Received: 9 July 2018 | Revised: 14 January 2019 | Accepted: 3 March 2019

DOI: 10.1002/ejp.1390

ORIGINAL ARTICLE

WILEY EJP European Journal of Pain

Does my pain affect your disgust? Cross-modal influence of first-hand aversive experiences in the appraisal of others' facial expressions

Lia Antico | Eugénie Cataldo | Corrado Corradi-Dell'Acqua

Theory of Pain Laboratory, Department of Psychology, Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

Correspondence
Lia Antico, Theory of Pain Laboratory, Department of Psychology, Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland.
Email: Lia.Antico@unige.ch

Funding information
This research was financed by the Swiss National Science Foundation grant no. PP00O1_157424/1.

Abstract

Background: Embodied models of social cognition argue that others' affective states are processed by re-enacting a sensory-specific representation of the same state in the observer. However, neuroimaging studies suggest that a reliable part of the representation shared between self and others is supramodal and relates to dimensions such as unpleasantness or arousal, common to qualitatively different experiences. Here we investigated whether representations of first-hand pain and disgust influenced the subsequent evaluation of facial expressions in modality-specific fashion, or in terms of unpleasantness or arousal.

Methods: Thirty volunteers were subjected to thermal painful and olfactory disgusting events, and subsequently were asked to classify computer-generated faces expressing pain (characterized by high unpleasantness and arousal), disgust (high unpleasantness and low arousal), surprise (low unpleasantness and high arousal) and hybrid combinations thereof.

Results: Thermal and olfactory events were associated with comparable unpleasantness ratings and heart rate (but stronger galvanic response was found for painful temperatures). Furthermore, we found that the appraisal of facial expressions was biased by the prior stimulus, with more frequent pain classifications following thermal stimuli, and more frequent disgust classifications following olfactory stimuli. Critically, this modulation was cross-modal in nature, as each first-hand stimulation influenced in comparable fashion facial traits diagnostic of both pain and disgust, without instead generalizing to features of surprise.

Conclusion: Overall, these data support the presence of shared coding between one's aversive experiences and the appraisal of others' facial responses, which is best describable as supramodal representation of the unpleasantness of the experience.

Significance: These results extend previous findings about common representational coding between the experience of first-hand and others' pain. In particular, they highlight that reliable part of the information shared is supramodal in nature and relates to a broad dimension of unpleasantness common also to painless aversive states such as disgust.

Journal Name EJP | Manuscript No. 1390 | WILEY | No. of pages: 14 | Dispatch: 16-3-2019 | PE: | CE:

1 | INTRODUCTION

How we understand the sufferance of others is a central but still unresolved issue in cognitive and affective sciences. One influential model suggests that this might be achieved by simulating the same experience on one's body. Consistently, many researches showed that the pain felt on oneself and observed in others can exert mutual influence, with sensitivity to noxious stimuli being enhanced by previous/concurrent exposure to facial expressions of pain and *vice versa* (Coll, Budell, Rainville, Decety, & Jackson, 2012; Godinho et al., 2012; Mailhot, Vachon-Presseau, Jackson, & Rainville, 2012; Reicherts, Gerdes, Pauli, & Wieser, 2013; Vachon-Presseau et al., 2011; Wieser, Gerdes, Reicherts, & Pauli, 2014). Furthermore, displaying injured limbs diminishes the muscular reactivity in homologous portions of the observers' body (Avenanti, Bueti, Galati, & Aglioti, 2005). Additionally, analgesic manipulations allegedly affecting the opioid system have been also shown to desensitize individuals to others' sufferance (Braboszcz, Brandao-Farinelli, & Vuilleumier, 2017; Mischkowski, Crocker, & Way, 2016; Rütgen et al., 2015). Overall, these studies converge with embodied accounts of social cognition, by suggesting that sensory-specific properties of one's painful experience are instrumental for appraising others' sufferance.

Embodied accounts have also been investigated through functional neuroimaging, with consistent evidence that observing others' pain recruits a neural network—including the cingulate cortex and insula—held to mediate first-hand nociception ("shared" network, Corradi-Dell'Acqua, Hofstetter, & Vuilleumier, 2011; Lamm, Decety, & Singer, 2011; Singer et al., 2004; but see Krishnan et al., 2016). Interestingly, the same "shared" network has been implicated frequently also in painless events, such as disgust, unfair treatments, risk-taking and error monitoring. (Corradi-Dell'Acqua, Tusche, Vuilleumier, & Singer, 2016; Klein et al., 2007; Preuschoff, Bossaerts, & Quartz, 2006; Sharvit, Corradi-Dell'Acqua, & Vuilleumier, 2018; Wicker et al., 2003). Furthermore, patients with congenital insensitivity to pain, who lack aching experiences in their own body, still show activations in the insular–cingulate cortex to the sight of others' injuries, thus opening the question on the information coded in these regions (Danziger, Faillenot, & Peyron, 2009). Hence, it is possible that previous researches investigating embodied pain processing might have instead tapped a representation of supramodal dimensions such as unpleasantness or arousal (see also, Iannetti & Mouraux, 2010).

In this study, participants underwent thermal (painful) and olfactory (disgusting) stimulations, and subsequently classified facial expressions of pain and disgust (both characterized by high unpleasantness), surprise (characterized by high arousal) and control stimuli. We expected that individuals would be biased in the evaluation of facial information matching the prior first-hand experience. The critical question is whether this information is modality-specific or supramodal and, in the latter case, whether it is describable in terms of unpleasantness or arousal. If individuals use modality-specific information to process others, their prior experience should influence only the appraisal of expressions conveying the same state (pain expressions following thermal painful stimulation). If, however, individuals use supramodal information, their prior experience should influence the appraisal of any facial expression conveying the same information. Specifically, if thermal stimuli influence the appraisal of disgust expressions, this would be evidence of supramodal coding of unpleasantness, whereas if they affect surprise expressions this would be more consistent with a representation of arousal.

2 | METHODS

2.1 | Participants

Thirty students (10 women, mean age ± standard deviation [*SD*] 23.78 ± 4.29 years old, range between 18 and 32) were recruited for the present study through advertisements posted at the University of Geneva. Two of them were subsequently discarded from the overall analysis due to their low proficiency in the classification of pure expressions (≤50% accuracy; all remaining subjects >65%; see Experimental Set-up for details). Thus, the overall population comprehended 28 participants (9 women; mean age ± *SD*, 23.68 ± 4.21 years old, range between 18 and 32). None of them declared they had been diagnosed with neurological or psychiatric disorder. Furthermore, none of the participants showed signs of depression as assessed by the Beck Depression Inventory (average score: 3.09 ± 2.45 *SD*, Beck, Ward, Mendelson, Mock, & Erbaugh, 1961; Beck, Steer, & Carbin, 1988). Scores from the State-Trait Anxiety Inventory revealed anxiety levels comparable with the student population (State scale: 29.89 ± 7.31, range 21–47; Trait scale: 38.67 ± 7.81, range 25–49, with three participants scoring above the 90th percentile of the normative data from university students, Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983). To maximize the likelihood that the recruited participants were naïve to the purpose of the experiment, psychology and neuroscience students were excluded, as they might have learned about embodied accounts for social cognition during their studies. All participants gave their informed written consent and were remunerated for their participation. The study was approved by the local ethical committee and carried out in accordance with the Declaration of Helsinki for experiments involving humans.

2.2 | Olfactory stimulation

Odours were provided by Firmenich, S.A. (Geneva) based on previous evaluations (Antico, Guyon, Mohamed, &

Corradi-Dell'Acqua, 2018; Chrea et al., 2009; Delplanque et al., 2008; Sharvit et al., 2018; Sharvit, Vuilleumier, Delplanque, & Corradi-Dell'Acqua, 2015). *Isovaleric acid* (evocating dirty socks) and *Scarymol* (evocating sweat) were diluted in a solution of odourless *Dipropylene glycol* at four different concentrations (0.1%, 0.5%, 5% and 10%) and were used to elicit different levels of disgust in the participants. At the beginning of the experimental session, we conducted a pleasantness-rating task to select, at the individual level, two odours, expected to elicit *low disgust* (LD, rated about ~ −0.2 in a scale ranging from +5 [extremely pleasant] to −4 [extremely unpleasant]), and *high disgust* (HD, rated about ~ −3) (see Supporting Information Methods S1 for more details). In addition, *Ariana* (evocating shampoo) was presented with a concentration of 10% and was used to give relief from disgusting odours and to avoid habituation effects. All odorants were stocked in liquid form in test tubes and were delivered by a computer-controlled, multi-channel, custom-built olfactometer to the participants' nostrils via a rubber mask. A constant air flow of 0.5 bars provided by the olfactometer allowed this diffusion without contaminating the next trial and without additional noise or tactile stimulation in the nose (Ischer et al., 2014).

2.3 | Thermal stimulation

A computer-controlled thermal stimulator with an MRI-compatible 25 × 50 mm fluid-cooled Peltier probe (MSA, Thermotest) was placed at the left wrist of the participant and delivered different thermal stimulations, ranging from 41 to 51°C. For each participant, we chose two different temperatures that were expected to evoke two different levels of pain, *low pain* (LP, rated about ~ −0.2) and *high pain* (HP, rated about ~ −3). Critically, the unpleasantness of these two temperatures matched that of the two disgusting odours selected for the same participant (see Supporting Information Methods S1 for more details about the temperature selection).

2.4 | Experimental set-up

2.4.1 | Facial stimuli

We created a database of expressions using a FACSGen software that allows to freely customize the facial movement in computerized avatars through the Facial Action Coding System (Roesch et al., 2011). In particular, we took the facial information of each state of interest from the well-established Montreal Pain and Affective Face Clips database (Simon, Craig, Gosselin, Belin, & Rainville, 2008; Simon, Craig, Miltner, & Rainville, 2006) which contains 1-s videos of eight individuals (4 males) mimicking pain, disgust, surprise or neutral facial expressions (plus other states of no interest for our study). This database has been validated on *valence* through a 9-point Likert-Scale (−4 = clearly unpleasant, +4 = clearly pleasant) and *arousal* (−4 = highly relaxed, +4 = high level of arousal) in a previous study (Simon et al., 2008). Within this validation, pain and disgust expressions were rated as the most negative (pain: mean −2.88 [*SEM* 0.17]; disgust: −2.61 [0.16]), as opposed to the others (surprise: 0.26 [0.14]; neutral: −0.08 [0.06]). Instead, pain and surprise were rated as most arousing (pain: 2.14 [0.23]; surprise: 1.51 [0.34]) as opposed to disgust (0.98 [0.29]) and especially neutral expressions (−1.20 [0.37]). Furthermore, pain and disgust expressions are characterized by similar engagement of facial action units (AUs) responses at the level of the brow lower (AU 4), check raiser (AU 6), nose wrinkle (AU 9) and upper lip raiser (AU 10). Instead, pain and surprise share similar engagement of the mouth aperture (AU 25). Disgust and surprise share no similar facial movements (Simon et al., 2008).

These video-clips were fed to the Computer Expression Recognition Toolbox (CERT) (Littlewort et al., 2011) which runs automated frame-by-frame analysis of facial AUs responses. This software estimates the likelihood of facial contraction in 20 predefined AUs through the combination of Gabor wavelet decomposition and support vector machine (SVM) classification. For each AU, and for each video-frame, CERT provides the distance of the extracted data vector from a SVM hyperplane discriminating whether or not a facial response occurred. In order to recode this outcome in a measure reflective of actual movement, we averaged AU data across the eight actors and considered values from neutral expressions as baseline for the other three states. This led, for each affective expression (pain, disgust and surprise), to 20 differential AU values, all of which were then used for the creation of templates of facial contractions that were imported in the FACSGen software.

We then created a database of 160 images, characterized by 16 facial identities (8 males) each associated with 10 different expressions: four were "pure" expressions, fully painful, disgusted, surprised and neutral (the last characterized by the absence of any AU response); the remaining six were "hybrid" expressions, resulting from the weighted mean between each combination of two pure states (Pain vs. Neutral; Disgust vs. Neutral; Surprise vs. Neutral; Pain vs. Disgust; Pain vs. Surprise; Disgust vs. Surprise). In particular, each hybrid stimulus was created through ad hoc weightings (e.g., Pain vs. Disgust: 0.35–0.65), to insure that it was as much ambiguous as possible, and that one state was not more easily detectable than the other. The specific weightings and the templates used were validated through an independent population of 20 subjects. Please see Supporting Information Methods S2 for more details.

2.4.2 | Task design

Participants were told that for the majority of trials they were going to first receive an olfactory or thermal stimulation and then to watch and classify facial expressions (classification trials), while for the remaining trials they were going to only receive the olfactory or thermal stimulation and to rate its level of unpleasantness (reference trials). More specifically, the task was organized into two blocks, each comprising of 80 Classification trials and 20 Reference trials, all presented in pseudo-random order, constrained in such way to prevent more than three subsequent HP or HD stimulations.

Each classification trial started with a fixation cross presented on the screen for 0.8 s, followed by a 1.5-s visual cue showing a human nose or an arm. These stimuli were taken from the revised Snodgrass object pictorial data set (Rossion & Pourtois, 2004) and informed about the following olfactory or thermal stimulation. In particular, nose cues predicted either LD or HD olfactory stimulations, whereas arm cues predicted either LP or HP thermal stimulations (Antico et al., 2018). Next, thermal and olfactory stimuli were delivered consistently with an instructed-sniff paradigm (Antico et al., 2018; Delplanque et al., 2009; Sharvit et al., 2018, 2015): Participants were instructed to "Breathe-out" during the numerical countdown of 3 s, and subsequently to "Breathe-in" during the stimulation's delivery, regardless of whether this was painful or disgusting. Both olfactory and thermal stimulations lasted 2 s, although for thermal stimuli additional 3 s were necessary to reach the plateau temperature. Subsequently, we displayed a face for 500 ms. At the bottom of the screen, we indicated the four response options, namely "NEUTRAL," "PAIN," "DISGUST" and "SURPRISE." Participants were asked to respond as accurately as possible with no limit of response time with "1," "2," "3" or "4" keys of the keyboard. Inter-trial interval lasted 4 s. Finally, a 1 s fixation cross appeared on the screen before the start of the next trial (see Figure 1).

During the reference trials, only olfactory and thermal stimulations were delivered with no facial stimuli presentation, and participants had to rate its level of unpleasantness on a visual analogue scale (VAS) ranging from "extremely pleasant" to "extremely unpleasant." Participants had no limit of time for delivering a response with directional keys of the keyboard, which was subsequently recoded as a scalar ranging from +5 to −5. In total, the study had 160 classification trials and 40 reference trials.

2.4.3 | Procedure

Participants listened to the instructions and signed the consent form. Once participants were seated in the lab-chair in front of a computer screen, they were connected to the

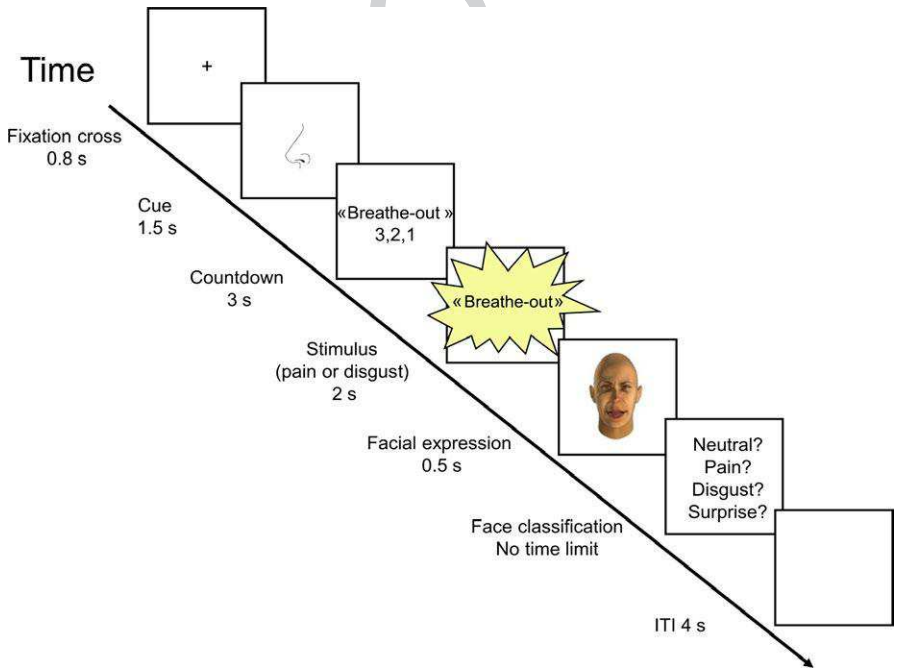

FIGURE 1 Trial structure. Each trial started with a fixation cross presented on the screen for 0.8 s, followed by a 1.5-s visual cue showing a human nose or an arm. Subsequently, one pictorial cue was presented for 1.5 s, predicting only the modality of the upcoming stimulus (thermal or olfactory). Participants were instructed to "breathe-out" during a 3-s countdown and then to "breathe-in" during the stimulus delivery—which could be either olfactory or thermal, consistently with the previous cue. All stimuli lasted 2 s (additional 3 s were necessary for thermal stimuli to reach the target temperature). Next, a face appeared for 500 ms and at the bottom of the screen the four response options, namely "Neutral," "Pain," "Disgust" and "Surprise." Finally, an inter-trial interval lasted 4 s

olfactometer and thermode and carried out stimuli pre-selection sessions as described in Supporting Information Methods S1. Subsequently, participants went through the main experimental session (two blocks of about 30 min each, with a pause of about 5 min in between). The entire experimental procedure lasted about 2 hr. Before and after the experiment, participants were asked to fill the State-Trait Anxiety Inventory (State score, 20 items, Spielberger et al., 1983) to assess changes in transitory level of anxiety due to the manipulation. At home, participants filled two questionnaires: the Beck Depression Inventory (BDI, 13 items, Beck et al., 1961) and the State-Trait Anxiety Inventory (Trait score, 20 items, Spielberger et al., 1983) to assess, respectively, their level of depression and stable aspects of anxiety proneness (Julian, 2011).

2.5 | Data analysis

2.5.1 | Thermal and olfactory stimulations

For each subject, we calculated the median value of each kind of stimulus in the Reference Trials and fed it on a repeated-measures analysis of variance (ANOVA) with Unpleasantness (high vs. low) and Modality (thermal vs. olfactory) as factors. The analysis was conducted with R 3.4.3 freeware software (https://cran.r-project.org/).

2.5.2 | Face classification

We first focused on participants' ability to discriminate 5 pure facial expressions. For this measure, the accuracy rate associated with each condition and the median Response Times for correct responses were fed into a repeated-measures ANOVA with Unpleasantness (high vs. low), Modality (thermal vs. olfactory) and Expression (Neutral, Pain, Disgust and Surprise) as factors. Significant effects associated with Expression were further explored with post hoc paired-sample *t* tests. We also conducted an analysis of the errors associated with the most difficult expressions. Hence, for each subject, and for each expression of interest, we calculated the sum of each kind of erroneous labelling (e.g. the frequency with which pain expressions were misclassified as "neutral," "disgust" or "surprise"). Friedman rank sum test was used to assess whether each expression was more misclassified with one label with respect to the other three. Instead, Wilcoxon sign rank test was used to assess whether specific errors were modulated by the preceding stimulation.

Similar analyses were run for the hybrid expressions. For Response Times, we took the median value associated on each condition and fed it to a repeated-measures ANOVA with Unpleasantness (high vs. low), Modality (thermal vs. olfactory) and Expression (Pain-Neutral, Disgust-Neutral, Surprise-Neutral, Pain-Disgust, Pain-Surprise, Disgust-Surprise) as factors. As these faces are not associated with a 6 clear correct/incorrect answer, the ANOVA was run on all trials. As for the response analysis, we ran the same non-parametric tests used in the analysis of pure classification, with the Wilcoxon sign rank test for pairwise comparisons, and the Friedman rank sum test for analysis of multiple levels factors. Non-parametrical analysis was run using the *coin* package of R 3.4.3 software. Effect sizes were reported as partial *eta-squared* (η_p^2) for ANOVAs, as *Cohen's* $d = \frac{t}{\sqrt{n}}$ for *t* tests. As for non-parametric tests, to our knowledge no effect size measure is available with Friedman rank sum tests, whereas we calculated $r = \frac{z}{\sqrt{n}}$ for pairwise Wilcoxon sign rank tests.

2.5.3 | Physiological responses

In keeping with our previous studies (Antico et al., 2018; Sharvit et al., 2015), we recorded electrodermal, cardiac and respiratory activity associated with thermal and olfactory stimulations. These measures allowed to gather a more comprehensive measure of the responses associated with thermal and olfactory stimulations (on top of explicit ratings) and to monitor participants' inspirations activity during the delivery of odorants. Physiological responses were acquired using the MP150 Biopac Systems (Santa Barbara, CA) with a 1,000 Hz sampling rate, which could reveal also effects of more implicit nature. To measure the electrodermal activity, Beckman Ag-Agcl electrodes (8 mm diameter active area) were filled with an isotonic, 0.05 molar NaCl, electrode paste and placed on the left hand of the participant on the palmar side of the middle phalanges of the second and the third fingers. We filtered the signal with a low-pass filter of 1 Hz and high-pass filter of 0.005 Hz. Cardiac activity was assessed by fixing the Biopac pre-gelled disposable electrodes under the participants' right clavicle and on the left waist. We filtered the signal with a band-pass filter (between 10–30 Hz), detected offline electrocardiographic R waves and then converted intervals between heartbeats into heart rate (HR), expressed in beats per minute. Finally, nose respiration was measured through a 2.5 mm tube (interior diameter) that was positioned at the entrance of the participant's right nostril. This tube was added to the mask used to deliver the odours, and it was connected to a differential pressure transducer (TSD160A; ±2.5 cm H_2O sensitivity range). Within this system, positive values refer to inspiration, whereas negative values refer to expiration. This allowed to record continuously variations in the nostril airflow and to determine nose breathing patterns across different stimulus conditions. This signal was filtered with a low-pass filter of 10 Hz.

For each subject, the time course of each physiological measure was *z*-transformed, down-sampled to 10 Hz and fed into a first level analysis using the general linear model (GLM) framework as implemented in PsPM 3.0.2 (Bach,

Friston, & Dolan, 2013) (http://pspm.sourceforge.net). More specifically, physiological responses associated with thermal and olfactory stimulations were modelled using a finite impulse response (FIR) basis function, which poses no a priori assumption on the properties of the event-related response (see also, Antico et al., 2018; Qiao-Tasserit, Corradi-Dell'Acqua, & Vuilleumier, 2018). In particular, for each kind of stimulus (LD, HD, LP & HD), we modelled the response from the onset of the inspiration countdown (after the cue presentation) with 20 bins of 1 s each, covering the 3-s countdown, and the subsequent 17 s in which stimuli were delivered and rated.

At the group level, for each measure, the parameter estimates (βs) from thermal and olfactory stimulations were fed into a repeated-measures ANOVA with Unpleasantness (low vs. high), Modality (thermal vs. olfactory) and Time (from −3 to +17) as fixed factors. Significant effects associated with factor Time were investigated in exploratory fashion with post hoc paired-sample *t* tests run on each time-bin separately.

3 | RESULTS

Following the experiment, participants exhibited a mild increase in transitory levels of anxiety, as assessed through the S-score of the STAI questionnaire (post vs. pre difference $+3.54 \pm 7.26$, $t_{(27)} = 2.57$, $p = 0.016$, $d = 0.50$).

3.1 | Thermal and olfactory stimulations

The analysis of the pleasantness ratings associated with thermal and olfactory stimuli (from the Reference trials) revealed a significant main effect of Unpleasantness ($F_{1,27} = 124.00$, $p < 0.001$, $\eta_p^2 = 0.82$), with lower pleasantness associated with painful and disgusting stimuli as compared with neutral controls (see Figure 2a). Furthermore, the main effect of Modality ($F_{1,27} = 0.12$, $p = 0.984$,, $\eta_p^2 = 0.004$) and an Unpleasantness*Modality interaction ($F_{1,27} = 3.70$, $p = 0.064$, $\eta_p^2 = 0.12$) were not found to be significant. Finally, planned paired-sample *t* test revealed no difference in unpleasantness between painful (unpleasant thermal) and disgusting (unpleasant olfactory) events ($t_{(27)} = 0.56$, $p = 0.579$, $d = 0.11$).

We analysed electrodermal and cardiac responses to thermal and olfactory stimuli, regardless of whether these involved Reference Trials, or facial classification events. This should allow an unbiased estimate of the overall event-related response, regardless of any confound of the subsequent facial expressions (see Methods). Electrodermal responses revealed significant main effects of Unpleasantness ($F_{1,27} = 7.91$, $p = 0.009$, $\eta_p^2 = 0.23$), Modality ($F_{1,27} = 4.47$, $p = 0.044$, $\eta_p^2 = 0.14$) and Time ($F_{19,513} = 7.42$, $p < 0.001$, $\eta_p^2 = 0.21$). Furthermore, the interactions Unpleasantness*Modality ($F_{1,27} = 19.53$, $p < 0.001$, $\eta_p^2 = 0.42$), Unpleasantness*Time ($F_{19,513} = 9.50$, $p < 0.001$, $\eta_p^2 = 0.26$), Modality*Time ($F_{19,513} = 5.69$, $p < 0.001$, $\eta_p^2 = 0.17$) and Unpleasantness*Modality*Time ($F_{19,513} = 10.82$, $p < 0.001$, $\eta_p^2 = 0.29$) were also found to be significant. We explored these interactions through paired-sample *t* tests testing effects of unpleasantness in each modality and each time-bin. For thermal-evoked activity, we found increased response to unpleasantness only after 4 s from the stimulus onset ($ts_{(27)} \geq 2.14$, $ps \leq 0.042$, $ds \geq 0.40$), whereas this was not the case for earlier time-bins ($ts_{(27)} \leq -0.03$, not significant [n.s.], $ds \leq 0.01$). For olfactory-evoked activity, we found no increased response to unpleasantness in any time-bin ($ts_{(27)} \leq 0.68$, $ps \geq 0.495$, $ds \leq 0.13$, see Figure 2a).

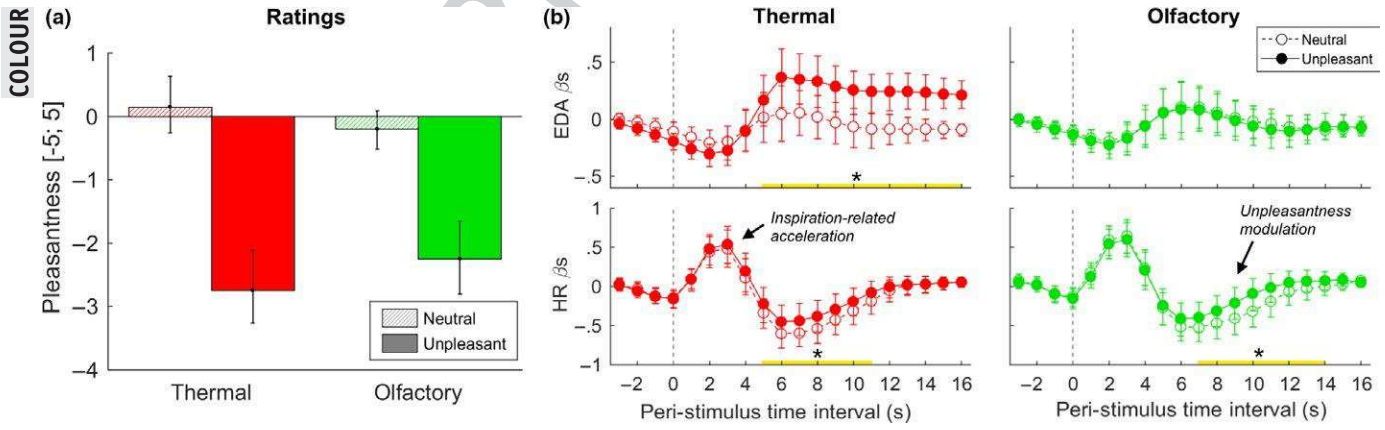

FIGURE 2 Thermal and Olfactory responses. (a) Average pleasantness ratings associated with thermal (red bars) and olfactory (green bars) reference trials. Full-colour bars refer to unpleasant events (painful/disgusting) whereas striped columns refer to neutral controls. (b) Electrodermal (higher subplot) and cardiac (lower subplot) responses associated with thermal (red lines) and olfactory (green lines) stimuli (full dataset). Full circles refer to unpleasant events, whereas empty circles refer to neutral controls. Physiological responses are plotted within a time-window of 20 s, from the 3 s preceding the stimulus onsets (corresponding to the countdown—see methods), to 17 s following the presentation of the stimulus. Error bars refer to bootstrap-based 95% confidence intervals. "*" and horizontal yellow bars refer to time-bins associated with higher signal for Unpleasant > Neutral even at $t_{(27)} \geq 2.05$, corresponding to $p < 0.05$

Cardiac responses revealed instead significant main effects of Unpleasantness ($F_{1,27} = 8.24$, $p = 0.008$, $\eta_p^2 = 0.23$) and Time ($F_{19,513} = 23.66$, $p < 0.001$, $\eta_p^2 = 0.47$), as well as a significant Unpleasantness*Time interaction ($F_{19,513} = 6.26$, $p < 0.001$, $\eta_p^2 = 0.19$). No significant main/interaction effects were associated with the factor Modality ($Fs \leq 3.16$, $ps \geq 0.08$, $\eta_p^2 \leq 0.11$). Paired-sample t tests revealed increased cardiac responses to Unpleasantness between 5 and 11 s from the onsets of the thermal event ($ts_{(27)} \geq 2.13$, $ps \leq 0.043$, $ds \geq 0.40$) and between 7 and 14 s from the onset of the olfactory stimulus ($ts_{(27)} \geq 2.13$, $ps \leq 0.042$, $ds \geq 0.40$). No cardiac increase to Unpleasantness was observed in other time-bins ($ts_{(27)} \leq 1.92$, $ps \geq 0.066$, $ds \leq 0.36$; see Figure 2a). Supporting Information Results S1 reports also data from Respiration volume, which confirms that participants followed the "breathe-in" instruction, with slight decreased inspiratory activity for disgusting odours (see Supporting Information Results S1; see also, Sharvit et al., 2015; Sharvit et al., 2018).

Supporting Information Results (Supporting Information Results S2) describe subsequent analysis investigating the role of Participants' Gender in the sensitivity to thermal/olfactory stimuli. Analysis of Ratings and electrodermal response is suggesting stronger sensitivity of male (but not females) subjects to thermal (relative to olfactory) stimulations. This seems at odds with previous studies suggesting higher pain sensitivity in females (relative to males) (Bartley & Fillingim, 2013; Fillingim, King, Ribeiro-Dasilva, Rahim-Williams, & Riley, 2009; Mattos Feijó et al., 2018), although the unequal and small size of each gender group and the uniqueness of our design might suggest caution in interpreting these effects (e.g., temperatures were not selected exclusively on individual pain thresholds, but also to the extent they were similarly unpleasant with the associated odorants).

3.2 | Classification of pure facial expressions

As a first step, we assessed how individuals' proficiency at classifying pure facial expressions was affected by the preceding stimulation. A repeated-measures ANOVA run on both accuracy rates and response time of correct responses revealed a main effect of Expression (Accuracy: $F_{3,81} = 13.54$, $p < 0.001$, $\eta_p^2 = 0.33$; Response Times: $F_{3,81} = 24.54$, $p < 0.001$, $\eta_p^2 = 0.48$), most likely reflecting an overall difficulty at processing pain and disgust faces (Figure 3a,b), and a Modality*Expression interaction (Accuracy: $F_{3,81} = 3.46$, $p = 0.020$, $\eta_p^2 = 0.11$; Response Times: $F_{3,81} = 4.68$, $p = 0.0248$, $\eta_p^2 = 0.15$). No other main effect/interaction was found to be significant ($Fs \leq 2.83$, $ps \geq 0.104$, $\eta_p^2 \leq 0.09$). We further inspected the interaction by running four paired-sample

COLOUR

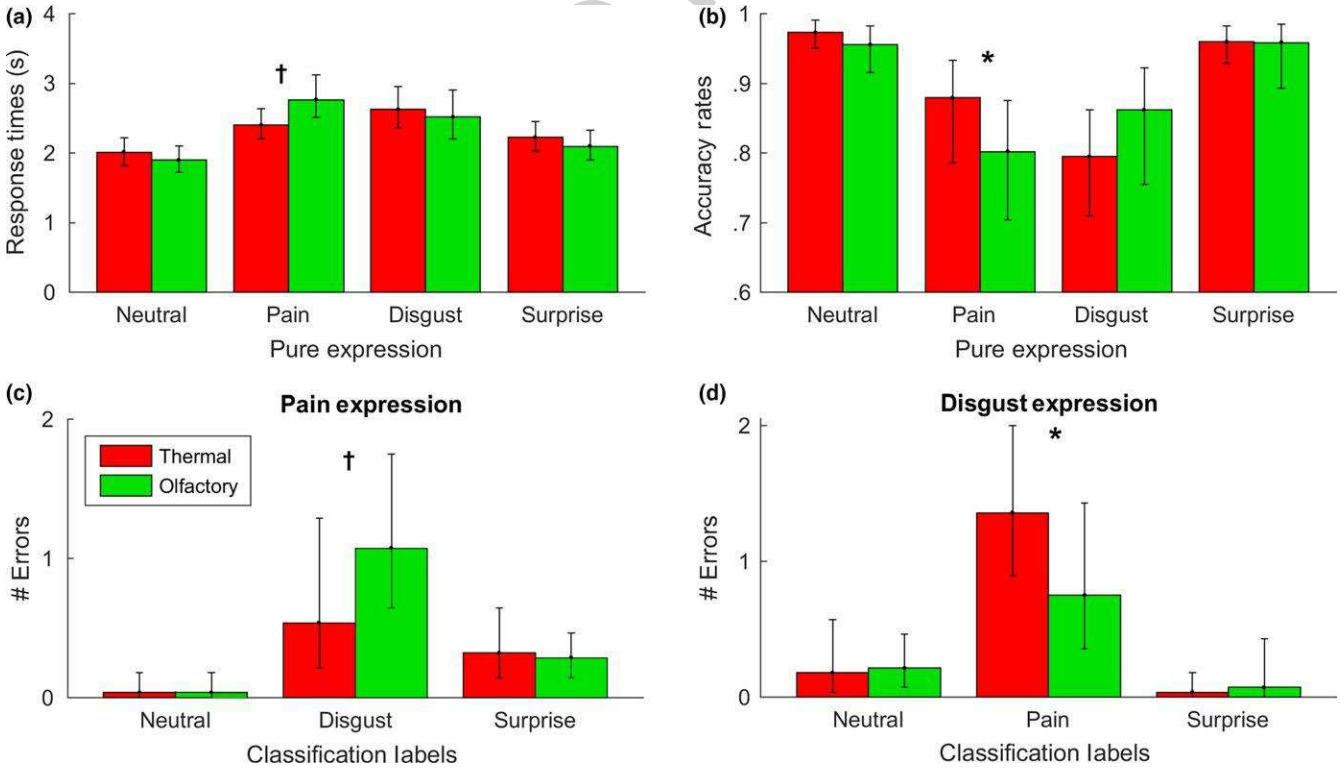

FIGURE 3 Classification of pure facial expressions. (a, b) Average response times and accuracy rates associated with each of the four expressions. (c) Errors analysis: for disgusting (left subplot) and painful (right subplot) expressions, the average amount of instances in which each kind of error occurred. Red bars refer to performance following thermal stimuli, whereas green bars refer to performance following olfactory stimuli. Error bars refer to bootstrap-based 95% confidence intervals. Significant effect of modality are also displayed at $^{*}p < 0.05$, $^{\dagger}p$ *(1-tailed)* <0.05

t tests probing for modality differences in each of the four expressions. Data from both Accuracy and Response Times converge in showing that facial responses of pain were more easily processed if following a thermal (vs. olfactory) stimulus (Accuracy: $t_{(27)} = 1.92$ p *(1-tailed)* $= 0.030$, $d = 0.36$; Response Times: $t_{(27)} = -2.40$, $p = 0.024$, $d = -0.45$). This was not the case for the other expressions ($|ts|_{(27)} \leq 1.63$, $ps \geq 0.114$, $ds \leq 0.31$), although visual inspection of Figure 3a,b might be suggestive an opposite trend for disgust.

We also ran an error analysis using non-parametrical approaches, to ascertain whether low proficiency observed for pain and disgust expressions reflected systematic misclassifications with another label, and whether this misclassification was in turn modulated by the preceding stimulation. For both pain and disgust expressions, we found a main effect of label (Friedman rank sum test for Pain: $\chi^2_{(2)} = 17.63$, $p < 0.001$; Disgust: $\chi^2_{(2)} = 24.59$, $p < 0.001$), reflecting more frequent cases in which pain and disgust were confused with one another, then with either neutral or surprise. Furthermore, the amount of times in which pain and disgust were confused with one another was modulated by the preceding stimulus modality, with disgust expressions misclassified as painful more frequently after thermal (vs. olfactory) stimuli (Wilcoxon sign rank test: $Z = 2.25$, $p = 0.023$, $r = 0.42$), and pain expressions misclassified as disgust marginally more frequently after olfactory (vs. thermal) stimuli ($Z = 1.71$, p *(1-tailed)* $= 0.041$, $r = 0.32$). Erroneous classifications with neutral and surprise were not modulated by the preceding stimulus modality ($|Z| < 0.43$, $p > 0.937$, $r = 0.08$—see Figure 3c).

Overall, these data suggest that the evaluation of others' pain and disgust is confounded by one's pre-existing somatic state. Most importantly, both pain and disgust expressions are equally influenced by the prior stimulus, as the same expressions are classified as painful when following thermal stimuli, and as disgusting when following olfactory events.

3.3 | Classification of hybrid expressions

It could be argued that somatic thermal/olfactory stimulations do not ease the processing of facial expressions per se, but rather facilitate the selection of compatible labels in facial expressions which are most ambiguous. Indeed, although we did not find any Modality effect in neutral and surprise faces, it could be argued that these expressions are classified at ceiling, thus making them inadequate as control. For this reason, we repeated the analysis above on fully ambiguous facial expressions which were hybrid combinations between two states (see Methods).

A repeated-measures ANOVA run on participants' Response Times in the classification of hybrid expressions revealed significant main effects of Expression ($F_{5,135} = 14.02$, $p < 0.001$, $\eta^2_p = 0.34$) and Modality ($F_{1,27} = 9.28$, $p = 0.005$, $\eta^2_p = 0.25$; all other effects $Fs \leq 0.97$, $ps \geq 0.332$, $\eta^2_p = 0.34$). As visible from Figure 4a, hybrid faces are overall slower at being classified following thermal (vs. olfactory) stimulations (especially in disgust–neutral [DN], and pain–disgust [PD] hybrids). The various hybrid expressions were also classified with different speed, with disgust–neutral (DN) faces being the most rapidly processed (average = 2.35 s) and pain–neutral (PN) the most slow (3.20 s). Overall, these response times are comparable, if not larger, to those associated with pure expressions of pain and disgust as shown in Figure 3a.

Table 1 reports how each hybrid was classified in terms of the four possible options. We then assessed whether preceding stimulation modalities influenced the actual classification, by altering the frequency in which one specific choice occurred. We ran an exploratory analysis, testing for each hybrid expression whether each response classification was differentially influenced by the Modality of the previous stimulus. Results are displayed in Figure 4b in matrix format. Overall, pain–disgust (PD) hybrid was the most influenced by the previous stimulation, with more frequent pain responses following thermal stimuli, and most frequent disgust responses following olfactory stimuli (Wilcoxon sign rank test: $|Z| > 3.25$, $p < 0.0007$, $r = 0.61$). Importantly, these effects on PD hybrids survive Bonferroni correction of 24 [4 responses * 6 hybrid expressions] independent tests (critical $p = 0.0021$). Similar effects were observed also for pain–surprise (PS) and disgust–surprise (DS) hybrids ($|Z| > 1.99$, $p < 0.050$, uncorrected, $r = 0.38$). Hybrids involving neutral expression were never found associated with a significant effect of modality.

We then assessed whether the modality–modulation on participants' responses interacted with the expression. In particular, for each subject, each response label, and each hybrid face, the differential amount of responses following thermal versus olfactory stimulations was calculated. Friedman rank sum test revealed no change across the six expressions of the modality effect in neutral or surprise responses ($|\chi^2|_{(5)} \leq 6.80$, $p \geq 0.230$). Instead, a significant modulation was observed for both pain ($\chi^2_{(5)} = 20.19$, $p = 0.001$; see Figure 4c) and disgust responses ($\chi^2_{(5)} = 15.23$, $p = 0.009$; see Figure 4d). Pairwise comparisons confirmed that the modality effect in both pain and disgust responses was stronger for the Pain–Disgust (PD) hybrids than for all other stimuli (pain responses: $Z > 2.36$, $p < 0.017$, $r = 0.45$; disgust responses: $Z > 2.32$, $p < 0.020$, $r = 0.44$). No effect was observed in any of the other pairwise comparisons (pain responses: $|Z| \leq 1.41$, $p \geq 0.171$, $r = 0.27$; disgust responses: $|Z| \leq 1.50$, $p \geq 0.149$, $r = 0.28$).

We then repeated the same exploratory analysis to ascertain whether similar effects could be explained by the preceding stimulation in terms of the Unpleasantness or the

COLOUR

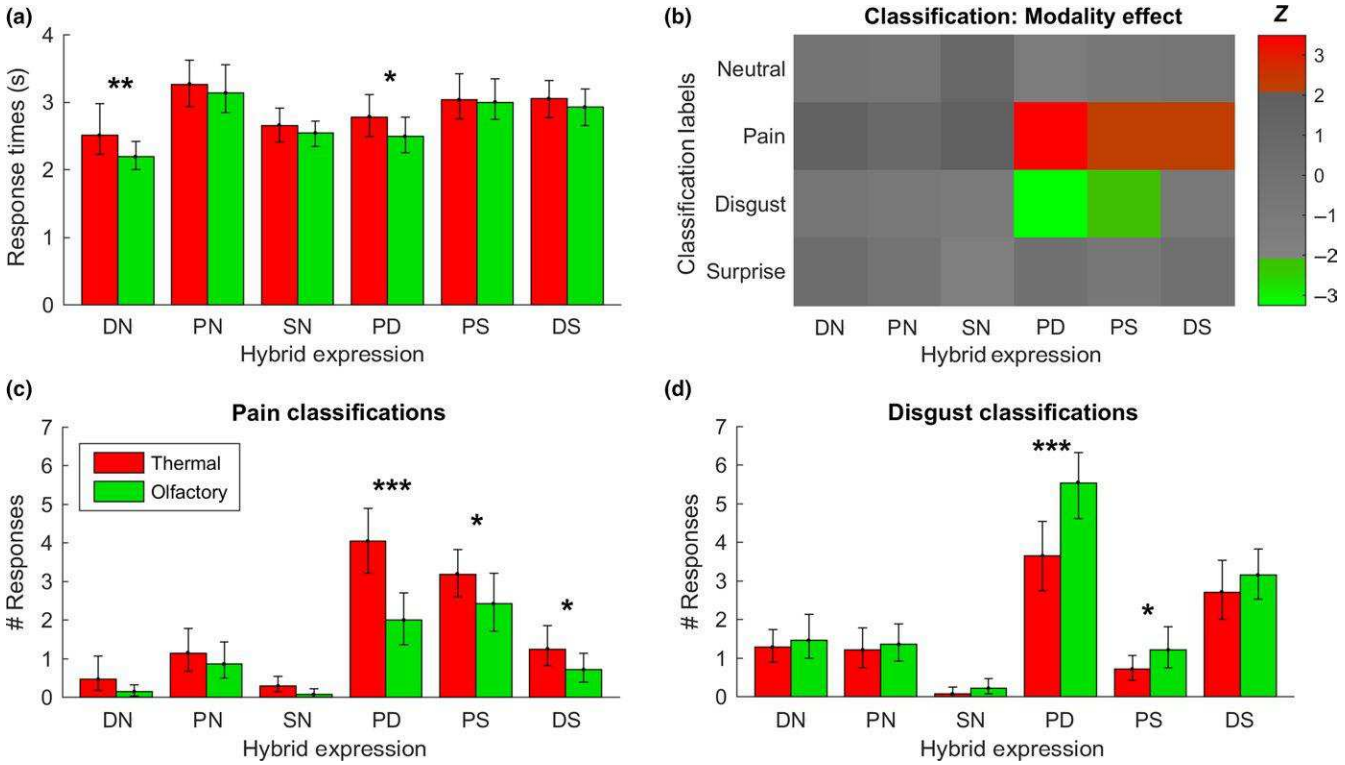

FIGURE 4 Classification of hybrid facial expressions. (a) Average response times associated with each of the six expressions. (b) Matrix of *Z* values obtained by Wilcoxon sign rank tests probing modality differences for each response label, and each expression. Red squares refer to increased number of responses following thermal (vs. olfactory) stimulation, whereas green squares refer increased number of responses following olfactory (vs. thermal) stimulation. Colour luminance refers to the strength of the effect. (c, d) Average amount of pain (left subplot) and disgust (right subplot) responses for each hybrid expression. Red bars refer to performance following thermal stimuli, whereas green bars refer to performance following olfactory stimuli. Error bars refer to bootstrap-based 95% confidence intervals. Significant effects of modality for each expression, following either via *t* test (a) or Wilcoxon sign rank test (c, d), are also displayed at ***$p < 0.001$, **$p < 0.01$ and *$p < 0.05$

TABLE 1 Average classification rates associated with 6 hybrid expressions (bracket values refer to 95% confidence intervals)

	Neutral	Pain	Disgust	Surprise
DN	12.18 (10.96, 13.18)	0.61 (0.21, 1.36)	2.75 (2.00, 3.64)	0.21 (0.07, 0.46)
PN	4.57 (3.54, 5.75)	2.00 (1.32, 3.14)	2.57 (1.75, 3.50)	6.00 (4.79, 7.25)
SN	7.50 (6.14, 8.79)	0.36 (0.18, 0.64)	0.29 (0.11, 0.54)	7.46 (6.14, 8.68)
PD	0.25 (0.11, 0.05)	6.04 (4.86, 7.39)	9.18 (7.68, 10.5)	0.14 (0.04, 0.39)
PS	0.21 (0.07, 0.39)	5.61 (4.50, 7.04)	1.93 (1.25, 2.75)	7.79 (6.57, 9.25)
DS	2.54 (1.68, 3.76)	1.96 (1.36, 2.96)	5.86 (4.68, 7.11)	4.86 (3.82, 6.11)

Note. Grey cells refer to hybrid expressions used in the main experiment together with mean values corresponding to the frequency of the chosen labels.

Unpleasantness*Modality interaction. None of the hybrid expressions showed a significant modulation in any of the response labels ($|Z| \leq 2.00$, $p \geq 0.053$, $r = 0.38$). The only exception was the hybrid PN, which was associated with less "Pain" responses following unpleasant (relative to neutral) events ($Z = -2.58$, $p = 0.012$, $r = -0.49$).

Overall, these data confirm that the evaluation of others' pain and disgust is influenced by the prior stimulus, even when the information is ambiguous. Critically, we found this effect in hybrid expressions that contain pain or disgust information, especially in pain–disgust hybrid, with more frequent pain responses following thermal stimuli, and most frequent disgust responses following olfactory stimuli. Less pronounced effect was found also in hybrids pain–surprise, and disgust–surprise, but not with those involving neutral expressions.

Supplementary Results (Supporting Information Results S2) describe subsequent analyses investigating the role of Participants' Gender and Expressions' Gender in the classification task. The findings suggest a role of Expressions'

Gender, with male models eliciting faster response time than females in specific expressions (e.g., disgust and surprise), and eliciting more frequent pain classifications (and consequent less surprise choices) in PS hybrids. Although not always consistent with one another, these findings are broadly in keeping with the literature, which suggests that emotional and painful expressions are classified more efficiently (Coll et al., 2012; Riva, Sacchi, Montali, & Frigerio, 2011; Simon et al., 2008) and evoked enhanced hemodynamic response (Simon et al., 2006), if conveyed by males (as opposed to female) models. It should be mentioned, however, that our original design involved four repetitions per condition (16 avatars, partitioned to four kinds of stimulations). Analysing the further effect of Expressions' Gender required additional data partitioning, leading to only two repetitions per condition. Hence, caution should be used in interpreting these findings.

4 | DISCUSSION

We investigated whether the appraisal of facial aversive expressions is biased by prior exposure to first-hand experience of the same state. To this end, we subjected participants to thermal (painful) and olfactory (disgusting) stimulations, and subsequently asked them to classify facial expressions of pain, disgust, surprise, neutral states and hybrid combinations thereof. We found that first-hand thermal and olfactory experiences influenced the subsequent evaluation of facial expressions, with thermal stimuli increasing the amount of pain classifications, and olfactory events increasing the amount of disgust classifications. This modulation was found prevalently for those faces containing traits diagnostic of pain and disgust (pure expressions and pain–disgust hybrids), but did not generalize to the remaining stimuli, including other hybrids purposefully designed to be ambiguous. Whereas some expressions (neutral and surprise, plus neutral-related hybrids) were unaffected by the prior stimulation, others (pain–surprise and disgust–surprise hybrids) showed an influence which was smaller than that observed for pain–disgust combinations, as revealed by interaction analysis.

4.1 | Effects of first-hand experiences on the appraisal of facial expressions

Extended literature has proven that the appraisal of others' facial expressions can influence, and is influenced by, first-hand experiences of the same state. For instance, exposing individuals to emotionally valenced videos is known to affect subsequent processing of ambiguous expressions, with induced happiness, anger or sadness enhancing one's sensitivity towards facial traits diagnostic of homologous states (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Qiao-Tasserit et al., 2017). A similar effect has been described also in the domain of pain, with noxious events enhancing the sensitivity to facial expressions of pain and *vice versa* (Coll et al., 2012; Godinho et al., 2012; Reicherts et al., 2013; Vachon-Presseau et al., 2011, see also, Wieser et al., 2014, as a review). These findings are reminiscent of the results from sequential priming tasks, where participants evaluate a target stimulus (e.g., facial expression) while avoiding any influence of a previous event (first-hand pain). Within this structure, *unintentional contagion* is provided by the degree to which participants mistakenly evaluate the to-be-ignored event at the expense of the target (Cameron, Spring, & Todd, 2017). However, it is unclear whether such unintentional contagion influences specifically the appraisal of others' pain or generalizes to stimuli conveying also painless states. The former case would reflect the engagement of a pain-specific representation shared between oneself and others, whereas the latter case would reflect a supramodal coding shared between different states. Unfortunately, the literature does not provide clear answer, as first-hand pain seems to decrease sensitivity to positive expressions, but at the same time exerts unsystematic effects on negative states like fear or anger, with some studies proposing exacerbation, whereas other a lack of influence (Gerdes, Wieser, Alpers, Strack, & Pauli, 2012; Reicherts et al., 2013; Wieser, Gerdes, Greiner, Reicherts, & Pauli, 2012, see also Wieser et al., 2014, as review).

A potential confound could lie in the fact that, whereas affective states are usually treated as qualitatively distinct entities, muscular changes in the face occur along continuous dimensions, and consequently, the expressions used as stimuli are often only characterized by subtle configurational changes. For instance, in the most commonly used stimuli databases (Goeleven, Raedt, Leyman, & Verschuere, 2008; Simon et al., 2008), fear and anger are depicted through contractions at the level of the frown that underlie also pain. In this perspective, it is possible that nociception induces unintentional contagion whenever participants are confronted with facial traits which are potentially diagnostic of pain, but could be observed in less pronounced/systematic fashion also in other states. Our results provide evidence in this direction, as they reveal that first-hand thermal stimulations influence the appraisal of both pain and disgust faces, but not surprise (unless combined with pain or disgust). Furthermore, the same expressions are influenced in opposite (but comparable in magnitude) direction by first-hand olfactory stimulations. Hence, both first-hand thermal and olfactory events lead to unintentional contagion towards facial traits which characterize both pain and disgust, highlighting a major role played by a supramodal coding common between these two experiences.

4.2 | Common coding between pain and disgust

Our findings are in keeping with recent neuroimaging research suggesting that first-hand and others' aversive experiences evoke shared activity patterns in insular and cingulate cortex, which code for supramodal properties common to pain, disgust and even unfair treatments (Corradi-Dell'Acqua et al., 2016). However, the nature of these supramodal coding is still unclear. Provided that, in the present study, thermal and olfactory stimuli were calibrated individually in terms of unpleasantness, it is highly plausible that the cross-modal effect observed reflects such dimension. Alternative interpretations are possible (at least in principle), under the assumption that matched unpleasantness would indirectly lead to comparable levels also in other affective components, such as arousal. We believe this conjecture to be unlikely. Indeed, in a previous study employing the same unpleasantness–calibration approach, pain was associated with stronger levels of self-reported fear and anxiety than disgust (Sharvit et al., 2015). Likewise, in both present and earlier studies, electrodermal responses to pain were much stronger than those associated with comparably unpleasant disgust (Antico et al., 2018; Sharvit et al., 2015). Hence, matched unpleasantness does not necessarily imply similar levels in other facets of the affective response, especially when considering measures like electrodermal activity that have been suggested to reflect autonomic arousal (see Sharvit et al., 2015, for a discussion on this issue). Most importantly, although in the present study we did not measure arousal directly, we believe that this dimension might not explain our results in satisfactory way. Indeed, if the arousal evoked by thermal events affected the appraisal of facial expressions, then such influence should involve primarily faces of pain, surprise and pain–surprise hybrids, something that we did not see in the present research.

It should be noted that pain is a heterogeneous experience, which is characterized by an acute nociceptive component, as well as by secondary affective responses associated with the appraisal of the context, the assessment of actual or potential body damage, and the preparation of potential coping responses (Price, 2000). Similar appraisal levels can be observed also for chemosensory disgust, although in this case individuals assess threats for ones' health in terms of poisoning, intoxication, contamination or disease (Rozin & Fallon, 1987; Rozin, Haidt, & McCauley, 1993). To our knowledge, no study systematically compared pain and disgust in terms of contextual evaluation (appraisal-based models of emotions never focused on pain; Scherer, 2009); however, it is reasonable to conceive that pain and disgust share, not only an intrinsic unpleasantness, but also an evaluation of potential risks for one's well-being, something that is not necessarily observed for other negative states (e.g., sadness). This conjecture might also explain why pain and disgust share such similarity in face responses (Kunz, Peter, Huster, & Lautenbacher, 2013; Simon et al., 2008), as appraisal-based models of emotions suggest that facial expressions might not reflect the occurrence of a specific state, but rather the underlying evaluation of the context in terms of predictability, implication for one's goals, ability to control potential outcomes, etc. (Scherer, Mortillaro, Rotondi, Sergi, & Trznadel, 2018; Sergi, Fiorentini, Trznadel, & Scherer, 2016). Future studies will need to compare systematically the appraisal levels of pain with that associated with different emotional states, in order to identify potential degrees of similarity that might explain the cross-modal effect observed here.

4.3 | Limitations of the study and conclusive remarks

Despite calibration efforts in making pain and disgust as matched as possible, disgusting odours seem marginally (although not-significantly) less unpleasant than painful temperatures (see Results section). Discrepancies between the experimental session and the calibration procedure could be related to habituation, with sensitivity to given odorants decreasing rapidly during the task. However, potential modality differences in unpleasantness do not undermine the main result of the study that both pain and disgust influence in comparable fashion (but opposite direction) the evaluation of others' facial expressions. Furthermore, first-hand experiences influenced the appraisal of others' states only in terms of modality (temperature vs. odours), and not in terms of unpleasantness*modality interaction (pain vs. disgust), as would be expected. Hence, neutral thermal/olfactory events contributed to the effects reported in this study, with no statistical difference from their unpleasant counterparts. This might be partially influenced by the expectancy cue informing about the modality (but not the unpleasantness) of the upcoming stimulation (as in Antico et al., 2018). It is possible that bottom-up information about stimulation unpleasantness was not sufficiently strong to affect individuals' classification of facial expressions, as it affected instead cardiac responses and explicit ratings in reference trials (Figure 2). Future studies will need to disentangle expectancy- from stimulus-related components of pain and disgust.

Notwithstanding these limitations, our study provides clear evidence that the subjective experiences related to pain and disgust influence the appraisal of those facial traits common between the two states. These findings provide the strong causal support to accounts suggesting that a reliable part of the representation shared between oneself and others' is supramodal in nature, possibly relating to unpleasantness coding.

ACKNOWLEDGEMENTS

We like to thank Sylvain Delplanque and Gil Sharvit for their assistance in relation to all aspects of olfactory and thermal stimulations, Lucas Tamarit for technical support on the FACSGen software, and Heather Carlson for overseeing the quality of the English text.

CONFLICT OF INTEREST

None declared.

AUTHOR CONTRIBUTIONS

L. Antico and C. Corradi-Dell'Acqua developed the study concept and contributed to the study design. Testing and data collection were performed by L. Antico and E. Cataldo. L. Antico performed the data analysis and interpretation under the supervision of C. Corradi-Dell'Acqua. L. Antico drafted the manuscript, and C. Corradi-Dell'Acqua provided critical revisions. All authors approved the final version of the manuscript for submission.

REFERENCES

Antico, L., Guyon, A., Mohamed, Z. K., & Corradi-Dell'Acqua, C. (2018). Beyond unpleasantness. Social exclusion affects the experience of pain, but not of equally-unpleasant disgust. *Cognition*, *181*, 1–11. https://doi.org/10.1016/j.cognition.2018.08.002

Avenanti, A., Bueti, D., Galati, G., & Aglioti, S. M. (2005). Transcranial magnetic stimulation highlights the sensorimotor side of empathy for pain. *Nature Neuroscience*, *8*, 955–960. https://doi.org/10.1038/nn1481

Bach, D. R., Friston, K. J., & Dolan, R. J. (2013). An improved algorithm for model-based analysis of evoked skin conductance responses. *Biological Psychology*, *94*, 490–497. https://doi.org/10.1016/j.biopsycho.2013.09.010

Bartley, E. J., & Fillingim, R. B. (2013). Sex differences in pain: A brief review of clinical and experimental findings. *British Journal of Anaesthesia*, *111*, 52–58. https://doi.org/10.1093/bja/aet127

Beck, A. T., Steer, R. A., & Carbin, M. G. (1988). Psychometric properties of the Beck Depression Inventory: Twenty-five years of evaluation. *Clinical Psychology Review*, *8*, 77–100. https://doi.org/10.1016/0272-7358(88)90050-5

Beck, A. T., Ward, C. H., Mendelson, M., Mock, J., & Erbaugh, J. (1961). An Inventory for Measuring Depression. *Archives of General Psychiatry*, *4*, 561–571. https://doi.org/10.1001/archpsyc.1961.01710120031004

Braboszcz, C., Brandao-Farinelli, E., & Vuilleumier, P. (2017). Hypnotic analgesia reduces brain responses to pain seen in others. *Scientific Reports*, *7*, 9778. https://doi.org/10.1038/s41598-017-10310-4

Cameron, C. D., Spring, V. L., & Todd, A. R. (2017). The empathy impulse: A multinomial model of intentional and unintentional empathy for pain. *Emotion*, *17*, 395–411. https://doi.org/10.1037/emo0000266

Chrea, C., Grandjean, D., Delplanque, S., Cayeux, I., Le Calvé, B., Aymard, L., … Scherer, K. R. (2009). Mapping the semantic space for the subjective experience of emotional responses to odors. *Chemical Senses*, *34*, 49–62. https://doi.org/10.1093/chemse/bjn052

Coll, M.-P., Budell, L., Rainville, P., Decety, J., & Jackson, P. L. (2012). The role of gender in the interaction between self-pain and the perception of pain in others. *Journal of Pain*, *13*, 695–703. https://doi.org/10.1016/j.jpain.2012.04.009

Corradi-Dell'Acqua, C., Hofstetter, C., & Vuilleumier, P. (2011). Felt and seen pain evoke the same local patterns of cortical activity in insular and cingulate cortex. *Journal of Neuroscience*, *31*, 17996–18006. https://doi.org/10.1523/JNEUROSCI.2686-11.2011

Corradi-Dell'Acqua, C., Tusche, A., Vuilleumier, P., & Singer, T. (2016). Cross-modal representations of first-hand and vicarious pain, disgust and fairness in insular and cingulate cortex. *Nature Communications*, *7*, 10904. https://doi.org/10.1038/ncomms10904

Danziger, N., Faillenot, I., & Peyron, R. (2009). Can we share a pain we never felt? Neural correlates of empathy in patients with congenital insensitivity to pain. *Neuron*, *61*, 203–212. https://doi.org/10.1016/j.neuron.2008.11.023

Delplanque, S., Grandjean, D., Chrea, C., Aymard, L., Cayeux, I., Le Calvé, B., … Sander, D. (2008). Emotional processing of odors: Evidence for a nonlinear relation between pleasantness and familiarity evaluations. *Chemical Senses*, *33*, 469–479. https://doi.org/10.1093/chemse/bjn014

Delplanque, S., Grandjean, D., Chrea, C., Coppin, G., Aymard, L., Cayeux, I., … Scherer, K. R. (2009). Sequential unfolding of novelty and pleasantness appraisals of odors: Evidence from facial electromyography and autonomic reactions. *Emotion*, *9*, 316–328. https://doi.org/10.1037/a0015369

Fillingim, R. B., King, C. D., Ribeiro-Dasilva, M. C., Rahim-Williams, B., & Riley, J. L. (2009). Sex, gender, and pain: A review of recent clinical and experimental findings. *Journal of Pain*, *10*, 447–485. https://doi.org/10.1016/j.jpain.2008.12.001

Gerdes, A. B. M., Wieser, M. J., Alpers, G. W., Strack, F., & Pauli, P. (2012). Why do you smile at me while I'm in pain? — Pain selectively modulates voluntary facial muscle responses to happy faces. *International Journal of Psychophysiology*, *85*, 161–167. https://doi.org/10.1016/j.ijpsycho.2012.06.002

Godinho, F., Faillenot, I., Perchet, C., Frot, M., Magnin, M., & Garcia-Larrea, L. (2012). How the pain of others enhances our pain: Searching the cerebral correlates of 'compassional hyperalgesia'. *European Journal of Pain*, *16*, 748–759. https://doi.org/10.1002/j.1532-2149.2011.00039.x

Goeleven, E., De Raedt, R., Leyman, L., & Verschuere, B. (2008). The Karolinska directed emotional faces: A validation study. *Cognition & Emotion*, *22*, 1094–1118. https://doi.org/10.1080/02699930701626582

Iannetti, G. D., & Mouraux, A. (2010). From the neuromatrix to the pain matrix (and back). *Experimental Brain Research*, *205*, 1–12. https://doi.org/10.1007/s00221-010-2340-1

Ischer, M., Baron, N., Mermoud, C., Cayeux, I., Porcherot, C., Sander, D., & Delplanque, S. (2014). How incorporation of scents could enhance immersive virtual experiences. *Frontiers in Psychology*, *5*, 736. https://doi.org/10.3389/fpsyg.2014.00736

Julian, L. J. (2011). Measures of anxiety: State-Trait Anxiety Inventory (STAI), Beck Anxiety Inventory (BAI), and Hospital Anxiety and Depression Scale-Anxiety (HADS-A). *Arthritis Care & Research*, *63*, S467–S472. https://doi.org/10.1002/acr.20561

Klein, T. A., Endrass, T., Kathmann, N., Neumann, J., von Cramon, D. Y., & Ullsperger, M. (2007). Neural correlates of error

awareness. *Neuroimage*, *34*, 1774–1781. https://doi.org/10.1016/j.neuroimage.2006.11.014

Krishnan, A., Woo, C.-W., Chang, L. J., Ruzic, L., Gu, X., López-Solà, M., … Wager, T. D. (2016). Somatic and vicarious pain are represented by dissociable multivariate brain patterns. *Elife*, *5*, e15166. https://doi.org/10.7554/eLife.15166

Kunz, M., Peter, J., Huster, S., & Lautenbacher, S.. (2013). Pain and disgust: The facial signaling of two aversive bodily experiences. *PLoS ONE*, *8*, e83277. https://doi.org/10.1371/journal.pone.0083277

Lamm, C., Decety, J., & Singer, T. (2011). Meta-analytic evidence for common and distinct neural networks associated with directly experienced pain and empathy for pain. *Neuroimage*, *54*, 2492–2502. https://doi.org/10.1016/j.neuroimage.2010.10.014

Littlewort, G., Whitehill, J., Wu, T., Fasel, I., Frank, M., Movellan, J., & Bartlett, M. (2011). The computer expression recognition toolbox (CERT). In Automatic Face & Gesture Recognition and Workshops (FG 2011), 2011 IEEE International Conference On, (IEEE), pp. 298–305.

Mailhot, J.-P., Vachon-Presseau, E., Jackson, P. L., & Rainville, P. (2012). Dispositional empathy modulates vicarious effects of dynamic pain expressions on spinal nociception, facial responses and acute pain. *European Journal of Neuroscience*, *35*, 271–278. https://doi.org/10.1111/j.1460-9568.2011.07953.x

Mattos Feijó, L., Tarman, G. Z., Fontaine, C., Harrison, R., Johnstone, T., & Salomons, T. (2018). Sex-specific effects of gender identification on pain study recruitment. *Journal of Pain*, *19*, 178–185. https://doi.org/10.1016/j.jpain.2017.09.009

Mischkowski, D., Crocker, J., & Way, B. M. (2016). From painkiller to empathy killer: Acetaminophen (paracetamol) reduces empathy for pain. *Social Cognitive and Affective Neuroscience*, *11*, 1345–1353. https://doi.org/10.1093/scan/nsw057

Niedenthal, P. M., Brauer, M., Halberstadt, J. B., & Innes-Ker, Å. H. (2001). When did her smile drop? Facial mimicry and the influences of emotional state on the detection of change in emotional expression. *Cognition & Emotion*, *15*, 853–864. https://doi.org/10.1080/02699930143000194

Preuschoff, K., Bossaerts, P., & Quartz, S. R. (2006). Neural differentiation of expected reward and risk in human subcortical structures. *Neuron*, *51*, 381–390. https://doi.org/10.1016/j.neuron.2006.06.024

Price, D. D. (2000). Psychological and neural mechanisms of the affective dimension of pain. *Science*, *288*, 1769–1772. https://doi.org/10.1126/science.288.5472.1769

Qiao-Tasserit, E., Corradi-Dell'Acqua, C., & Vuilleumier, P. (2018). The good, the bad, and the suffering. Transient emotional episodes modulate the neural circuits of pain and empathy. *Neuropsychologia*, *116*, 99–116. https://doi.org/10.1016/j.neuropsychologia.2017.12.027

Qiao-Tasserit, E., Garcia Quesada, M., Antico, L., Bavelier, D., Vuilleumier, P., & Pichon, S. (2017). Transient emotional events and individual affective traits affect emotion recognition in a perceptual decision-making task. *PLoS ONE*, *12*, e0171375. https://doi.org/10.1371/journal.pone.0171375

Reicherts, P., Gerdes, A. B. M., Pauli, P., & Wieser, M. J. (2013). On the mutual effects of pain and emotion: Facial pain expressions enhance pain perception and vice versa are perceived as more arousing when feeling pain. *Pain*, *154*, 793–800. https://doi.org/10.1016/j.pain.2013.02.012

Riva, P., Sacchi, S., Montali, L., & Frigerio, A. (2011). Gender effects in pain detection: Speed and accuracy in decoding female and male pain expressions. *European Journal of Pain*, *15*, 985.e1–985.e11. https://doi.org/10.1016/j.ejpain.2011.02.006

Roesch, E. B., Tamarit, L., Reveret, L., Grandjean, D., Sander, D., & Scherer, K. R. (2011). FACSGen: A tool to synthesize emotional facial expressions through systematic manipulation of facial action units. *Journal of Nonverbal Behavior*, *35*, 1–16. https://doi.org/10.1007/s10919-010-0095-9

Rossion, B., & Pourtois, G.. (2004). Revisiting Snodgrass and Vanderwart's object pictorial set: The role of surface detail in basic-level object recognition. *Perception*, *33*, 217–236. https://doi.org/10.1068/p5117

Rozin, P., & Fallon, A. E. (1987). A perspective on disgust. *Psychological Review*, *94*, 23. https://doi.org/10.1037/0033-295X.94.1.23

Rozin, P., Haidt, J., & McCauley, C. R. (1993). Disgust. In M. Lewis & J. M. Harviland (Eds.), *Handbook of Emotions* (pp. 575–594). New York, NY: Guilford Press.

Rütgen, M., Seidel, E.-M., Silani, G., Riečanský, I., Hummer, A., Windischberger, C., … Lamm, C. (2015). Placebo analgesia and its opioidergic regulation suggest that empathy for pain is grounded in self pain. *Proceedings of the National Academy of Sciences*, *112*, E5638–E5646. https://doi.org/10.1073/pnas.1511269112

Scherer, K. R. (2009). The dynamic architecture of emotion: Evidence for the component process model. *Cognition & Emotion*, *23*, 1307–1351. https://doi.org/10.1080/02699930902928969

Scherer, K. R., Mortillaro, M., Rotondi, I., Sergi, I., & Trznadel, S. (2018). Appraisal-driven facial actions as building blocks for emotion inference. *Journal of Personality and Social Psychology*, *114*, 358. https://doi.org/10.1037/pspa0000107

Sergi, I., Fiorentini, C., Trznadel, S., & Scherer, K. R. (2016). Appraisal inference from synthetic facial expressions. *International Journal of Synthetic Emotions*, *7*, 45–61. https://doi.org/10.4018/IJSE.2016070103

Sharvit, G., Corradi-Dell'Acqua, C., & Vuilleumier, P. (2018). Modality-specific effects of aversive expectancy in anterior insula and medial prefrontal cortex. *Pain*, *159*, 1529–1542.

Sharvit, G., Vuilleumier, P., Delplanque, S., & Corradi-Dell'Acqua, C. (2015). Cross-modal and modality-specific expectancy effects between pain and disgust. *Scientific Reports*, *5*, 17487. https://doi.org/10.1038/srep17487

Simon, D., Craig, K. D., Gosselin, F., Belin, P., & Rainville, P. (2008). Recognition and discrimination of prototypical dynamic expressions of pain and emotions. *Pain*, *135*, 55–64. https://doi.org/10.1016/j.pain.2007.05.008

Simon, D., Craig, K. D., Miltner, W. H. R., & Rainville, P. (2006). Brain responses to dynamic facial expressions of pain. *Pain*, *126*, 309–318. https://doi.org/10.1016/j.pain.2006.08.033

Singer, T., Seymour, B., O'Doherty, J., Kaube, H., Dolan, R. J., & Frith, C. D. (2004). Empathy for pain involves the affective but not sensory components of pain. *Science*, *303*, 1157–1162. https://doi.org/10.1126/science.1093535

Spielberger, C. D., Gorsuch, R. L., Lushene, R. E., Vagg, P. R., & Jacobs, G. A. (1983). *Manual for the state-trait anxiety inventory*. Palo Alto, CA: Consulting Psychologists Press, Inc.

Vachon-Presseau, E., Martel, M. O., Roy, M., Caron, E., Jackson, P. L., & Rainville, P. (2011). The multilevel organization of vicarious pain responses: Effects of pain cues and empathy traits on spinal nociception and acute pain. *Pain*, *152*, 1525–1531. https://doi.org/10.1016/j.pain.2011.02.039

Wicker, B., Keysers, C., Plailly, J., Royet, J. P., Gallese, V., & Rizzolatti, G. (2003). Both of us disgusted in My insula: The common neural basis of seeing and feeling disgust. *Neuron*, *40*, 655–664. https://doi.org/10.1016/S0896-6273(03)00679-2

Wieser, M. J., Gerdes, A. B. M., Greiner, R., Reicherts, P., & Pauli, P. (2012). Tonic pain grabs attention, but leaves the processing of facial expressions intact—Evidence from event-related brain potentials. *Biological Psychology*, *90*, 242–248. https://doi.org/10.1016/j.biopsycho.2012.03.019

Wieser, M. J., Gerdes, A. B. M., Reicherts, P., & Pauli, P. (2014). Mutual influences of pain and emotional face processing. *Frontiers in Psychology*, *5*, 1160. https://doi.org/10.3389/fpsyg.2014.01160

SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section at the end of the article.

How to cite this article: Antico L, Cataldo E, Corradi-Dell'Acqua C. Does my pain affect your disgust? Cross-modal influence of first-hand aversive experiences in the appraisal of others' facial expressions. *Eur J Pain*. 2019;00:1–14. https://doi.org/10.1002/ejp.1390