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The enfacement illusion boosts facial mimicry.

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ABSTRACT

Facial mimicry, the automatic imitation of another person's emotion, is a mechanism underlying emotion recognition and emotional contagion, a phylogenetically conserved form of empathy that precedes later developing empathic skills. We tested the possibility to increase facial mimicry by blurring self-other distinction via the enfacement illusion. To do so we delivered synchronous, versus asynchronous, visuo-tactile interpersonal multisensory stimulation on the observer and expresser's faces and then recorded surface facial EMG while participants observed videos of happy and sad facial expressions displayed by the expresser. Our results show that synchronous visuo-tactile stimulation can indeed enhance facial mimicry and that this depends on participants' baseline tendency to mimic. Our findings could set the basis for developing novel interventions for conditions characterized by reduced empathic and emotion recognition skills, including autism and schizophrenia.

KEYWORDS

Enfacement illusion, emotional contagion, empathy, facial mimicry, multisensory stimulation

ABBREVIATIONS

EMG: electromyography

FACS: Facial Action Coding System

LMM: linear mixed models

PCA: principal component analysis

SD: standard deviation

SE: standard error

SME: standard mean error

VT-IMS: visuo-tactile interpersonal multisensory stimulation

1. Introduction

Humans and other highly social animals, seemingly effortlessly, read from their conspecific's body a multitude of crucial information, ranging from their basic emotions, to their attentional focus and intentionality. Such bodily-conveyed information, accessed via simulation mechanisms, is used to understand others and engage in successful social interactions (Era, Aglioti, Mancusi, & Candidi, 2018; Panasiti, Porciello, & Aglioti, 2017). Among all body parts, the face is a major source of social inputs and outputs. Soon after birth, humans and other non-human primates, attend and mimic the facial expressions of others (Ferrari et al., 2006; Meltzoff et al., 2019; Myowa-yamakoshi, Tomonaga, Tanaka, & Matsuzawa, 2004). This rapid and hard to voluntarily suppress (Dimberg, Thunberg, & Grunedal, 2002; Korb, Grandjean, & Scherer, 2010) imitation of another person's facial expression, is referred to as facial mimicry. It involves overt (Sato & Yoshikawa, 2007) or just covert (Dimberg & Petterson, 2000) activation of similar muscles in the expresser and in the observer, and can occur also when the expresser's emotion is not perceived consciously by the observer (Dimberg, Thunberg, & Elmehed, 2000; Tamietto et al., 2009). Although automatic, facial mimicry can be modulated by higher order social factors including group membership, familiarity, fairness, cooperation and competition (Seibt, Mhlberger, Likowski, & Weyers, 2015) as well as by the expresser's use of ostensive social gaze (de Klerk, Hamilton, & Southgate, 2018; Soussignan et al., 2018).

In keeping with simulationist accounts, diminished or altered facial feedback (via real or Transcranial Magnetic Stimulation-induced virtual lesions to the sensorimotor cortex, botulinum toxin or muscle restrain) during imitation or observation of facial expressions, results in reduced activation of brain areas related to emotional experience (Hennenlotter et al., 2009), impaired emotion recognition (Wood, Rychlowska, Korb, & Niedenthal, 2016), worsened the discrimination between spontaneous and fake smiles (Rychlowska, Ca~nadas, et al., 2014), and diminished facial mimicry later in development (Niedenthal et al., 2012; Rychlowska, Korb, et al., 2014).

Facial mimicry might therefore be one of the embodied mechanisms linking emotional self-experience to emotion observation in another person, and might serve several, not necessarily mutually exclusive, adaptive purposes, ranging from emotion recognition (Wood et al., 2016) to affiliation (Fischer & Hess, 2017). Here, we focus on facial mimicry as a mechanism underlying emotional contagion (Hess & Blairy, 2001; Prochazkova & Kret, 2017), a phylogenetic and ontogenetic early emerging form of empathy by which individuals experience the emotion they observe in others (De Waal & Preston, 2017; Tousignant, Eugene, & Jackson, 2017). Indeed, facial mimicry is linked to neural and autonomic changes related to the actual emotional experience of the observer (Likowski et al., 2012; Price & Harmon-Jones, 2015) and is modulated by the observer's emotional empathic traits (Dimberg, Andr————————easson, & Thunberg, 2011; Sonnby-Borgstr€om, 2002). Moreover, autistic individuals, known to have difficulties in empathic skills (Greenberg, Warrier, Allison, & Baron cohen, 2018), show reduced and/or delayed facial mimicry (Mathersul, McDonald, & Rushby, 2013; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006; Oberman, Winkielman, & Ramachandran, 2009; Stel, Van Den Heuvel, & Smeets, 2008; Yoshimura, Sato, & Uono, 2015). Similarly, atypical facial mimicry is also found in neurotypical individuals with high number of autistic traits (Hermans, van Wingen, Bos, Putman, & van Honk, 2009; Neufeld, Ioannou, Korb, Schilbach, & Chakrabarti, 2016).

The open question and enthralling translational opportunity we wanted to address in the current study, was to find a way to increase facial mimicry, as a future route to improve emotional contagion and emotion recognition. To serve our purpose, we tried to covertly boost facial mimicry via the 'enfacement illusion' (Paladino, Mazzurega, Pavani, & Schubert, 2010; Sforza, Bufalari, Haggard, & Aglioti, 2010; Tsakiris, 2008), a simple, yet powerful, bodily illusion in which participant's face is touched at the same time and to the same location of another person's face. As an attempt to reconcile the invisible tactile feeling participants perceive on their face, with the visible tactile stimuli they observe delivered to another person's face, self-other boundaries are blurred (Bufalari, Porciello, Sperduti, & Minio-Paluello, 2015; Porciello, Minio-Paluello, & Bufalari, 2016). Previous studies showed that as a result of this synchronous and spatially congruent (versus asynchronous and spatially incongruent) visuo-tactile interpersonal multisensory stimulation (VTIMS), participants merge, at different levels, with the other person, from their facial identity to their sensory experience and behaviour (Porciello, Bufalari, Minio-Paluello, Di Pace, & Aglioti, 2018). Our hypothesis that synchronous VT-IMS might enhance facial mimicry was also supported by evidence that mirror-touch synaesthesia, a condition characterized by lifelong enhanced shared sensorimotor overlap between self and other, is associated to improved emotion recognition (Banissy et al., 2011) and empathic skills (Ward, Schnakenberg, & Banissy, 2018; but see; Baron-

Cohen, Robson, Lai, & Allison, 2016). Lastly, further support to our working hypothesis came from a recent study by Ma and colleagues (Ma, Sellaro, Lippelt, & Hommel, 2016) in which participants reported to be in a mood congruent to the emotion expressed by an avatar that moved his/her head and was touched on his/her face synchronously with them. Overall, in the current study we therefore expected that synchronous VT-IMS would be an effective route to increase facial mimicry and that baseline facial mimicry as well as its enhancement via VT-IMS would be modulated, in opposite directions, by participants' emotional empathic and autistic traits.

2. Materials and Methods

2.1 Participants

We tested 41 neurotypical adult participants (21 females, age 24.7 ± 4.7 years, range: 20e45) with no history of psychiatric or neurologic conditions, no first degree autistic relatives, an autism spectrum quotient (AQ) score below the autism cut off (Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010) and either one or both Interpersonal Reactivity Index (Davis, 1983) perspective taking and empathic concern scores outside the ± 1SD range (Supplementary Material). Participants provided written informed consent approved by IRCCS Santa Lucia Foundation's Institutional Review Board according to the 1964 Declaration of Helsinki and received a small compensation for their time.

2.2 Video stimuli

2.2.1 Illusion videos
In Synchronous/Asynchronous videos, actors' face was touched by a ball attached to a stick, while in Baseline videos, it was not. The experimenter moving the stick with the ball was not visible. Actors had a neutral facial expression and looked at the camera (Supplementary Material).

2.2.2 Emotional videos
To elicit participants' facial mimicry, we used FACS (Facial Action Coding System) and EMG (electromyography) validated videos of happy and sad facial expressions (Fig. 1, Figure S1 and Supplementary Material). Supplementary videos related to this article can be found at https://doi.org/10.1016/j.cortex.2019.10.001.
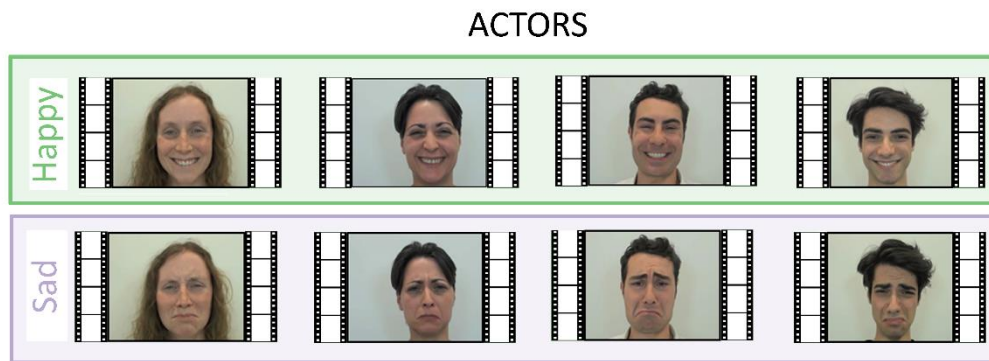
Figure 1. Emotional videos

Frames of FACS and EMG validated emotional videos. Participants saw videos of their same sex actors expressing sad or happy faces (see Supplementary Material for video files). We obtained actors' consent to use their images.

2.3 Experimental Procedure

2.3.1 EMG

We recorded participants' EMG activity from two eye muscles: Corrugator Supercilii (Corrugator) and Orbicularis Oculii (Orbicularis), and two mouth muscles: Zygomaticus Major (Zygomaticus) and Depressor Anguli Oris (Triangularis) involved either in happy (Orbicularis and Zygomaticus) or sad (Corrugator and Triangularis) expressions (see Supplementary Material for EMG acquisition and processing). Notably, each muscle is active more during execution and observation of its congruent emotion (e.g., happiness for Orbicularis and Zygomaticus) compared to its incongruent emotion (e.g., sadness for Orbicularis and Zygomaticus).

2.3.2 Visuo-Tactile Interpersonal Multisensory Stimulation

Participants were touched on their face by a ball attached to a stick manoeuvred by the experimenter. During synchronous VT-IMS, participants were touched on the same spatial location and at the same time with the actor portraited in the illusion videos. Instead, during asynchronous VT-IMS each stroke to the participant's face happened while, in the video clip, the ball was not touching the actor's face. Blinders prevented participants from seeing the ball and the stick approaching and touching their face.

2.3.3 Timeline

The experiment was constituted by 4 blocks: a first Baseline with no tactile stimulation, then a

Synchronous and an Asynchronous block (in counterbalanced order across participants) and last a second Baseline. In each block participants first watched a Baseline/Synchronous/Asynchronous illusion video with actor A/B, then, as their facial EMG was recorded, participants passively watched the emotional videos with the same actor, and lastly rated via a 0e100 visual analogue scale (VAS) what they felt during the illusion video with respect to 3 facets of the enfacement illusion: Agency, to be in control of the observed face, Ownership, to own the observed face and Location, to feel the tactile stimulus originating from the observed face (Fig. 2). Before the end of the experiment, participants rated the emotional videos for their intensity and realism and the actors for their attractiveness. Lastly participants had to imitate the emotional videos while their facial EMG was recorded.
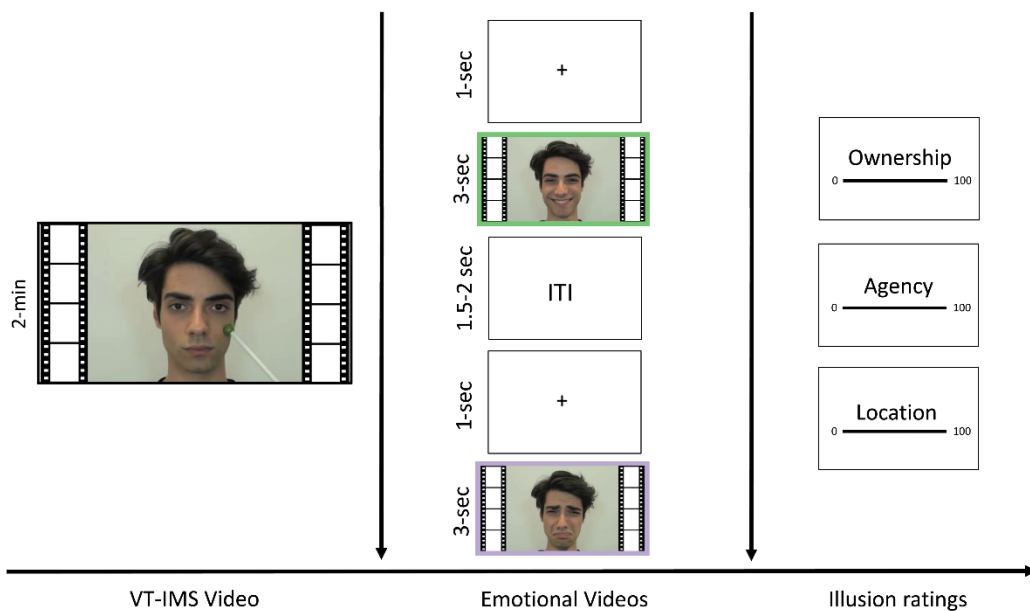

Figure 2. Half-block timeline

Participants' face was stroked for 2 min synchronously (or asynchronously) with actor B portraited in the video (see Supplementary Material for the Illusion videos). Then 10 emotional videos (50% happy, 50% sad) were randomly presented (with a inter-trial interval -ITI- ranging from 1.5 to 2 sec) while participants' facial mimicry response was recorded. Lastly, participants rated, via Visual Analogue Scale (range 0e100), what they felt while their face, together with the actor's face, was stroked. We obtained actor's consent to use his image.

2.4 Data analysis

Multilevel mixed linear regression (LMM) analysis was performed using R (R Development Core Team 2013, package lme4) with fixation-cross-corrected log 10 integral of the rectified EMG activation as our continuous dependent variable. We built the random effects structure of each

statistical model by means of Principle Components Analysis (PCA; R, package RePsychLing, function rePCA), run type III ANOVAs and used Tukey correction for multiple comparisons (Supplementary Material). We used STATISTICA for remaining analysis (StatSoft, Inc. 2007).

   We report, here or in the Supplementary Materials, how we determined our sample size, all data exclusions, all inclusion/exclusion criteria, whether inclusion/exclusion criteria were established prior to data analysis, all manipulations, and all measures collected in the study. Analysis code can be obtained at the following link https://osf.io/tjbqe/ and by agreeing, when code is used, to cite the current work, and to share with the corresponding author any results and interpretations emerging from new analysis run on the current data. No part of study procedures or analyses was pre-registered prior to the research being conducted.

3. Results

Data supporting the reported results can be obtained at the following link https://osf.io/tjbqe/ and by agreeing to share with the corresponding author any results and interpretations emerging from new analysis run on the current data.

3.1 Questionnaires

Descriptive statistics of participants' perspective taking, empathic concern and autism spectrum quotient scores are provided in Table 1.

	N	mean	SD	95% CI	range
Autism spectrum quotient	41	15	5	[14, 16]	4-24
Perspective taking	41	19	6	[18, 21]	9-33
Empathic concern	41	19	5	[17, 20]	9-28

Table 1. Participants' scores at the perspective taking and empathic concern subscales of the Interpersonal Reactivity Index questionnaire and at the Autism spectrum quotient questionnaire.

3.2 Ratings

3.2.1. Participants experienced the enfacement illusion after synchronous VT-IMS

Illusion-related ratings relative to Baseline 1 and Baseline 2 were collapsed after a MANOVA with Agency, Ownership and Location as dependent variables, showed no difference between the two Baselines, Wilks' Λ= .902820, $F(3,38) = 1.36$, $p = .27$, $\eta_p^2 = .10$. A similar MANOVA over collapsed Baselines, Synchronous and Asynchronous blocks found a significant effect of block on Agency, Ownership and Location, $\Lambda = .26$, $F(6,35) = 16.38$, $p = 7.00e^{-09}$, $\eta_p^2 = .74$. Separate

univariate ANOVAs, revealed that Agency, Ownership and Location illusion ratings were higher for Synchronous compared to Asynchronous stimulation (ps < .0005) while, compared to Baseline, Synchronous stimulation was associated with higher Ownership and Location (ps = .0001) but not Agency (p = .06). Asynchronous and Baseline blocks instead did not differ in Agency, Ownership and Location (ps > .05) (Fig. 3 and Supplementary Material).
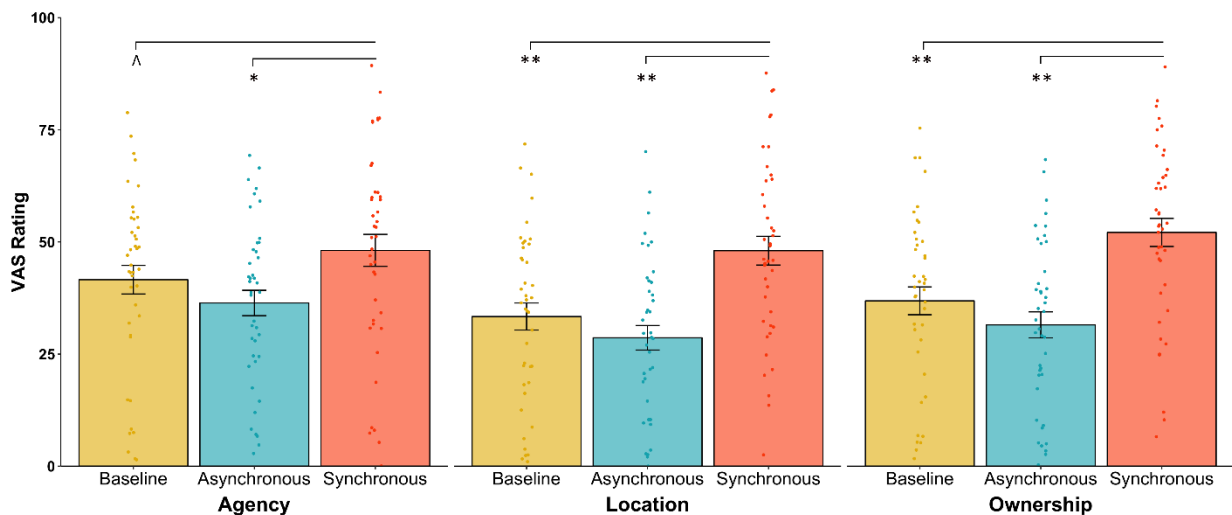

Figure 3. Self-report ratings of the enfacement illusion.

Participants' ratings of the three facets of the enfacement illusion: Agency, Location and Ownership experienced during Baseline (i.e., no visuo-tactile stimulation), Asynchronous and Synchronous visuo-tactile interpersonal stimulation. Λ p = .06, *p < .0005, **p < .0001.

3.2.2 Actors are rated differently by participants.

Paired t-tests showed that female participants gave, across actors, similar intensity and realism ratings to happiness (ps > .23) but different ratings to sadness (ps < .03) videos. Actress' attractiveness was rated similarly (p = .37). Male participants gave, across actors, different intensity and realism ratings to happiness (ps < .05) but not to sadness (ps > .74) videos. Actors' attractiveness was rated differently (p = .001). We controlled for these differences by including participants' subjective ratings as covariates in our models.

3.3 EMG

3.3.1 Recordings of the Triangularis are not reliable.

We removed Triangularis from further analysis because, although FACS coding results assured that all muscles were more active during overt imitation of their congruent, versus incongruent emotion

(ps < .0003), analysis of the Triangularis' EMG signal showed no difference between overt imitation of its congruent (i.e., sadness) and incongruent (i.e., happiness) emotions (p = .81) (Figure S2 and Supplementary Material).

3.3.2 Facial mimicry response does not habituate.

First, we tested whether facial mimicry evoked during Baseline1 differed from that evoked during Baseline2, that is, whether there was any habituation of the facial mimicry response due to repetition of the emotional video stimuli. LMM analysis followed by type III ANOVA confirmed that facial mimicry did not differ between Baseline1 and Baseline2, as the three way emotion x muscle x block interaction was not significant $F(2, 2163.51) = .22$, $p = .80$ (Supplementary Material).

3.3.3 All muscles show facial mimicry at Baseline.

Based on the aforementioned results, we collapsed Baseline1 and Baseline2 and run LMM to investigate Baseline facial mimicry (see Supplementary Material for the model used). Type III ANOVA found significant main effects of muscle $F(2, 56.79) = 6.37$, $p = .003$ and actor's attractiveness $F(1, 177.42) = 6.19$, $p = .01$ and a significant emotion x muscle interaction $F(2, 50.78) = 21.92$, $p < .0001$. No other main effects nor interactions were significant (ps > .12). Post-hoc tests confirmed the presence of facial mimicry for all muscles, that is, all contrasts between congruent and incongruent emotions were statistically significant (ps < .005) (Fig. 4 and Supplementary Material).
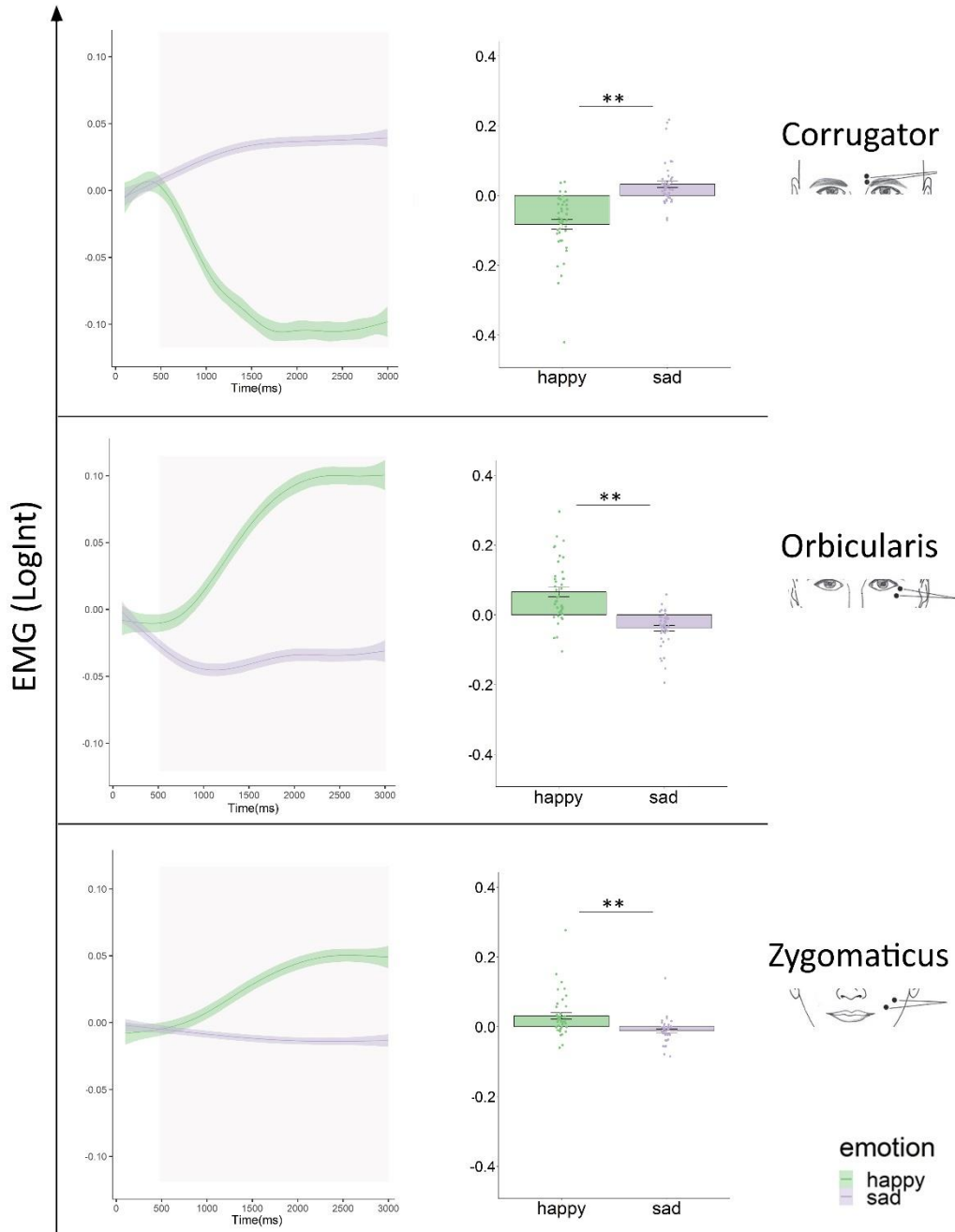
Figure 4. Facial mimicry at baseline

For each muscle and emotion the figure represents the time course of fixation crosssubtracted EMG activation and the mean EMG activation. EMG analysis considered the signal starting from 500 msec post stimulus onset. **p < .005.

3.3.4 Synchronous VT-IMS enhances facial mimicry depending on participants' baseline tendency to mimic.

We ran LMM to investigate whether synchronous stroking, compared to asynchronous stroking, modulates the strength of facial mimicry (see Supplementary Material for the model used). Type III ANOVA showed a significant interaction between participants' facial mimicry (i.e., emotion x muscle), block (i.e., Synchronous versus Asynchronous) and participants' Baseline tendency to show facial mimicry, $F(2, 4528) = 3.63$, $p = .03$. Analysis of the 4-way interaction showed that after synchronous stroking the contrasts between congruent and incongruent emotions were significant for all muscles ($ps < .0015$), while this was not the case after asynchronous stroking (Fig. 5 and Supplementary Material). In particular, the interactions between participants' facial mimicry, block and participants' empathic concern, $F(2, 4527) = 2.68$, $p = .07$ (Figure S3), or autistic traits, $F(2,4528) = .85$, $p = .43$ were not significant. No other 4-way interaction reached significance ($ps > .42$).
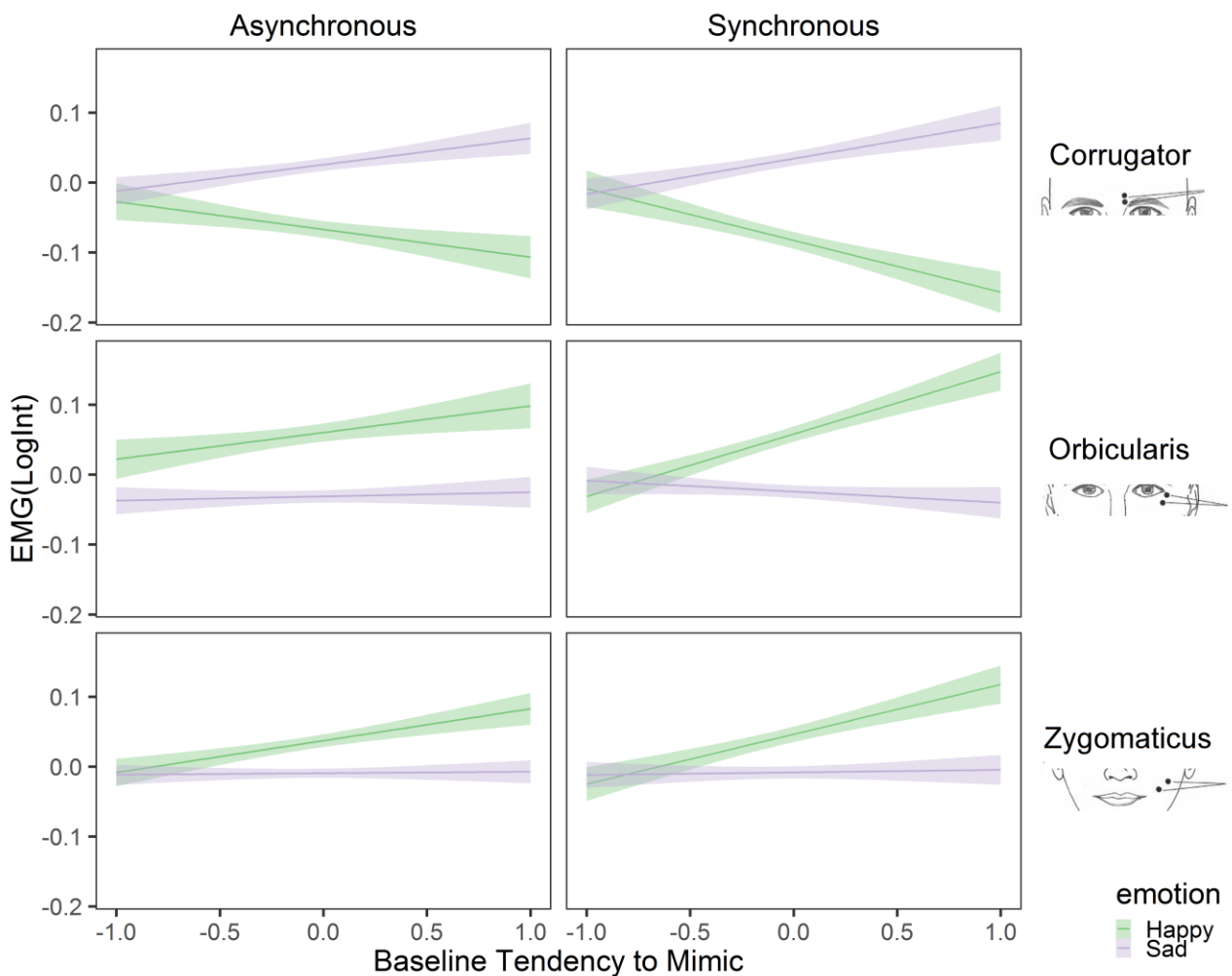
Figure 5. Illusion-driven enhancement of facial mimicry depends on participants' baseline tendency to mimic.

After synchronous stroking, the contrasts between congruent and incongruent emotions are significant for all muscles, while this was not the case after asynchronous stroking, when considering participants' baseline tendency to mimic another person's facial expression.

4. Discussion

We tested the possibility to enhance facial mimicry to emotional expressions, as a promising future route to improve emotion understanding and emotional contagion, an early form of empathy at the basis of later developing empathic concern and perspective taking. We covertly recorded participants' facial EMG while they observed videos of sad and happy facial expressions i) when self-other distinction processes were not altered (baseline condition) and ii) after participants experienced synchronous (and as control asynchronous) visuo-tactile interpersonal multisensory stimulation (VT-IMS), which blurs self-other boundaries and induces the enfacement illusion (Sforza et al., 2010). Our emotional videos were effective to induce, in all muscles, a facial mimicry response that did not habituate over time, that is, there was no difference in facial mimicry during baseline at the beginning and at the end of the experiment. We characterized facial mimicry in terms of participants' personality traits and appraisal of the emotional stimuli. Differently from our hypothesis and from previous studies, inter-individual differences in emotional empathic traits (Harrison, Morgan, & Critchley, 2010; Sonnby-Borgstr€om, Jonsson, & Svensson, 2003) or in the number of autistic traits (Haffey, Press, O'Connell, & Chakrabarti, 2013; Sims, Van Reekum, Johnstone, & Chakrabarti, 2012) did not modulate the strength of facial mimicry. The latter result might be because we tested neurotypical participants with a low number of autistic traits i.e., all participants but one fell outside the broad autism phenotype range (Wheelwright et al., 2010). In agreement with a previous study (Korb, With, Niedenthal, Kaiser, & Grandjean, 2014), we found that attractiveness did not modulate facial mimicry.

Our findings confirmed that simple synchronous VT-IMS induces the illusory experience of owning and controlling the face of another person, and the feeling of mapping on oneself the tactile stimulation observed on the other. Importantly, our findings show for the first time, that the enfacement illusion can enhance facial mimicry towards the enfaced other when individual baseline facial mimicry response is taken into account. Indeed, synchronous, compared to asynchronous, VT-IMS enhanced facial mimicry more so in individuals with higher baseline tendency to mimic another person's emotions. Our findings suggest that increased facial mimicry might be the

neurophysiological mechanism at the basis of initial evidence in favour of VT-IMS-induced emotional contagion (Ma et al., 2016) and improved emotion recognition (Maister, Tsiakkas, & Tsakiris, 2013). The current study provides physiological evidence extending to the crucial social realm of emotions, the effects played by synchronous VT-IMS on self-identity representation (Bufalari, Sforza, Di Russo, Mannetti, & Aglioti, 2019; Sforza, Bufalari, Haggard, & Aglioti, 2010), tactile and proprioceptive perception (Cardini, Tajadura-Jiménez, Serino, & Tsakiris, 2013; Maister, Cardini, Zamariola, Serino, & Tsakiris, 2015), attention (Porciello et al., 2014) and social behaviour (Maister, Slater, Sanchezvives, & Tsakiris, 2015; Paladino et al., 2010).

When we considered participants' emotional empathic traits, we found a pattern of results similar, although not significant, to that found for participants' baseline tendency to mimic: individuals with higher emotional empathy tended to show greater facial mimicry after synchronous, versus asynchronous, VT-IMS. That baseline facial mimicry and selfreport emotional empathy (in trend) modulate qualitatively in a similar direction the boosting effect of synchronous VTIMS, is in keeping with the role played by empathy in strengthening bodily illusions in general (Asai, Mao, Sugimori, & Tanno, 2011; Seiryte & Rusconi, 2015) and the enfacement illusion in particular (Sforza et al., 2010). Overall, our findings are in line with the idea that facilitating sensorimotor simulation by blurring self-other boundaries (in our case via the enfacement illusion), might be a key mechanism for enhancing empathy, as also suggested by mirror-touch synaesthesia. Mirror-touch synesthetes feel on their body the touch they observe on another person (Banissy, Kadosh, Maus, Walsh, & Ward, 2009), they experience the enfacement illusion just by looking at another person's face being touched, without the need for synchronous VT-IMS (Bufalari, Porciello, & Aglioti, 2015; Maister, Banissy, & Tsakiris, 2013) and, in turn, show better facial emotion understanding (Banissy et al., 2011) and empathy (Banissy & Ward, 2007). In a similar vein, Maister, Banissy, and Tsakiris (2013) found that synchronous VT-IMS improved emotion recognition of fearful faces and recent results showed that participants' neural empathic response to another person's pain increased when they embodied the hand receiving the painful stimulation (Riecansky´, Lengersdorff, Pfabigan, & Lamm, 2019).

Since our first aim was to establish whether VT-IMS could enhance facial mimicry, we presented happy and sad facial expressions in random order to reduce possible habituation effects. This made it not feasible to assess whether our VT-IMS manipulation changed participants' emotion congruently to the observed oneshence, we cannot directly claim that synchronous VT-IMS enhances emotional contagion. However, given the existing links between facial mimicry and emotional contagion (Niedenthal, 2007; Söderkvist, Ohlén, & Dimberg, 2018) and between VT-

IMS and emotional contagion (Ma et al., 2016), it is plausible that mood migration has taken place in the current study and has also been enhanced by synchronous VT-IMS. Further studies could directly test this effect.

We think our results could prompt investigation of innovative clinical interventions to improve empathic and emotion recognition difficulties in clinical populations, including autistic individuals and individuals with a diagnosis of schizophrenia. Indeed, studies suggest that both populations exhibit atypical facial mimicry (Riehle & Lincoln, 2017; Varcin, Bailey, & Henry, 2010; Yoshimura et al., 2015) and/or atypical links between facial mimicry and emotion recognition (Torregrossa et al., 2019), in addition to their empathic (Bonfils, Lysaker, Minor, & Salyers, 2016; Minio- Paluello, Baron-Cohen, Avenanti, Walsh, & Aglioti, 2009; Minio-Paluello, Lombardo, Chakrabarti, Wheelwright, & Baron-Cohen, 2009; Tschacher, Giersch, & Friston, 2017) emotion recognition (Green, Horan, & Lee, 2015; Kohler, Walker, Martin, Healey, & Moberg, 2010; Loth et al., 2018) and interpersonal motor coordination (Curioni, Minio- Paluello, Sacheli, Candidi, & Aglioti, 2017; Varlet et al., 2012) difficulties. An intervention where the enfacement illusion is used to boost facial mimicry and in turn emotional contagion, could be more effective than training intentional facial mimicry, in light of the behavioural and neural differences between faked and genuine emotional expression (Korb et al., 2014; Krumhuber & Manstead, 2009) and of the negative effect of intentionalmimicking on emotion recognition (Kulesza et al., 2015).

In our study, individuals with higher baseline levels of facial mimicry were those responding more to VT-IMS. This might hamper the translatability of our results to clinical populations with low empathic traits. To overcome this possible limitation, future studies with clinical populations could employ multiple VT-IMS sessions or couple VT-IMS with non-invasive brain stimulation (Antal et al., 2017; Rossi, Hallett, Rossini, Pascual-Leone, & Group, T. S. of T. C, 2009). This could be used to increase susceptibility of the neural substrates underlying visuo-tactile interpersonal multisensory integration and/or the blurring of self-other boundaries during the enfacement illusion (Apps, Tajadura-Jiménez, Sereno, Blanke, & Tsakiris, 2015; Bufalari, Sforza, Di Russo, Mannetti, & Aglioti, 2019).

Author contributions

IMP: Conceptualization, Project administration, Investigation, Data curation, Formal analysis, Writing-original draft.

GP: Investigation, Formal analysis, Visualization, Writing - review & editing.

MG: Investigation, Data curation, Visualization, Writing - review & editing.

SB: Methodology, Writing - review & editing.

SMA: Supervision, Funding acquisition, Writing - review & editing.

Supplementary data

Supplementary data to this article can be found online at
https://doi.org/10.1016/j.cortex.2019.10.001.

Open practices

The study in this article earned an Open Data badge for transparent practices. Materials and data for the study are available at https://osf.io/tjbqe/?view_only¼1a641ad1e0b24883aecb41ac22766e33.

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Supplementary Material

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S.2 Materials and Methods

S.2.1 Participants

We did not to recruit psychology students as they could have been familiar with facial mimicry and the enfacement illusion. Few weeks prior to participation, participants were pre-screened via the Interpersonal Reactivity Index (Davis, 1983) and the autism spectrum quotient (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001) questionnaires. In order to avoid possible ceiling or floor effects, we recruited 50% of participants (half female) with either one or both perspective taking and empathic concern Interpersonal Reactivity Index subscales' scores above (or below) 1 SD from the mean of their own sex group (Albiero, Matricardi, Speltri, & Toso, 2009). Further inclusionary criteria was an autism spectrum quotient score below the autism cut off (Wheelwright, Auyeung, Allison, & Baron-Cohen, 2010). Sample size was based on previous facial mimicry studies as no previous other study assessed the effects of VT-IMS on facial mimicry.

S.2.2 Video stimuli

S.2.2.1 Illusion videos

For each actor we produced two videos (2 minutes each) in which their face, holding a neutral expression, was touched by a ball attached to a stick. The ball stroked the left side of the actors' face following three possible pathways (i.e., below the eye, over the cheek, by the side of the nose). Participants felt a total of four different stroking sequences across blocks and actors and observed a total of two different stroking sequences with different visible sequences used in synchronous and asynchronous illusion videos of the same actor. Stroking frequency was approximately 0.5 Hz and there were no more than three consecutive strokes over the same face location. In the synchronous

block, the audio stroking sequence guided the (trained) experimenter to touch participants' face at the same time and on the same location as the actor in the video, while in the asynchronous block, it guided the experimenter to deliver participants asynchronous touches over spatial locations that could not be predicted based on the video.

S.2.2.2 Emotional videos

We used dynamic displays of emotional expressions since they are more ecologic (Dobs, Bülthoff, & Schultz, 2018) and induce a stronger facial mimicry response (Rymarczyk, Zurawski, Jankowiak-Siuda, & Szatkowska, 2016; Sato, Fujimura, & Suzuki, 2008) compared to static ones. Prior to video recording, we asked four professional actors (2 females and 2 males in their 20's and in their 30's) to recall an autobiographical event in which they respectively felt happy or sad. Surface electromyography (EMG) signal was recorded from actors' Corrugator, Orbicularis, Zygomaticus and Triangularis face muscles (placed according Fridlund and Cacioppo guidelines for human EMG research, Fridlund & Cacioppo, 1986) while actors performed facial emotional expressions, to make sure they activated each muscle more during its congruent, rather than incongruent, emotion (i.e., Corrugator and Triangularis more for sadness than happiness, and vice versa for Orbicularis and Zygomaticus). Emotional video clips were then coded and decoded according to Ekman's Facial Action Coding System (FACS) (Ekman, Friesen, & Hager, 2002) by a certified FACS coder blind to the study hypothesis. Emotional video stimuli resulted from selecting those video clips, one for each emotion and actor that had a single emotional peak which best met coding and decoding criteria. For coding, only the action units (AU) corresponding to the intended emotional facial expression were supposed to be active at the emotional peak, while for decoding, each video clip was supposed to score high only on the emotion it was meant to portrait (i.e., no mixed emotions) (**Figure S1**). Emotional video stimuli were therefore validated both at the physiological level, in that they implied correct EMG activation of the actors' muscles, and at the coding and decoding level, according to the FACS coder's judgment. Final emotional videos lasted 3 seconds each, starting from a neutral expression they reached, in 1 second, the emotional peak, which then lasted the remaining 2 seconds. Participants just watched videos of their same sex actors, while their EMG signal coming from the aforementioned muscle was covertly recorded.

Samples of the experimental stimuli used in the current study (i.e., illusion and emotional videos) can be viewed as Supplementary Material. Ethical restrictions prevent us from archiving the full set of experimental stimuli in a publicly accessible repository. In particular, the actors consented for their videos and images to be used for dissemination purposes only. Scientists interested to use the full set of stimuli for research purposes, please email the corresponding author to check whether consent to use the stimuli for research purposes has been secured from all actors. If and when

consent is secured, experimental stimuli will be added to

Actor B – Happiness Video

Coding

Time	Upper Face	Description	Intensity	Note
00.00.02	AU6	AU6 – Cheek Raiser and Lid Compressor	A	
00.00.02	AU7	AU7 – Lid Tightener	B	
00.00.02	AU45	AU45 - Blink	A	Blink
Time	Up-Down-Lower Face	Description	Intensity	Notes
00.00.01	AU25	AU25 – Lips Part	D	
Time	Oblique	Description	Intensity	Notes
00.00.01	AU12	AU12 – Lip Corner Puller	D	Social smile

Decoding

Actor A – Sadness Video

Coding

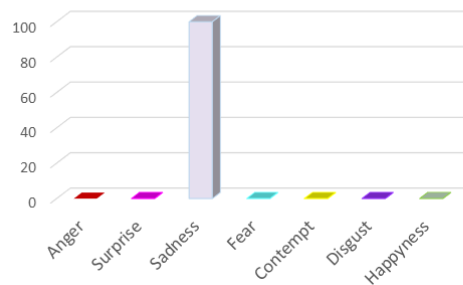| Time	Upper Face	Description	Intensity	Notes
00.00.02	AU1	AU1 – Inner Brow Raiser	D	
00.00.02	AU4	AU4 – Brow Lowerer	B	
00.00.02	AU7	AU7 – Lid Tightener	C	
Time	Up-Down-Lower Face	Description	Intensity	Notes
00.00.02	AU15	AU15 – Lip Corner Depressor	D	
00.00.02	AU17	AU17 – Chin Raiser	D	
Time	Oblique	Description	Intensity	Notes
00.00.02	AU11	AU11 – Nasolabial Furrow Deepener	A	
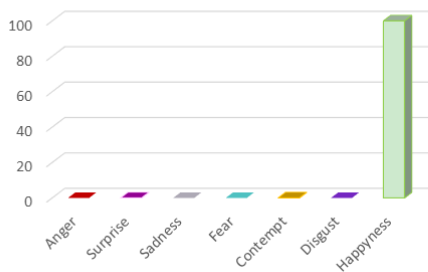
Decoding

Figure S1. FACS validation of emotional videos

Top part: Coding the facial expression displayed in the video according to which action units (AU) are active and how intense is their activation. Intensity scale ranges from A (minimum) to E (maximum). Bottom part: Decoding the emotional facial expression displayed in the video according to its emotional content.

S.2.3 Questionnaires

The Interpersonal Reactivity Index is a 28-items self-report questionnaire with four subscales each measuring an independent component of empathy (Albiero et al., 2009; Davis, 1983). Participants indicate on a five-point Likert scale how much they agree with each statement. Here, we focused only on *perspective taking* , which measures the ability to adopt another person's view point, and *empathic concern* , which measures the tendency to respond with warm, compassionate feelings for others, subscales as they respectively tap cognitive and emotional empathy, whose role has been considered in previous facial mimicry studies (Sonnby-Borgström, 2002; 2003; Dimberg, 2011; Harrison, 2010; Likowski, 2011). Further, we believe the remaining IRI *personal distress* subscale does not contribute to the focus of our investigation, and *fantasy* subscale is not clear how to place it within current constructs of empathy. Score at each IRI subscale ranges from 0 to 28.

The Autism spectrum quotient (Baron-Cohen et al., 2001; Ruta, Mazzone, & Mazzone, 2012) is a 50-items self-report questionnaire measuring the number of autistic traits across five domains: communication, social skills, attention switching, imagination, and attention to detail. Participants indicate how strongly they agree or disagree with each statement, using a four-point Likert scale. Total score ranges from 0 to 50 and when above 31 is indicative of autism. Scores between 23 and 28 are considered Broad Autism Phenotype (BAP), between 29 and 34 Medium Autism Phenotype (MAP) and above 34 Narrow Autism Phenotype (NAP) (Wheelwright et al., 2010).

S.2.4 Experimental Procedure

No part of the study procedures was pre-registered prior to the research being conducted.

S.2.4.1 EMG electrodes, acquisition and processing

Two Ag/AgCl surface electrodes (diameter = 4mm) were placed with a bi-polar montage over each muscle according to Fridlund and Cacioppo guidelines for human EMG research (Fridlund & Cacioppo, 1986), of the left hemiface as it seems to show greater facial mimicry response (Dimberg & Petterson, 2000). The ground electrode was placed below the hairline on the center of the forehead. Recorded muscles are known to be active either during happy or sad facial emotional expressions with Corrugator responsible for frowning, Triangularis for pulling the corners of the mouth downward, Orbicularis for shrinking the eyes and Zygomaticus for pulling the corners of the mouth upward. Participants were told the electrodes were '*sensors to detect micro changes in skin temperature and sweat*'. EMG signal was recorded via PowerLab data acquisition device (ADInstrument Ltd) with 2kHz sampling rate, then it was off-line band-pass (20-500 Hz) and Notch (50Hz) filtered and rectified via LabChart data analysis software (ADInstruments Ltd). We considered the EMG signal starting from 500 ms after the beginning of the emotional video to its end, as it has been previously shown that in this time window the facial mimicry response is stronger (Beall, Moody, McIntosh, Hepburn, & Reed, 2008; Mathersul, McDonald, & Rushby, 2013). EMG traces were divided into 100 ms long time bins. We calculated the integral of the EMG signal and log 10 transformed it to reduce the impact of extreme values (Beall et al., 2008; Moody, McIntosh, Mann, & Weisser, 2007; Oberman, Winkielman, & Ramachandran, 2009). A change from baseline score was calculated for each trial by subtracting the EMG signal recorded during the last 500 ms of the fixation cross from that recorded during each 100ms long time bin of the emotional video (Künecke, Hildebrandt, Recio, Sommer, & Wilhelm, 2014; McIntosh, Reichmann-Decker, Winkielman, & Wilbarger, 2006).

In order to exclude signal artefacts, for each participant we removed trials if 1) the EMG signal recorded during the fixation cross was equal or higher than the mean plus 2.5 SD of all their fixation crosses across blocks (Korb, With, Niedenthal, Kaiser, & Grandjean, 2014) or if 2) the difference in EMG signal between two consecutive bins was equal or higher than the mean for that trialplus 3 SD (Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008).

S.2.4.2 Visuo-Tactile Interpersonal Multisensory Stimulation (VT-IMS)

During a/synchronous visuo-tactile interpersonal multisensory stimulation (VT-IMS) procedure participants were touched by a ball attached to a stick and maneuvered by the experimenter and, for consistency also during observation of neutral videos with no VT-IMS, participants wore blinders that prevented them from seeing the ball approaching and then touching their face, as well as the experimenter's hand moving. The experimenter delivering touch wore headphones through which she could hear where and when to touch the participant's face. This allowed her to 1) keep stroking sequence consistent across participants, 2) avoid the risk to adopt implicit rules that could link observed and delivered strokes and 3) help the experimenter delivering an accurate synchronous or asynchronous stimulation. Two synchronous and two asynchronous stroking sequences were used (counterbalanced for the two actors, across participants). In the synchronous and asynchronous blocks participants watched the same videos, however the experimenter delivered the tactile stimuli according to a different audio sequence. While in the synchronous block, felt and observed touch happened at the same time and over the same portion of the face (i.e., temporal and spatial congruency), in the asynchronous block participants were touched while the ball in the video was not touching the actor's face (i.e., temporal incongruency) and the portion of participant's face being touched was not predictable based on the one previously touched on the actor's face (i.e., spatial incongruency). This was done in order to prevent that participants could anticipate where they would be touched next, based on where the actor was touched, as it is instead always the case in studies where a single spatial location is touched (Cardini, Tajadura-Jiménez, Serino, & Tsakiris, 2013; Ma, Sellaro, Lippelt, & Hommel, 2016; Sforza, Bufalari, Haggard, & Aglioti, 2010; Tsakiris, 2008).

S.2.4.3 Illusion ratings

At the end of each block, participants agreed or disagreed, via a Visual Analogue Scale (VAS) ranging from 0 to 100, with statements (presented in random order) assessing how much they experienced the illusion. Statements were adapted from Longo and colleagues (Longo, Schuur, Kammers, Tsakiris, & Haggard, 2008) and regarded 3 crucial facets of the enfacement illusion: Agency, experiencing to be in control of the face being observed (3 statements), Ownership,

experiencing to own the face being observed (3 statements), and Location, experiencing the tactile stimulus originating from the face being observed and experiencing ones face being in the place of the face being observed (4 statements for Synchronous and Asynchronous blocks and, given there is no ball touching the actor's and participant's face, only 2 statements for Baseline blocks). For each participant and actor, statements relative to each facet of the illusion were averaged to provide Agency, Ownership and Location summary scores. Further, for each visuo-tactile stimulation block, we calculated an illusion index corresponding to the average of participant's Agency, Ownership and Location summary scores relative to the Synchronous (or Asynchronous) block, divided by the average of participant's Agency, Ownership and Location summary scores relative to the Baseline blocks.

S.2.4.4 Timeline

The experiment comprised 4 blocks: one initial Baseline, a Synchronous and an Asynchronous block (presented in counterbalanced order across participants) and a final Baseline (initial Baseline and final Baseline were considered as two parts of the same block). Each block had 60 trials and was divided in two parts, one with actor A and one with actor B, presented in counterbalanced order across participants. Each block started with participants either experiencing synchronous or asynchronous VT-IMS or observing the Baseline video where the actor was not touched. Then 10 emotional videos followed (50% Happy, 50% Sad) with the same actor portrayed in the previous VT-IMS or baseline (no VT-IMS) video. Every trial consisted of a fixation cross (1000 ms), followed by an emotional video (3000 ms) and a blank screen (variable duration between 1500 – 2000 ms). At the end of each block, participants rated how much they experienced the illusion during the illusion videos. Before the end of the experiment, participants also rated, via 0-100 VAS, the intensity and realism of each emotional video, and the attractiveness of their same sex actors (presented via a neutral static picture). To check whether the electrodes were correctly placed on the targeted facial muscles, and therefore recorded a reliable signal, participants were asked to overtly imitate the actor's facial expressions as they watched the emotional videos. Emotional videos (i.e., one video for each actor and emotion) were repeated three times each and presented in random order. To check the effectiveness of our cover story, participants were asked what the sensors on their face measured and about the aim of our study. None of the participants thought their face muscles were being recorded in order to assess facial mimicry. Lastly, participants were debriefed about the content of the cover story and the study's actual aims.

S.2.5 Data analysis

We run LMM models with the package lme4 Version 1.1–5 (Bates et al., 2014) and the package afex Version 0.23-0 (Singmann et al., 2019). All variables, except the independent variable, were scaled and centred prior to analysis. Principle Components Analysis (PCA; R, package RePsychLing, function rePCA), was used to select the random structure of each model as it tests the over-parameterization of the maximum random structure which affects the interpretability and reliability of the parameters' estimates (Bates et al., 2015). Based on PCA results, we removed by-subject random effects that explained an amount of variance close to zero. The *mixed* function was used to estimate each model, with either Kenward-Roger or Satterthwaite approximation for degrees of freedom and to calculate p-values for each fixed effect in Type III ANOVA. Post-hoc comparisons and interactions with covariates were performed with the 'Estimated Marginal Means' R package (version 1.3.3, Lenth, 2017) via the *emmeans* and *emtrends* functions, respectively, and Tukey correction for multiple comparisons. All the remaining analyses were done via STATISTICA data analysis software (StatSoft, Inc. 2007).

S.3 Results

S.3.1 Ratings

S.3.1.1 Participants experience the illusion after synchronous VT-IMS

First we tested whether participants differently rated the illusion in Baseline1 and Baseline2, via a MANOVA with *Agency*, *Ownership* and *Location* as dependent variables. Using Wilks's statistic, we found no significant effect of block (Baseline1 vs Baseline2) on Agency, Ownership and Location, $\Lambda = 0.90$, $F(3,38)= 1.36$, p= 0.27, $\eta_p^2 = 0.10$. We therefore run a similar MANOVA over collapsed Baseline, Asynchronous and Synchronous blocks and, using Wilks's statistic, we found a significant effect of block on Agency, Ownership and Location, $\Lambda = 0.26$, $F(6,35)= 16.38$, p=7.00e-09, $\eta_p^2 = 0.74$. Separate univariate ANOVAs on the outcome variables revealed significant effects on Agency, $F(2,80)= 8.54$, p= 0.00043, $\eta_p^2 = 0.18$, Ownership, $F(2,80)= 43.23$, p= 1.87e-13, $\eta_p^2 = 0.52$ and Location, $F(2,80)= 29.33$, p= 2.79e-10, $\eta_p^2 = 0.42$. Follow up Tukey post-hoc tests revealed that Synchronous differed from Asynchronous for all outcome measures (Agency: p=0.0002; Ownership: p=0.0001; Location: p=0.0001) and from Baseline for Ownership (p = 0.0001), Location (p=0.0001) and marginally for Agency (p = 0.06). Asynchronous did not differ from Baseline for any of the outcome measures (ps>0.05).

S.3.1.2 Emotions' intensity and realism, and actors' attractiveness

Paired t-tests showed that female participants gave, across actors, similar intensity and realism ratings to the videos depicting happiness (Intensity: Actress A= 71.76, sd= 22.50; Actress B= 69.45, sd = 16.36, t(20)= 0.40, p= 0.70; Realism: Actress A= 68.08, sd= 24.87; Actress B= 76.17, sd = 22.93, t(20)= -1.21, p= 0.24) while not to those depicting sadness (Intensity: Actress A= 46.76, sd= 21.20; Actress B= 58.79, sd = 22.15, t(20)=-2.66, p= 0.02; Realism: Actress A= 29.37, sd= 16.17; Actress B= 48.49, sd =23.59, t(20)= -4.33, p=0.0003). Paired t-tests showed that male participants gave, across actors, different intensity and realism ratings to the videos depicting happiness (Intensity: Actor A = 78.27, sd = 12.96; Actor B = 57.06, sd = 14.99, t(19) = 5.15, p = 0.000057; Realism: Actor A = 64.35, sd = 27.43; Actor B = 78.48, sd = 17.54, t(19) = -2.06, p = 0.05) while not to those depicting sadness (Intensity: Actor A = 50.90, sd = 19.58; Actor B = 49.20, sd = 25.30, t(19) = 0.33, p = 0.75; Realism: Actor A = 35.52, sd = 21.46; Actor B = 36.62, sd = 22.64, t(19) = -0.20, p = 0.84).Paired t-tests showed that female participants similarly rated actress' attractiveness (Actress A: mean = 52.93, sd = 24.57; Actress B: mean = 47.89, sd = 23.32, t(20) = 0.91, p = 0.37) while male participants did not similarly rate actors' attractiveness (Actor A: mean=38.16, sd = 20.14; Actor B: mean = 55.13, sd =24.51, t(19) =-3.75, p = 0.001).

S.3.2 EMG

S.3.2.1 Recording of the Triangularis is not reliable.

Thirty-two (out of 41) participants at the end of the experiment performed overt imitation, which was introduced to check for electrodes' correct placement. Participants were video recorded while imitating the emotional videos.The FACS coder coded the intensity of each action unit (AU) activated by participants during overt imitation. Paired t-tests showed that for all AUs (i.e., muscles), visible contraction was stronger for congruent, vs. incongruent, emotions (AU4-Corrugator: Sad = 3.7 (1.1), Happy = 1.2 (0.8), t(30)=10.4, p < 0.001; AU6-Orbicularis: Happy = 2.0 (0.9), Sad = 1.1 (0.4), t(30)=5.7, p<0.001; AU12-Zygomaticus: Happy=3.9(0.6), Sad=1.1(0.3), t(30)=21.9, p<0.001; AU15-Triangularis: Sad=3.1 (1.4), Happy= 1.1(0.3), t(30)=7.4, p<0.001). However, just for the Triangularis, its EMG activation did not parallel its visible contraction, that is, recorded EMG activation for the congruent emotion (in this case sadness) was not stronger than for the incongruent emotion (in this case happiness) (Corrugator: Sad=0.42 (0.43), Happy= -0.03(0.37), t(31)= 4.12, p=0.0003; Orbicularis: Happy= 0.48(0.31), Sad=0.23 (0.34), t(31)= 4.08, p=0.0003; Zygomaticus: Happy= 0.57(0.31), Sad=0.18 (0.34), t(31)= 4.54, p=0.00008; Triangularis: Sad= 0.62 (0.33), Happy=0.60 (0.34), t(31) = 0.24, p = 0.81; **Figure S2**). We therefore decided to discard

Triangularis from further analysis as it seemed apparent that we were not able to place the electrodes in a correct and reliable fashion.
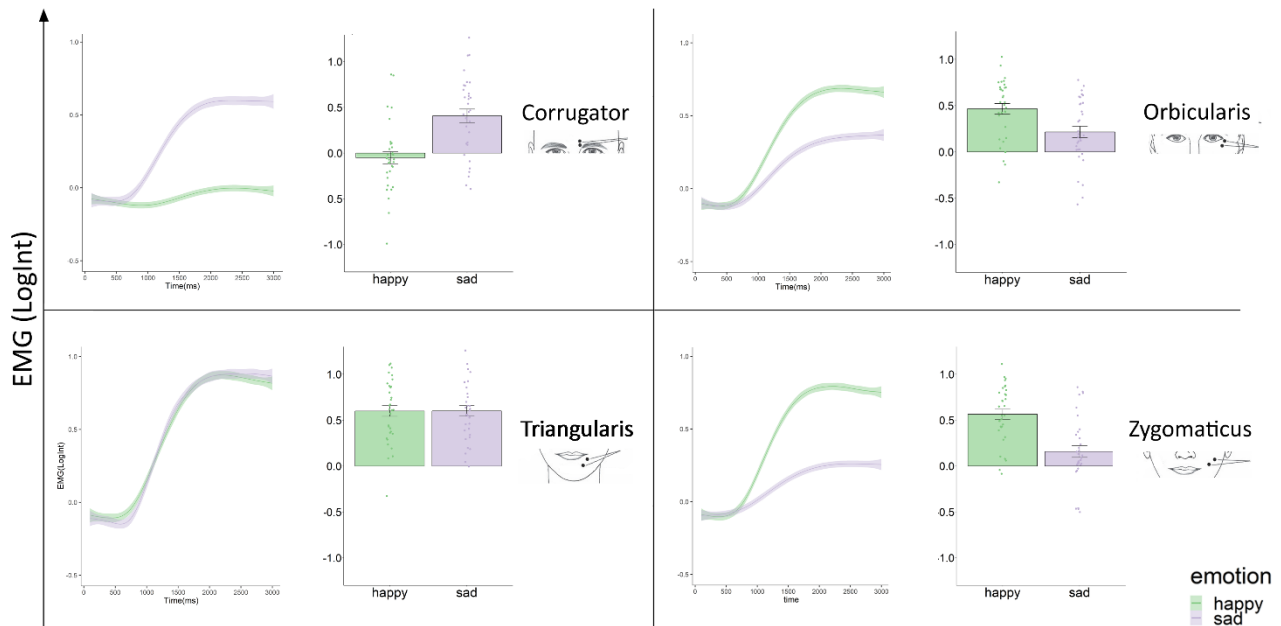

Figure S2. EMG during intentional imitation of facial emotional expressions
The figure depicts, for each muscle, the Log of the integral of the fixation cross-subtracted EMG activation over time and the average LogInt EMG activation from 500ms post stimulus onset to the end of stimulus presentation (i.e., 3000 ms). Deviation around the curve represents 95% CI, while the error bar represents SME.

S.3.2.2 No difference in facial mimicry measured at the beginning and at the end of the experiment: mixed-model structure.
We tested whether facial mimicry evoked during Baseline1 differed from that evoked during Baseline2. To select the random structure of our model, we ran a PCA over the model that did not include the three-way interaction, as it was dropped in order to allow for convergence. We then ran LMM with EMG activation as our dependent continuous variable, *emotion* (happy vs. sad), *muscle* (Corrugator, Orbicularis, Zygomaticus), *block* (Baseline1 vs. Baseline2) and their respective interactions as our fixed effects, and, based on the PCA results, *participant*s (i.e., random intercept) as well as *emotion*, *block* and *muscle* (i.e., random slopes over participants) as our random part.

S.3.2.3 Facial mimicry at baseline: mixed-model structure and results.
Based on the aforementioned results, we therefore collapsed Baseline1 and Baseline2 and ran a LMM with EMG activation as our dependent continuous variable, *emotion* (happy vs. sad) and

muscle (Corrugator, Orbicularis, Zygomaticus) as fixed effects, *empathic concern*, *perspective taking*, *autism spectrum quotient*, *emotion's realism*, *emotion's intensity*, *actor's attractivene*ss as continuous covariates (interacting with the categorical main effects but not between each other) and, for the random part, *participants* as random intercept as well as *emotion*, *muscle* and *emotion x muscle* as random slopes. Based on the PCA results we kept *participant*s (i.e., random intercept) as well as *emotion*, *muscle* and *emotion x muscle* (i.e., random slopes over participants) as our random part. Post-hoc tests confirmed the presence of facial mimicry for all muscles, that is, all contrasts between congruent and incongruent emotions were statistically significant (Corrugator: b = -0.12, SE= 0.02, df= 45.0, t ratio = 5.44, p <0.0001, Orbicularis: b = 0.10, SE= 0.02, df= 50.3, t ratio = 5.60, p <0.0001, Zygomaticus: b = 0.04, SE= 0.01, df= 54.5, t ratio = 3.03, p = 0.004).

S.3.2.4 Synchronous VT-IMS enhances facial mimicry: mixed-model structure and results.
To investigate whether synchronous stroking, compared to asynchronous stroking, modulates the strength of facial mimicry, we ran our LMM analysis on a model with EMG activation as our dependent continuous variable (i.e., fixation cross-subtracted Log10 of the integral of the EMG signal), *emotion*, *muscle* and *block* (synchronous vs. asynchronous) as fixed effects, *empathic concern*, *perspective taking*, *autism spectrum quotient*, *Emotion's Realism*, *Emotion's Intensity*, *Actor's attractiveness*, *Baseline Tendency to Mimic* (i.e., for each actor, we calculated the average of the difference between congruent and incongruent EMG activation of all musclesrecoded at Baseline) and *Subjective Rating of the Illusion* (i.e., for each visuo-tactile stimulation block and actor, we calculated the average between Agency, Ownership and Location summary scores and divided it by the corresponding average relative to the Baseline blocks) as continuous covariates (interacting with the categorical main effects but not between each other) and, for the random part, *participants* as random intercept as well as *emotion*, *muscle* and *block* as random slopes, as suggested by the PCA procedure. Type III ANOVA showed a significant interaction between participants' facial mimicry (i.e., emotion x muscle), block (i.e., synchronous versus asynchronous) and participants' baseline tendency to show facial mimicry, F(2,4528)= 3.63 , p = 0.03. Analysis of the 4-way interaction showed that after synchronous stroking the contrasts between congruent and incongruent emotions were significant for all muscles (Corrugator: b = 0.10, SE= 0.02, df = Inf, z ratio = 5.10, p < 0.0001; Orbicularis: b = 0.09, SE= 0.02, df = Inf, z ratio = 4.41, p < 0.0001; Zygomaticus: b = 0.06, SE= 0.02, df = Inf, z ratio = 3.19, p = 0.0014) while after asynchronous stroking they were not significant in all but one muscle (Orbicularis: b = 0.02, SE= 0.02, df = Inf, z ratio = 1.15, p = 0.25; Zygomaticus: b = 0.03, SE = 0.019, df= Inf, z ratio = 1.78, p = 0.08;

Corrugator: b = 0.08, SE= 0.02, df = Inf, z ratio = -4.04, p = 0.0001). That for Corrugator, facial mimicry depends on participants' baseline tendency to mimic also after asynchronous stroking, may suggest investigating whether our modulatory effect is specific for positive emotions. Unfortunately, the unreliable recording of the Triangularis in the current study, did not allow additional evidence on this issue. Future studies could instead use Mentalis, another mouth muscle involved in sad facial expressions. Finally, contrary to our expectations, the interactions between participants' facial mimicry (i.e., emotion x muscle), block (i.e., synchronous versus asynchronous) and number of autistic traits, $F_{(2, 4528)} = 0.85$, $p = 0.43$, or empathic concern, $F_{(2, 4527)} = 2.68$, $p = 0.07$, were not significant. Interestingly, although not significant (p=0.07) the interaction of our effect with participants' empathic concern had a pattern of results qualitatively similar to that found for participants' baseline tendency to mimic (**Figure S3**). No other 4-way interaction tended to or reached significance (ps > 0.42) including the interaction with perspective taking, $F_{(2,4528)} = 0.74$, $p = 0.48$.
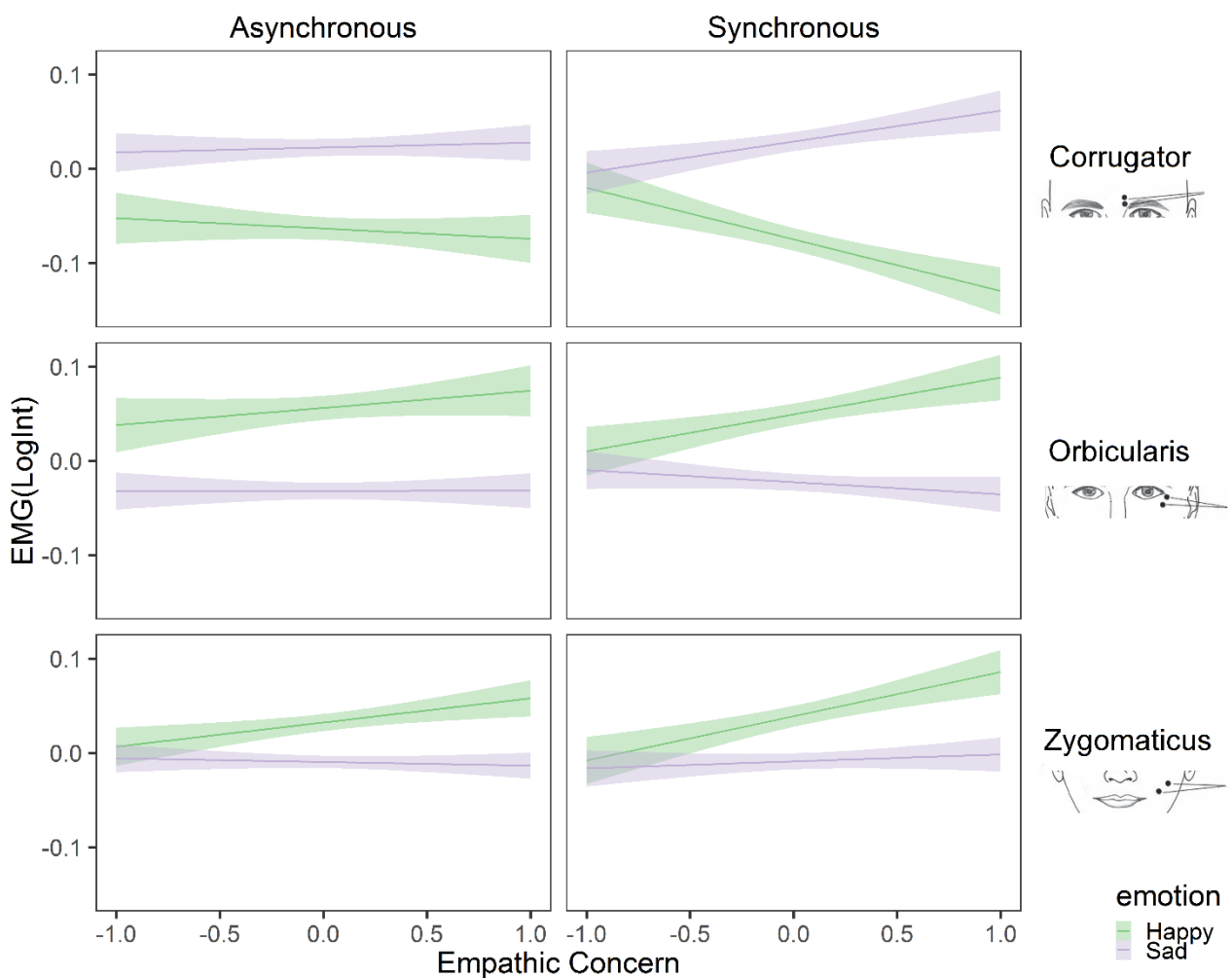
Figure S3. Illusion-driven enhancement of facial mimicry tends to depend on participants' emotional empathy.

Participants with higher empathic concern tend to show greater facial mimicry after synchronous (vs. asynchronous) visuo-tactile interpersonal multisensory stimulation.

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