and Whalen 2001; LeDoux 2012). For example, the central nucleus is indirectly connected to nuclei in the brainstem that mediate the production of emotional facial expressions (see Cattaneo and Pavesi 2014). Moreover, electrically stimulating the amygdala evokes movements of the facial muscles that resemble facial expressions of fear (Davis and Whalen 2001; Gloor et al. 1981; Chapman et al. 1954). A recent study also suggested that the amygdala is involved in RFRs and embodiment of fearful facial expressions (Harrison et al. 2010). Neuroimaging studies on alexithymia have consistently demonstrated lower amygdala reactivity to negative emotional stimuli in HA participants (van der Velde et al. 2013); thus, it is not surprising to find that alexithymia is associated with a deficit in embodiment of negative emotions. Furthermore, our HA participants exhibited a deficit in somato-motor embodiment of happy expressions (i.e., delayed RFRs to happy faces). This is not surprising, since the amygdala is also involved, to a lesser extent (Vytal and Hamann 2010), in processing positive emotions through direct projections to the nucleus accumbens in the ventral striatum (McDonald 1991; Pohl et al. 2013).

Embodied simulation theories of emotion suggest that observing a facial expression elicits stereotyped facial movements specific to that expression, and these automatic reactive expressions entrain a feedback process that produces the corresponding emotional state in the observer (Gallese 2007; Goldman and Sripada 2005; Hatfield et al. 1992). This emotion “embodiment” (Niedenthal et al. 2001; Niedenthal 2007) then facilitates recognition of the emotion expressed by the other person. Importantly, these theories predict that emotion recognition will be impaired when somato-motor responses to emotions are blocked (Niedenthal et al. 2001). The findings of the present study provide evidence for somato-motor emotion embodiment in LA participants, but also show that these embodiment mechanisms are altered in HA participants (Scarpazza et al. 2014). According to the embodied simulation theories, the altered embodiment of emotion in HA participants should prevent them from normally recognizing and sharing the emotions of others. Although this hypothesis seems to be supported by the fact that HA individuals have less emphatic abilities than LA individuals (revealed by the IRI results and correlation between IRI scores and RFRs; please see discussion below), it is *prima facie* in contrast with the explicit emotion rating results. Notably, alexithymia level influenced somato-motor reactions to affective facial expressions without affecting explicit recognition of emotional faces, as measured by arousal and valence ratings.

The data on explicit emotion recognition are in line with those of the previous studies on alexithymia and recognition of emotional faces or scenes (Kano et al. 2003; Meriau et al. 2006; Pollatos et al. 2008, Heinzel et al. 2010; Lee et al. 2011; Pollatos and Grahaman 2011; Scarpazza et al. 2014, 2015; Martinez-Velazques et al. 2017; see; Grynberg et al. 2012 for a review), where HA participants were consistently found to have normal explicit emotion recognition capabilities. Alexithymia is associated with poor explicit emotion recognition only when stimuli are presented under temporal constraints (Ihme et al. 2014; Parker et al. 2005) or when the emotion is expressed at a low intensity (Starita et al. in revision; Swart et al. 2009). In the present study, we used prototypical facial expressions that were presented for a long period of time. Thus, an impairment in explicit recognition in HA participants was not expected.

Furthermore, in agreement with the previous literature (Eastabrook et al. 2013), our data suggest that the processes supporting explicit emotion recognition are partly dissociated from those producing somato-motor and physiological responses to emotional stimuli. Such a dissociation has also been found in the previous work. For instance, patients with amygdala lesions showed reduced (LaBar et al. 1995) or absent (Bechara et al. 1995) anticipation of a negative emotional event, even though they were aware of the associations between conditioned and unconditioned stimuli. On the contrary, patients with split brain syndrome (Ladavas et al. 1993), hemispatial neglect (Tamietto et al. 2015), and affective blindsight (Bertini et al. 2013) show intact physiological responses to emotional stimuli without being aware of them. Together, these studies suggest that physiological responses to and awareness of emotional expressions can be separated. However, somatic and physiological information from one's own body is generally incorporated with semantic and contextual knowledge to generate an integrated representation of an affective state (Barrett et al. 2007; Critchley et al. 2004). In the case of HA, a lack of integration of these different sources of information might contribute to difficulties in emotional tasks.

Another interesting finding of the present study is that HA individuals show differences in empathy relative to LA participants, as revealed by IRI scores. In particular, HA participants showed diminished perspective taking abilities, a result which is nicely in accordance with the RFR findings. A previous study suggested that a person's empathic ability predicts the degree to which that person produces RFRs in response to others' emotional expressions (Hussey and Safford 2009). Both our group (Scarpazza et al. 2014) and other groups (for instance: Moriguchi et al. 2007; Martinez-Velazques et al. 2017; Sonnby-Borgstrom 2009) have previously demonstrated reduced empathic abilities in HA participants relative to LA participants using the IRI. The new aspect of the present study is the correlation between somato-motor embodiment of emotions (measured by RFR magnitude) and empathic ability (measured by the IRI perspective taking score). This correlation was present in LA participants, but not in HA participants. This further corroborates the previous evidence suggesting that highly empathic individuals show more automatic reactions to others' facial expressions than less empathic people do (Chartrand and Bargh 1999; Dimberg and Thunberg 2012). It also highlights the importance of embodiment mechanisms for normal sharing of others' emotions. Finally, this finding suggests that a deficit in emotional embodiment might account for the reduction in empathy in people with HA.

Following this theoretical and empirical framework, our data seem to indicate that participants with HA are less efficient than LA participants at automatically embodying others' emotions. Our results are in accordance with SonnbyBorgstrom's report (2009) that HA participants showed decreased RFRs in response to angry faces. However, they seem to be *prima facie* inconsistent with another study that found no modulation of RFRs according to alexithymia level (Peasley-Miklus et al. 2016). However, methodological differences between that study and our study might easily explain the difference in results. Among these methodological differences, the most important one regards the task used. Peasley-Miklus et al. (2016) used an emotional imagery task that, although well validated, measures one of the most troublesome aspects of alexithymia: the ability to fantasize. The previous research found that the ability to fantasize is poorly associated with the other features of alexithymia, so items measuring fantasizing were removed from the TAS (Bagby et al. 1994). Thus, it is not surprising that muscle activity was not modulated during an emotional imagery paradigm, and did not correlate with the TAS-20. Our results on RFRs and RTs to fearful expressions provide convergent evidence supporting diminished responses to emotional stimuli in

HA individuals compared to LA individuals. In addition, our results extend Sonnby-Borgstrom's (2009) findings in many ways. First, Sonnby-Borgstrom did not investigate RFRs in response to expressions of fear. Thus, our results expand upon the previous findings by showing a deficit in the somato-motor embodiment of fearful faces, in addition to angry faces. Second, our findings provide convergent evidence (i.e., RTs and RFRs) supporting the idea that alexithymia is associated with a difficulty in processing fear. Third, we showed that RFRs to fearful faces in the *corrugator supercilii* correlated with the IRI perspective taking score in LA participants, but not in HA participants. Together, these findings support the hypothesis that HA participants are deficient in the embodiment of fear (Scarpazza et al. 2014, 2015). They further reveal that a deficit in implicit fear processing is present alexithymia even if it is not reflected in the explicit recognition of emotional faces.

The main weakness of the present study is that the sample size was small. We screened a large number of potential participants and used a highly selective procedure to enroll HA participants, which ensured a homogenous sample. Nevertheless, it is worth noting that single-subject reactions to affective facial expressions, reported in the supplementary material, reveal a highly consistent pattern of EMG activation in LA participants, but an inconsistent pattern in HA participants, supporting the reliability of these data. A second drawback is that our study only included individuals with a high cognitive dimension of alexithymia (measured by the TAS-20). We did not consider possible differences in emotional embodiment in individuals with high cognitive vs. high affective alexithymia dimensions (Vorst and Bermond 2001). We chose not to consider the affective alexithymia dimension, because there is no strong evidence that alexithymia can be reliably decomposed into two dimensions. Instead, the idea of alexithymia as a multi-faceted construct still prevails (Bagby et al. 2009). The findings of the present study cannot be considered conclusive, due to the limitations described above. They nevertheless have strong merit, because they shed light on a neglected topic, i.e., somato-motor embodiment of emotions in alexithymia. Future research on this topic should attempt to answer the following important questions: Will these results be corroborated when using stimuli with higher social relevance than Ekman faces? Since the amygdala is more active when processing dynamic faces than static faces (Trautmann et al. 2009), will these results be affected by using moving faces (i.e., video) instead of static pictures? Are HA individuals impaired in the embodiment of more complex affective states (such as embarrassment, pain, shame, etc.)? Is the deficit in emotional embodiment similarly present in individuals with high cognitive and high affective alexithymia dimensions?

To summarize, our findings provide convergent results supporting a difficulty in processing fear in people with HA. HA individuals manifest neither congruent RFRs to fearful expressions, nor the fear RT facilitation effect observed in the LA participants. Interestingly, RFRs to fearful expressions correlate with empathic abilities in LA participants but not in HA participants. Taken together, these results support the hypothesis of a deficit in somatomotor embodiment of fear in people with high levels of alexithymia.

Acknowledgements This study was supported by grants from the University of Bologna (FARB 2014, protocol number: RFBO120993) awarded to Elisabetta Làdavas. We are grateful to Ermelinda Gunnella for helping with data collection and to Dr. Brianna Beck for her help in editing this article. Several results included in this manuscript are also described in CS PhD thesis "Deficit in the emotional embodiment in alexithymia" (2015).

Author contributions Conceived and designed the experiments: CS, EL, and LC. Performed the experiments: CS. Analyzed the data: CS and LC. Wrote the paper: CS, EL, and LC.
Conflict of interest None of the authors have potential conflicts of interest to be disclosed.

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Table 1 Demographic, alexithymia, and empathy profiles of the low and high alexithymia groups

	Low alexithymia	High alexithymia		
n (male/female)	10 (2/8)	10 (2/8)		
Age in years, mean (SD)	24.9 (2.28)	24.7 (2.35)		
TAS-20	Mean (SD), range		*t*	*p*
Total score	33.1 (4.86), 26–39	62.9 (1.66), 61–65	− 18.3	< 0.001*
DIF	10.7 (2.79), 6–15	25 (3.05), 21–31	− 9.8	< 0.001*
DDF	8.6 (2.17), 5–12	19.1 (2.55), 15–23	− 10.9	< 0.001*
EOT	13.8 (2.39), 10–17	18.8 (3.73), 13–23	− 3.5	0.002*
DPCR	1.3 (0.67), 0–2	3.2 (0.42), 3–4	− 7.5	< 0.001*
IRI	Mean (SD), range		*t*	*p*
Total score	78.1 (12.2), 64–100	67.5 (11.5), 51–82	2.03	0.057
Fantasy	21.2 (3.9), 16–28	16.7 (4.6), 9–24	2.33	0.032
Empathic concern	20.8 (3.6), 15–26	18.2 (4.2), 13–27	1.46	0.16
Perspective taking	21.6 (2.6), 18–26	15.0 (3.5), 11–19	4.65*	< 0.001*
Personal distress	14.5 (6.2), 8–28	17.5 (4.5), 10–27	− 1.22	0.23

Low alexithymia (*n* = 10) and high alexithymia (*n* = 10) groups were obtained by excluding volunteers with discrepancies between their TAS-20 and DPCR scores (cf. Methods)

The reported values for DPCR refer to the mean number of positive DCPR criteria for alexithymia

TAS-20 20-item Toronto Alexithymia Scale; *DIF* difficulty in identifying feelings; *DDF* difficulty in describing feelings; *EOT* externally oriented thinking; *SD* standard deviation; *DPCR* Alexithymia Module of Diagnostic Criteria for Psychosomatic Research; *IRI* Interpersonal Reactivity

Index; *t* independent samples *t* test statistic; *p, p* value

*Significance after a Bonferroni correction for multiple comparisons

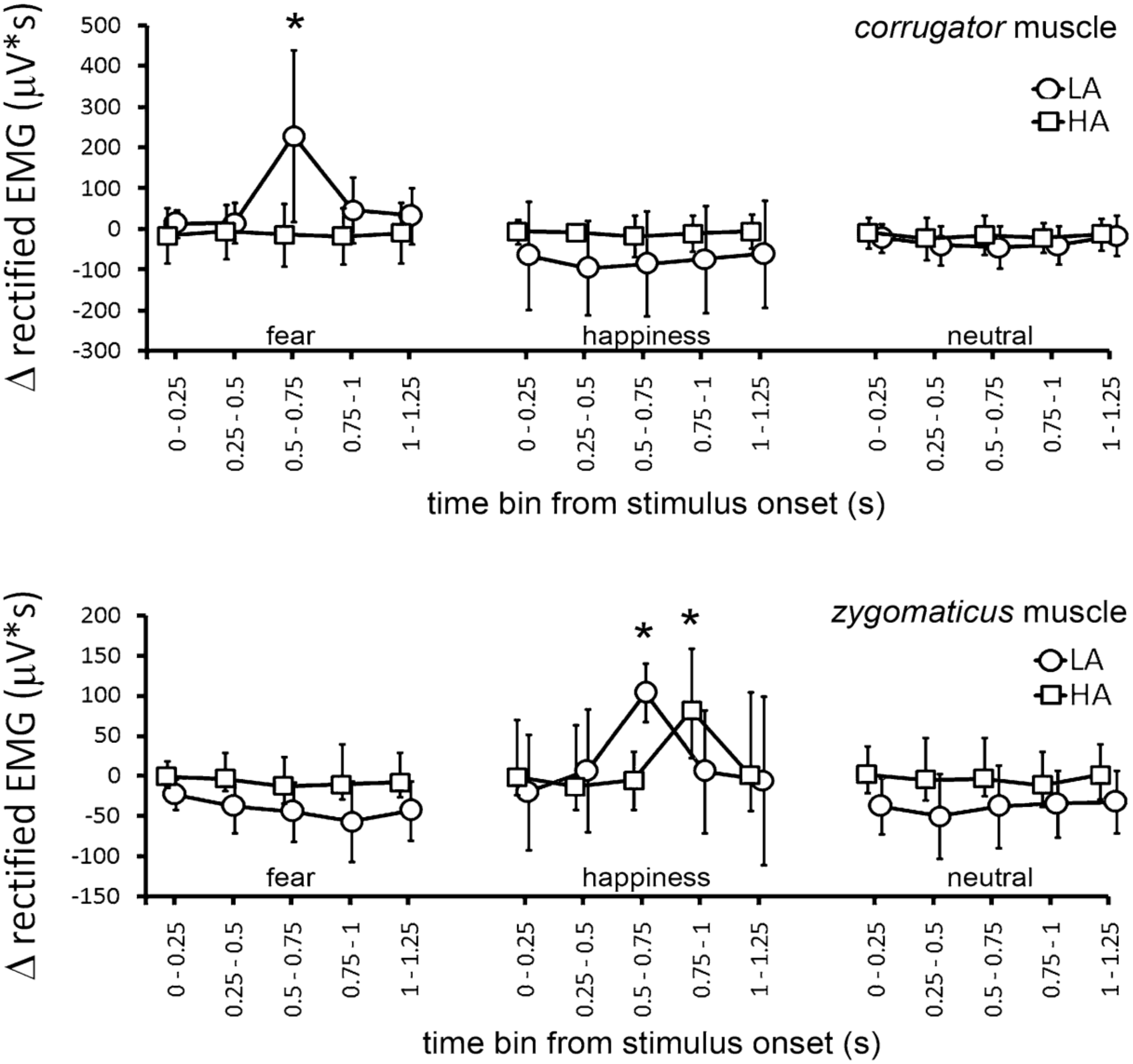

Fig. 1 *LA* Low alexithymia group; *HA* High alexithymia group. The chart shows the difference in EMG activity (Δ) between the post-stimulus signal and the pre-stimulus (baseline) signal. Positive values indicate increased activity compared to baseline and negative values indicate decreased activity compared to baseline. Error bars denote SEM (standard error of the mean)