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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

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ABSTRACT

Perception of emotional stimuli alters the perception of pain. Although facial expressions are powerful emotional cues – the expression of pain especially plays a crucial role for the experience and communication of pain – research on their influence on pain perception is scarce. In addition, the opposite effect of pain on the processing of emotion has been elucidated even less. To further scrutinize mutual influences of emotion and pain, 22 participants were administered painful and nonpainful thermal stimuli while watching dynamic facial expressions depicting joy, fear, pain, and a neutral expression. As a control condition of low visual complexity, a central fixation cross was presented. Participants rated the intensity of the thermal stimuli and evaluated valence and arousal of the facial expressions. In addition, facial electromyography was recorded as an index of emotion and pain perception. Results show that faces per se, compared to the low-level control condition, decreased pain, suggesting a general attention modulation of pain by complex (social) stimuli. The facial response to painful stimulation revealed a significant correlation with pain intensity ratings. Most important, painful thermal stimuli increased the arousal of simultaneously presented pain expressions, and in turn, pain expressions resulted in higher pain ratings compared to all other facial expressions. These findings demonstrate that the modulation of pain and emotion is bidirectional with pain faces being mostly prone to having mutual influences, and support the view of interconnections between pain and emotion. Furthermore, the special relevance of pain faces for the processing of pain was demonstrated.

1. Introduction

Emotions and pain are highly interconnected [37] and represented in widely overlapping networks of the human brain [49]. These shared neural networks most likely constitute the biological substrates of pain-modulating effects of emotions [51].

The influence of various affective stimuli like affective pictures [17,18,28,36], pain-related pictures [11], or odors [48] on pain has been demonstrated such that negative emotions lead to increased pain perception, while positive emotions result in decreased pain perception. However, a crucial feature in nonverbal emotion communication – facial expressions – has been widely neglected so far. Only recently, emotional compared to neutral facial expressions have been demonstrated to increase pain perception accompanied by alterations of pain-related brain oscillations [39]. Similarly, pain, compared to neutral, expressions were found to augment pain perception [27], however, the opposite effect of pain on emotion was not quantified.

Research on the impact of pain on emotion processing is rather scarce. One study found that pain led to decreased pleasantness ratings of positive pictures, while negative pictures were unaffected [12]. Likewise, it was observed that pain disrupts performance in an emotional evaluation task for happy faces only, while fearful faces remained unaffected [10]. Also, a current study addressing the influence of pain on face processing showed attention effects of pain, but no modulation of emotion-related brain potentials [52].

Pain and emotion both come along with distinct facial expressions [8,19,32,33,54]. Pain expressions, in particular, are supposed to be of great importance for social interactions [3,14] and for the communication of danger and sorrow. Moreover, pain faces receive elevated cortical processing compared to other facial expressions [13,35], which points at a special relevance of facial pain expressions.

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However, the influence of pain faces on pain processing and the opposite effect has not yet been systematically investigated.

Consequently, in the present study we aimed at elucidating the mutual influence of pain and emotional face processing, with a special focus on the expression of pain. Spontaneous, subtle facial reactions can be reliably measured by facial electromyography (EMG) in response to emotional stimuli, thus providing a suitable measure of emotion processing on the one hand [5,7,25,35,50] and pain processing on the other hand [23,27]. Therefore, we recorded facial EMG in response to dynamic facial expressions of pain, fear, joy, and a neutral expression during painful and nonpainful thermal stimulation. To disentangle emotional from attentional pain modulation, we also presented fixation crosses as a low-level control condition. To document pain modulation by emotion, each thermal stimulus was to be rated regarding its intensity, while alterations of emotion processing should be reflected in ratings of valence and arousal of each video. In addition, to control for potential modulation by state or trait variables, psychometric key measures were assessed. We assumed that negative emotional faces result in increased pain perception, with pain faces having the greatest effect. In addition, thermal heat pain was hypothesized to alter implicit (EMG) and explicit (valence and arousal ratings) measures of emotion processing.

2. Method

2.1. Participants

Twenty-four participants were recruited from the University of Würzburg and received course credit or €12 as compensation. None of them had taken any analgesic medication or alcohol for at least 12 hours prior to the test session (self-report). Two participants were excluded from further analysis due to psychopharmacological medication and vision disorder. All 22 remaining subjects (age M = 21.47 years, SD = 2.21; 17 women) had normal or corrected-to-normal vision, and no current or prior history of chronic pain, or neurological or psychiatric disorders (self-report). Participants were given a detailed explanation of the experimental procedure and signed a written informed consent before participating in the study. Participants filled out questionnaires on candid psychological variables that were found to impact emotion processing, such as state and trait anxiety (State-Trait Anxiety Inventory-T/S [24,42]), altered pain processing such as pain catastrophizing (Pain Catastrophizing Scale [29,43]), and that could have an influence on pain-related as well as emotion-related measures, such as dispositional empathy (Saarbrücker Persönlichkeitsfragebogen, German version of the Interpersonal Reactivity Index [4,31]). Furthermore, sociodemographic information and personal attitudes towards pain were collected. The experimental procedure was approved by the institutional review board of the medical faculty of the University of Würzburg.

2.2. Video stimuli

Affective stimuli consisted of joy, pain, fear, and neutral facial expressions (displayed by 4 male and 4 female actors) that were taken from a database of 1-second video clips [40]. A total of 128 videos and, additionally, 32 control trials (fixation cross) were randomly shown.

2.3. Thermal pain

Thermal heat stimuli were delivered using a Somedic MSA thermal stimulator (Somedic Sales AB, Hörby, Sweden) and a Peltier thermode with an active surface of 25 × 50 mm. The thermode was attached to the volar forearm of the nondominant hand. The individual thermal pain thresholds were assessed by applying 10 trials of gradually increasing temperature (1°C/second) from a baseline of 32°C; participants were asked to stop the stimulus delivery by a button press as soon as they felt pain. The average pain threshold temperature was M = 42.48°C, SD = 2.87. The individual thermal pain threshold was used as painful stimulus, whereas the same temperature minus 2°C was used as nonpainful stimulus in the following experimental session. During the actual experiment, heat stimuli were applied at a heating rate of 5°C/second starting from a baseline that was defined as 10°C lower than the individual pain threshold temperature. After 50 and 100 trials, the experimenter changed the position of the thermode on the participant's forearm (position order was counterbalanced across participants).

2.4. EMG measurement

EMG was recorded from *M. corrugator supercilii*, *M. orbicularis oculi*, and *M. zygomaticus major* on the left side of the face [6] using bipolar montages of 13/7-mm Ag/AgCl surface-electrodes according to the guidelines established by Fridlund and Cacioppo [9]. The EMG raw signal was measured with a V-Amp amplifier (Brain Products Inc., Munich, Germany) at a sampling rate of 1000 Hz. Raw signals were rectified and filtered off-line with a 30-Hz high-pass, a 500-Hz low-pass, a 50-Hz notch, and a 125-ms moving average filter. Visual stimulus-evoked EMG activity was scored as the mean activity during 2 time windows (0–1000 ms and 1000–2000 ms after video stimulus onset) as change in activity from a 1000-ms prestimulus baseline. Intervals were chosen due to a potential response delay when using dynamic stimuli [50], which in the present case show the peak of the target expression close to the stimulus end at about 1000 ms. Pain-evoked EMG activity was scored as the mean activity during 0 ms and 1000 ms, and 1000–2000 ms after thermal pain onset as change in activity from a 1000-ms prestimulus baseline. For the pain responses during fixation cross trials, the same intervals were chosen according to the time window when thermal stimulation reached the target temperature (0–1000 ms) and at a later period of equal length to measure slower facial responses to pain.

2.5. Procedure

After arrival, participants signed the informed consent, answered sociodemographic questions, and filled out the questionnaire on state anxiety. Subsequently, the individual pain threshold was assessed. After EMG electrodes were attached, the participants were instructed about the experimental procedure. The thermode was attached to their left forearm and participants were given a stop device to interrupt the thermal stimulation whenever they felt the heat being too painful (actually, this was never the case). Subsequently, the participants completed 3 training trials (including the painful thermal stimulation and the rating procedure for valence, arousal, and pain intensity), and were instructed to attentively watch the screen during the experiment, before the main experiment was started. Each trial consisted of a central fixation cross, which was presented for 6 seconds until the thermal stimulus reached the target temperature (thermal stimulation began 1.4 seconds after trial onset during painful trials and 2 seconds after trial onset during nonpainful trials in order to synchronize the time point when the temperature reached target level and the video stimulus began). Then the video stimulus or the fixation cross (control trials) was presented for 1 second followed by a blank screen for 0.5–2.5 seconds. After each trial, participants were asked to rate the video with regard to valence (−4 = very unpleasant, 0 = neutral, and +4 = very pleasant) and arousal (1 = not at all arousing and 9 = very arousing), and the ther-

mal stimulus on a computerized visual analogue scale (0 = no pain and 100 = unbearable pain). All trials (facial video stimuli as well as control trials) were separated by an intertrial interval (2.8–5.2 seconds) and presented in a fully randomized sequence. A schematic of the trial structure is given in Fig. 1. Overall, the experiment consisted of 160 trials (128 video clips and 32 fixation crosses); in 50% of the trials of each condition the painful, and in 50% of the other trials the nonpainful, thermal stimulus was delivered. After the experiment the participants filled out the questionnaires on pain catastrophizing, pain anxiety, trait anxiety, and empathy.

2.6. Statistical analysis

The affective ratings of the videos were analyzed separately for valence and arousal by employing 2-factorial repeated-measures analyses of variance (ANOVAs) with the within-subjects factors facial expression (neutral, joy, fear, pain) and pain intensity level (painful vs nonpainful). Mean pain intensity ratings were analyzed using repeated-measures ANOVAs with the within-subjects factors stimulus (5 levels: 4 facial expressions and fixation cross) and pain level (painful vs nonpainful). Mean EMG amplitudes were analyzed in 2 separate analyses: first, a repeated-measures ANOVA with the within-subjects factors facial expression (neutral, joy, fear, pain), pain intensity level (painful vs nonpainful), and time (0–1000 ms after video onset vs 1000–2000 ms after video onset) was applied to investigate effects of painful vs nonpainful heat stimulation on an implicit measure of emotion processing (ie, emotion-congruent muscle responses). Second, for low-level control trials (fixation cross), a repeated-measure ANOVA containing the within-subjects factors pain intensity level (painful vs nonpainful) and time (0–1000 ms after fixation cross onset vs 1000–2000 ms after fixation cross onset) was applied to investigate the facial muscle response to pain in a low-level control condition. This procedure allows for determining facial muscle responses as a mere result of the painful stimulation without any additional contamination by emotion-congruent facial reactions [50]. When necessary, Greenhouse-Geisser corrections of degrees of freedom were used. Post hoc comparisons were realized using planned contrasts or pair-wise *t*-tests. Correlational analysis between *z*-standardized EMG responses during control trials (fixation cross) and pain intensity ratings were conducted. Significance level was defined as $P < 0.05$.

3. Results

3.1. Affective ratings

The analysis of arousal ratings revealed a significant main effect of facial expression $F(3,63) = 37.02$, $P < 0.001$, $\eta_p^2 = .638$, indicating that all emotional facial expressions were rated as more arousing compared to neutral expressions (all *P*s < 0.001). Pain faces did not significantly differ from joy faces, but were rated as more arousing in comparison to fear, $F(1,21) = 6.24$, $P = 0.021$, $\eta_p^2 = .229$. Joy and fear did not significantly differ from each other, $F(1,21) < 1$. Furthermore, higher arousal ratings of the videos during painful compared to nonpainful stimulation were observed, $F(1,21) = 10.17$, $P = 0.004$, $\eta_p^2 = .326$.

A significant interaction of facial expression and pain intensity level, $F(3,63) = 3.50$, $P = 0.021$. $\eta_p^2 = .143$, was found due to higher arousal ratings under painful in comparison to nonpainful thermal stimulation for fearful, $t(21) = 2.10$, $P = 0.049$, and especially for painful facial expressions, $t(21) = 3.10$, $P = 0.006$, only. Mean arousal and valence ratings and SEM are given in Fig. 2.

The analysis of valence ratings revealed a significant main effect of facial expression, $F(3,63) = 275.75$, $P < 0.001$, $\eta_p^2 = .93$, with pain expressions being rated as most unpleasant, followed by fear, neutral, and joy being rated as most pleasant (all comparison *P*s < 0.001). Valence ratings were unaffected by thermal stimulation, $F(1,21) = 1.10$, $P = 0.31$, $\eta_p^2 = .05$.

3.2. Pain ratings

Pain intensity ratings were higher for painful thermal stimulation, $F(1,21) = 43.06$, $P < 0.001$, $\eta_p^2 = .67$, and modulated by the concurrently presented visual stimulus, $F(4,84) = 5.73$, $P < 0.001$, $\eta_p^2 = .21$. Moreover, a significant interaction of pain intensity level and visual stimulus points at a differential modulation of pain perception by the different visual stimuli, $F(4,84) = 15.83$, $P < 0.001$, $\eta_p^2 = .43$. The painful thermal stimulus was rated most intense during the presentation of a fixation cross, compared to the facial video stimuli depicting expressions of joy, fear, pain, or a neutral expression (all *P*s < 0.01). Whereas under nonpainful thermal stimulation, the intensity of the stimulation was rated as significantly lower while watching a fixation cross in comparison to videos showing fear, or pain expressions, $t(21) = 4.46$, $P < 0.001$, and $t(21) = 2.12$, $P = 0.046$, respectively (Fig. 3). Most important, only painful facial expressions selectively led to higher pain intensity ratings compared to all other emotional and neutral facial expressions during high painful stimulation (all *P*s < 0.03). Mean pain intensity ratings during the 2 thermal conditions separated for the different presented stimuli are given in Fig. 3.

3.3. EMG responses to facial expressions

M. corrugator activity was higher under painful compared to nonpainful thermal stimulation, $F(1,20) = 4.81$, $P = 0.04$, $\eta_p^2 = .19$. Also, *M. corrugator* activity was higher in the second compared to

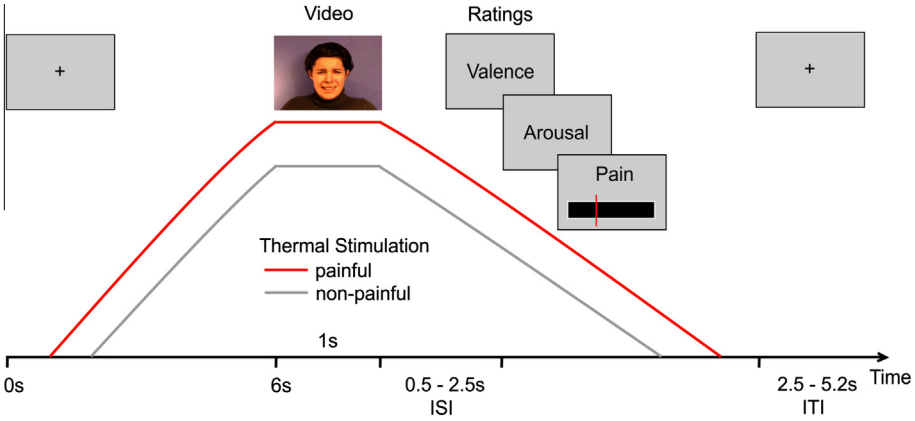

Fig. 1. Schematic of trial structure: participants were shown a central fixation cross until thermal stimulation reached target temperature, followed by a dynamic facial expression [40] or a central fixation cross, respectively; participants were asked to rate valence and arousal of the videos and pain intensity of the thermal pain stimuli.

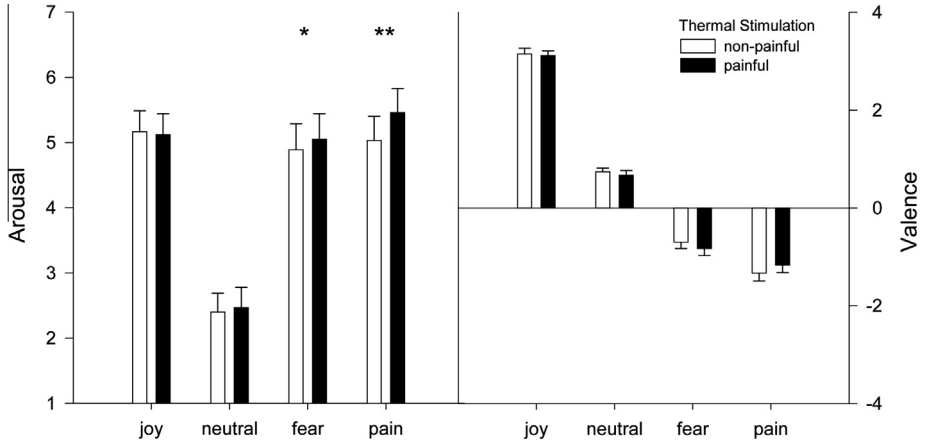

Fig. 2. Mean valence (−4 to +4) and arousal (1 to 9) ratings (+SEM) for dynamic neutral, joy, fear, and pain expressions, separately per pain condition; pain, and fear were rated as more arousing during painful compared to nonpainful stimulation; $^{*}P < 0.05$; $^{**}P < 0.01$.

the first time interval after video onset, $F(1,20) = 5.54$, $P = 0.029$, $\eta_p^2 = .217$, and was modulated by facial expressions, $F(3,60) = 16.38$, $P < 0.001$, $\eta_p^2 = .450$, such that in response to joy faces, *M. corrugator* was significantly relaxed compared to all other emotion expressions, all *Ps* < 0.003. These effects were further qualified by a significant interaction of time and pain intensity level, $F(1,20) = 7.94$, $P = .011$, $\eta_p^2 = .28$, indicating higher relaxation in the second time interval (1000–2000 ms) under nonpainful compared to painful stimulation. Additionally, a significant interaction of time and facial expression, $F(1,20) = 17.90$, $P < 0.001$, $\eta_p^2 = .47$, revealed that the *M. corrugator* was significantly more relaxed to joy faces in the second compared to the first time interval, $t(21) = 4.26$, $P < 0.001$, and marginally significantly less deactivated for fearful expressions during the second time interval compared to the first, $t(21) = 2.03$, $P = 0.055$.

For *zygomaticus major*, a marginally significant main effect of pain intensity level, $F(1,21) = 3.25$, $P = 0.086$, $\eta_p^2 = .13$, suggests more activation under painful compared to nonpainful stimulation. A significantly higher activation in the second compared to the first time interval was observed, $F(1,21) = 15.31$, $P = 0.001$, $\eta_p^2 = .42$. No effects of facial expressions were found.

Pain level had no general influence on *M. orbicularis* activity, $F(1,21) = 2.22$, $P = 0.15$. $\eta_p^2 = .10$. Generally, *M. orbicularis oculi* was stronger activated in the second compared to the first time interval, $F(1,21) = 64.12$, $P < 0.001$, $\eta_p^2 = .75$. A significant interaction of time and facial expression $F(3,63) = 5.61$, $P = 0.017$, $\eta_p^2 = .211$, was followed-up by 2 separate analyses for each time interval, and revealed a significant effect of facial expression only for the second interval, $F(3,63) = 3.82$, $P = 0.05$, $\eta_p^2 = .154$. Planned contrasts showed that during the second interval, *M. orbicularis* was more activated in response to joy than to neutral faces, $F(1,21) = 6.38$, $P = 0.02$, $\eta_p^2 = .233$. No differences were found for other planned comparisons. For an overview of all EMG results in response to the different emotional faces, see Fig. 4.

3.4. EMG responses to pain (fixation cross)

M. corrugator activity was neither influenced by pain level nor showed changes over the 2 time intervals, all F-values < 1. The analysis of *M. zygomaticus* activity revealed an almost significant interaction of time and pain level, $F(1,21) = 4.22$, $P = 0.053$, $\eta_p^2 = .167$. Post hoc comparisons revealed a tendency of stronger zygomaticus activation to painful compared to nonpainful thermal stimulation in the second interval, $t(21) = 1.86$, $P = 0.077$ (Fig. 5).

The analysis of orbicularis activity revealed a significant main effect of time, $F(1,21) = 16.36$, $P = 0.001$, $\eta_p^2 = .44$, and a significant main effect of pain level, $F(1,21) = 5.04$, $P = 0.036$, $\eta_p^2 = .194$. These

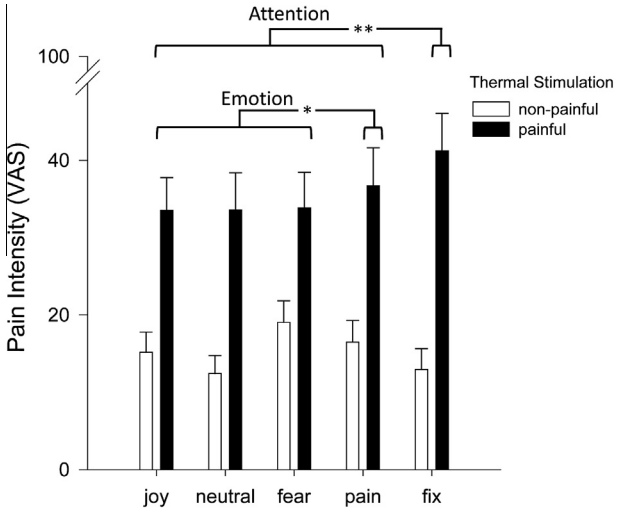

Fig. 3. Mean pain intensity ratings for each facial expression and the control condition; for painful stimulation, pain ratings were increased during control trials (fixation cross) compared to all video stimuli, revealing pain modulation by attention allocation; during presentation of pain faces, pain ratings were higher compared to all other facial expressions revealing emotion-specific modulation of pain; $^{*}P < 0.05$; $^{**}P < 0.01$. VAS = visual analogue scale.

effects were further qualified by a significant interaction, $F(1,21) = 6.39$, $P = 0.020$, $\eta_p^2 = .23$. Post hoc comparisons showed significantly stronger *M. orbicularis* activation in response to painful compared to nonpainful thermal stimulation, $t(21) = 2.62$, $P = 0.016$.

3.5. Correlation of standardized EMG responses and pain intensity ratings

Correlation analysis of facial muscle responses during control trials (fixation cross) and pain ratings for painful thermal stimulation revealed a significant linear relationship between *zygomaticus major* activity and pain intensity ratings, $r = 53$, $P = 0.01$ (n = 22). For *orbicularis* activity, this correlation was only marginally significant, $r = -38$, $P = 0.08$ (n = 22), whereas for *corrugator* activity, no relation to pain ratings was found, $r = -.31$, $P = 0.17$ (n = 21). No correlations were found for nonpainful thermal stimulation with respect to all facial muscles.

3.6. Psychological traits

Correlational analysis showed no association between measures of emotion processing (facial EMG, valence, and arousal ratings) or

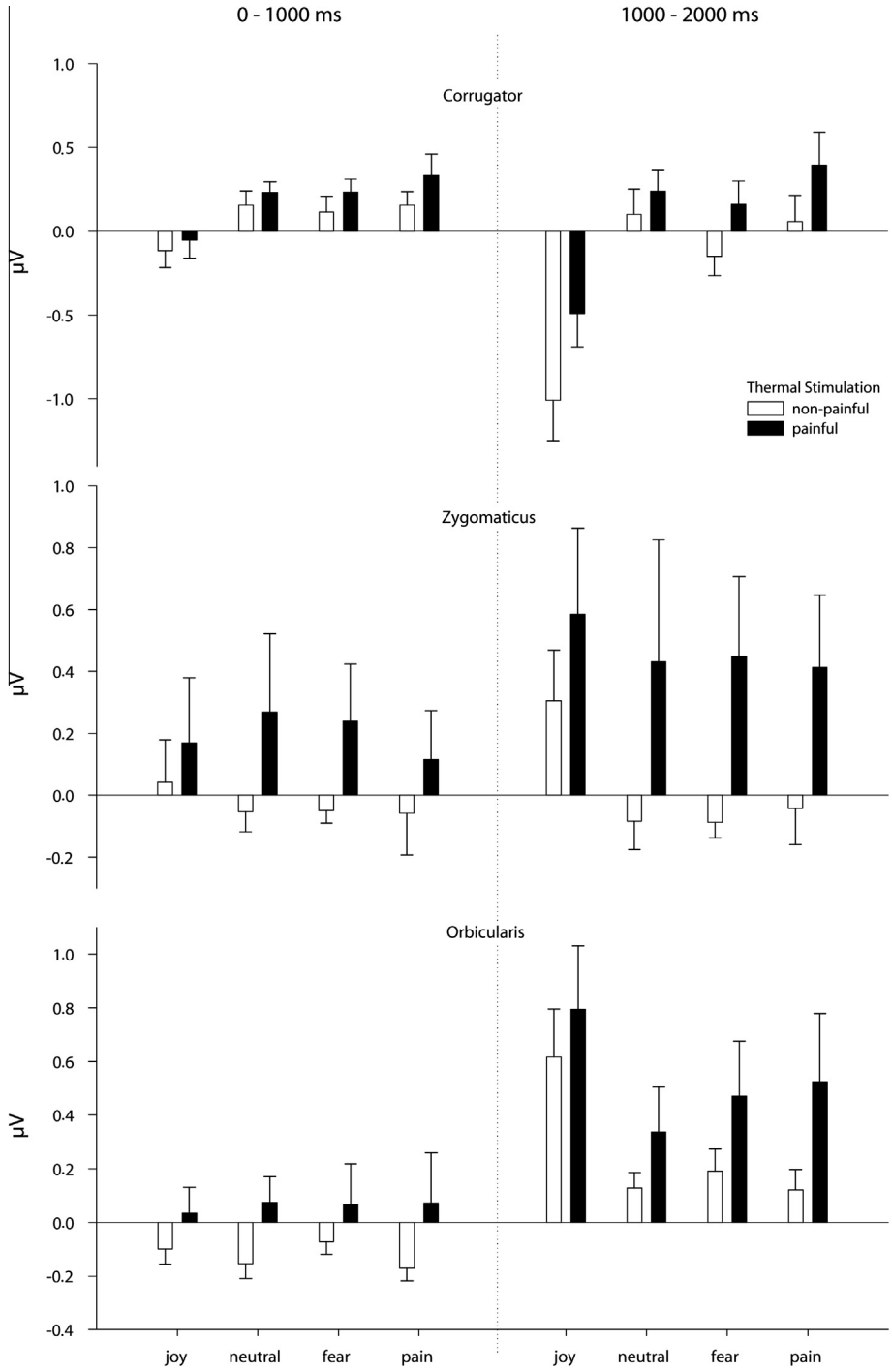

Fig. 4. Mean facial muscle activity for *Musculus zygomaticus major*, *M. corrugator supercilii* and *M. orbicularis oculi* in response to dynamic facial expressions (neutral, joy, fear, and pain), under painful vs nonpainful thermal stimulation; plots are separated for the first and second time interval after stimulus onset (0–1000 ms; 1000–2000 ms), and level of thermal stimulation (painful vs nonpainful).

pain processing (facial EMG and intensity ratings), and psychometric measures (state and trait anxiety, pain catastrophizing, empathy).

4. Discussion

How does pain influence the processing of dynamic facial expressions and – in contrast – how does the perception of facial expressions influence pain perception? In the current study we combined measures of face and pain perception within the same paradigm to scrutinize these questions. The results show a modulation of pain perception by the emotional content of facial expressions such that highest pain ratings to painful thermal stimuli were obtained while watching faces of pain compared to other facial expressions. In addition, the results suggest an attentional effect of visual stimulation on pain in general, since pain ratings were decreased when watching face videos compared to a simple fixation cross under painful thermal stimulation. These results point at two different processes: (1) a general effect of attention allocation,

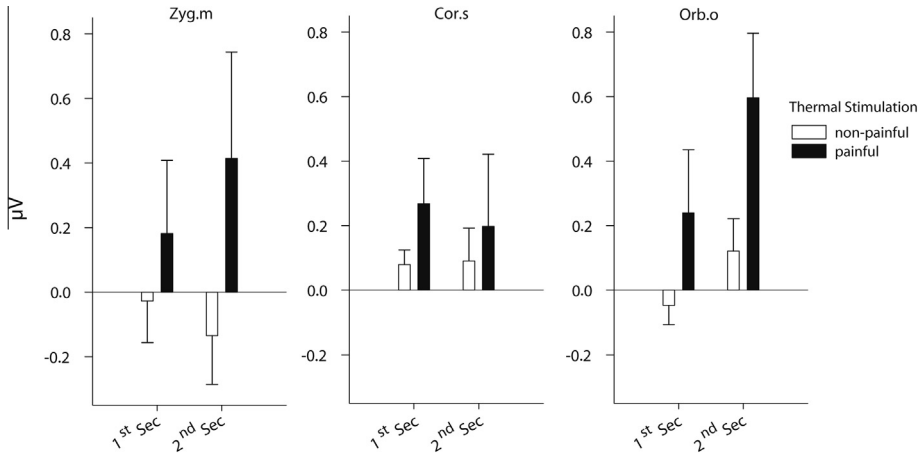

Fig. 5. Mean facial muscle activity for *M. zygomaticus major*, *M. corrugator supercilii*, and *M. orbicularis oculi* during control trials (central fixation cross) in response to painful stimulation; plots are separated for the first and second time interval after stimulus onset (0–1000 ms; 1000–2000 ms), and level of thermal stimulation (painful vs nonpainful).

demonstrating that any complex visual stimulus (eg, a face) withdraws attentional resources from the pain stimulus and (2) an emotion-specific modulation of pain perception by faces expressing pain. In addition, affective ratings of the face videos showed a modulation by pain such that perceived arousal of negative facial expressions, especially pain faces, was augmented under painful thermal stimulation. Taken together, these findings demonstrate mutual effects of pain and emotion processing. The EMG recordings revealed that facial muscle activity to painful thermal stimulation was increased in *M. orbicularis oculi*, and *M. zygomaticus major* activity was positively correlated with subjective pain ratings. These findings underscore the notion that facial reactions to pain may serve as an indicator of subjective pain experiences.

4.1. Pain modulation by emotion and attention

So far, little evidence has been gathered on the capacity of emotional faces to modulate pain perception. One study found emotional, compared to neutral, faces to increase pain perception, supporting earlier findings of pain modulation by emotion [39]. Surprisingly, happy faces also increased pain perception, which is discussed with regard to a potential ambiguity of happy faces in the context of pain, for example, when seeing others' pain elicits schadenfreude in bystanders. Similarly, we also did not find any pain reduction in response to happy, compared to neutral, facial expressions. As expected, facial pain expressions have the greatest impact on pain perception compared to all other facial expressions. This is in line with findings that hypnotic induction of a pain-related negative affect leads to increased pain perception [34]. Alternatively, viewing facial pain expressions of a person displaying his/her sorrow could promote empathic responses in an observer [3,54], which in turn might heighten the perception of the observer's pain [15,41].

Thus, the congruency between the one's own experience and the perception of pain signals observed in others might drive a potentiating proalgesic mechanism. In a similar vein, pain-related pictures were found to increase pain perception, which is explained by the induction of compassionate hyperalgesia [11]. Additional evidence for the amplification of pain driven by the congruency of extero- and interoceptive sensations (seeing pain vs feeling pain) comes from a recent study showing that watching facial pain expressions results in augmented pain ratings compared to neutral faces [27].

It is difficult to disentangle the effects of attention and emotion on pain even more since the neural circuits seem to overlap to a large extent [46,47]. In the present study, the comparison between pain ratings in video trials (dynamic facial expressions) and control trials (fixation cross) indicates a general pain reduction, most probably induced by an attentional capture of the face stimuli. This is in line with earlier findings showing that distraction leads to reduced pain perception [45,51], for instance, when participants were exposed to virtual reality scenarios [30] or when focusing on the content of distractive emotional pictures [16]. Our results show that this effect is further modulated by the emotional content of the facial video stimuli, such that pain faces resulted in highest pain ratings. This is particularly remarkable because threatening facial stimuli [38,53], and especially the expression of pain [35], were shown to receive highest processing resources and, according to the attentional modulation of pain, should have resulted in decreased pain ratings. The relative increase of pain perception while watching pain compared to other emotional facial expressions points to the assumption of a congruency-mediated pain modulation that further underscores the special relevance of facial pain expressions for the communication and actual experience of pain [35].

For the investigation of interactions between pain and emotion, the quality of experimental pain and the selection of affective stimuli seem crucial. In the present study, we administered phasic painful stimuli that can easily be linked to the facial reactions in the videos. Aspects of compatibility and context during concomitant pain and emotion experience need to be further investigated in future research.

4.2. Facial reactions to emotions and pain

Facial expressions of pain were expected to lead to enhanced responses in facial muscles (*M. corrugator supercilii*, *M. orbicularis oculi*, and *M. zygomaticus major*), which have been found to be reliably activated during the actual experience of pain [19–21,32,33]. However, in the present study, no emotion-congruent facial reactions were observed in response to painful facial expressions; only for joy faces were congruent facial reactions found. This is in line with our recent study where no distinct pattern of facial muscle activity in response to pain faces was observed [35], which supports the assumption that pain-congruent facial responses rely on actively taking the perspective of a person in pain [35], which is further modulated by trait empathy [44].

The application of pain in absence of video stimuli resulted in elevated responses of *M. orbicularis oculi*, in line with descriptions

of the facial pain expression that includes muscle contraction around the eyes [32,33].

Altogether, facial activity seems to be most pronounced in the second interval of data analysis, for the responses to both the video stimuli and the pain stimulation, suggesting an accumulating response that evolves over time. A significant correlation of *M. zygomaticus* responses and pain ratings are in accordance with recent observations of the so-called smile of pain, accompanying the actual experience of pain [21]. Nonpainful stimulation showed no significant correlation between subjective ratings and muscular reactions, underscoring the pain specificity of the results. These findings highlight the crucial role of facial pain expression for encoding and communicating individual pain experiences, which might represent a promising nonverbal alternative for quantifying pain, especially with regard to individuals that are unable to communicate their pain status adequately [22].

4.3. Pain affects emotional face processing

Research on the impact of pain on emotion processing is rather scarce, but one study investigated how pain modulates the processing of affective pictures [12], and found a dampening effect of pain only for the perception of positive emotional stimuli. Similarly, it was found that pain distorted concomitant emotion evaluation processes only for happy faces, showing how pain diminishes positive affective appraisal [10]. In a recent study on the impact of pain on electrocortical emotional face processing, a general reduction of face-evoked event related potential (ERP) amplitudes was found, suggesting a broad allocation of attentional resources towards pain and away from the emotional faces [52]. In the present study, we found higher arousal ratings for negative facial expressions – most prominent for pain expressions – when participants received pain, whereas no differences were found for neutral or joy expressions. This demonstrates a similar effect that we found for pain ratings, that is, a congruency-mediated increase of pain perception that holds true for emotional arousal perception as well.

4.4. Limitations

A possible limitation of the present study is the assessment of pain intensity ratings only due to timing issues. In general, affective pain ratings were shown to be more sensitive for emotional modulation [26,46], whereas pain intensity measures seem to be more sensitive for attention manipulation [18]. Accordingly, in the present study, effects on affective pain measures would probably have been even more pronounced. Also, the parametric modulation of pain (eg, no pain, above threshold) could help to disentangle facial muscle activity in response to emotions and thermal stimulation. Similarly, the variation of task instructions and thereby attentional focus during the experiment might be crucial to scrutinize the modulation of pain by attention and emotion.

4.5. Conclusion

While the influence of emotion on pain has often been investigated, the opposite effect of pain on emotion is only roughly understood. In addition, although pain is often accompanied by a distinct facial expression, its influence on the actual experience of pain is unclear. The present study showed that pain increases the perceived emotional arousal of painful facial expressions and, in turn, facial expressions of pain most strongly increase the perception of concomitant painful stimulation, compared to other facial expressions. For the first time, to our knowledge, the present study investigated effects of pain perception on emotional facial expressions including pain, and vice versa, the effect of facial expressions on pain processing within the same experimental protocol. Results point at mutual influences of pain and emotion processing in healthy individuals and raise the question of maladaptive mechanisms in patients suffering chronic pain or affective disorders, who show alterations in these interacting processing systems [1,2].

Conflict of interest statement

The authors declare no conflict of interest.

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