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Sarah Fabi & Hartmut Leuthold

To cite this article: Sarah Fabi & Hartmut Leuthold (2017) Empathy for pain influences perceptual and motor processing: Evidence from response force, ERPs, and EEG oscillations, Social Neuroscience, 12:6, 701-716, DOI: 10.1080/17470919.2016.1238009

To link to this article: https://doi.org/10.1080/17470919.2016.1238009

Accepted author version posted online: 17 Sep 2016.
Published online: 28 Sep 2016.

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Empathy for pain influences perceptual and motor processing: Evidence from response force, ERPs, and EEG oscillations

Sarah Fabi and Hartmut Leuthold
Department of Psychology, University of Tübingen, Tübingen, Germany

ABSTRACT
In the present study we investigated the nature and chronometry of empathy for pain influences on perceptual and motor processes. Thus, event-related brain potentials (ERPs), response force (RF) and oscillatory electroencephalography (EEG) activity were measured while participants were presented with pictures of body parts in painful or neutral situations. Their task consisted in either judging the painfulness of the stimuli or counting the body parts displayed. ERP results supported the assumption of an early automatic component of empathy for pain, as reflected by the early posterior negativity (EPN), and of a late controlled component, as reflected by the late posterior positivity (P3). RF indicated that empathy-evoking stimuli facilitate motor responses if attention is directed toward the pain dimension, whereas EEG oscillations in the mu-and beta-band revealed, independent of the task, an enhanced activation of the sensorimotor cortex after the response to painful compared to neutral stimuli. In conclusion, present findings indicate that empathy-evoking stimuli produce automatic and controlled effects on both perceptual and motor processing.

ARTICLE HISTORY
Received 15 December 2015
Revised 1 September 2016
Published online
29 September 2016

KEYWORDS
Empathy; pain; ERP; response force; EEG oscillations; information processing

Observing another person suffering from physical or psychological pain changes our own feelings accordingly. This ability to share the feelings of another person, and at the same time knowing that the other is the source of one’s own, is referred to as empathy (e.g., de Vignemont & Singer, 2006). It is evident that empathy plays a crucial role in our everyday social life. Therefore, it is not surprising that empathy, especially for pain, has been extensively studied recently. Specifically, functional magnetic resonance imaging (fMRI) studies revealed the neural substrates underlying empathy for pain, with brain regions forming the so-called pain matrix (anterior insula, anterior cingulate cortex) being activated while experiencing pain oneself, as well as while watching others experience pain (e.g., Decety & Meyer, 2008; Gu & Han, 2007; Singer et al., 2004; for a review, see Lamm, Decety, & Singer, 2011). Yet, it is still an unresolved issue as to which processes in the course of stimulus–response (S-R) processing are selectively influenced by empathy for pain, and whether empathy-related effects automatically modulate early perceptual as well as late motor processing stages. Therefore, it is the main objective of this study to investigate the time course of empathic influences on the various information processing stages by analyzing oscillatory electroencephalographic (EEG) activity, event-related brain potentials (ERPs), reaction time (RT), and response force (RF).

Different models have been proposed with regard to the time course and automaticity of empathic processes (e.g., de Vignemont & Singer, 2006); however, our understanding about these issues is still limited as will become clear later. For instance, de Vignemont and Singer (2006) suggested on the one hand a late appraisal model, according to which emotional cues automatically elicit empathy, while the emotional context is processed in parallel (see also Preston & de Waal, 2002). Appraisal processes then modulate the automatically elicited empathic response. On the other hand, their early appraisal model understands the empathic response as a mere result of the appraisal processes elicited by the emotional cue and its context. That is, the outcome of the contextual appraisal process determines whether or not an empathic response is triggered. The critical difference between the two models is that in the late appraisal model, the empathic response happens automatically and is only modulated by the cognitive appraisal, whereas in the early appraisal model it is triggered in a controlled way dependent on the outcome of the appraisal process.
As concerns the automaticity assumption, fMRI studies have provided mixed results, for instance, showing activation of the neural pain matrix only in a task that required attention to pain (rating pain intensity), but not in a task in which pain was task-irrelevant (Gu & Han, 2007), whereas others found an activation pattern of pain matrix brain regions even if participants were informed that the hands in painful situations were anesthetized (e.g., Lamm, Nusbaum, Meltzoff, & Decety, 2007; see also Decety & Lamm, 2006). Furthermore, because of the low temporal resolution of fMRI, it is difficult to draw definite conclusions concerning the time course of empathic processes on the basis of the above-reviewed studies (cf. Zaki & Ochsner, 2012). Therefore, it has been recommended to use methods with high temporal resolution, such as EEG and ERPs, to investigate the mental chronometry of empathy-related automatic and controlled processing (e.g., de Vignemont & Singer, 2006; Zaki & Ochsner, 2012).

To guide such time course inferences, we propose to consider a model of information processing that consists of a sequence of distinct stages between stimulus input and response output, including stimulus encoding, categorization, response selection, and motor processing (cf. Sternberg, 2004; Sanders, 1990; cf. Figure 1). Since specific ERP components are known to sensitively reflect either the duration or the extent of automatic and controlled mental processes, ERPs seem ideally suited to investigate the locus of empathic influences within information processing (for a review, see Olofsson, Nordin, Sequeira, & Polich, 2008). Thus, positively and negatively valenced stimuli (e.g., pictures, faces) have been shown to trigger larger visual ERP amplitudes than neutral stimuli between 100 and 300 ms after stimulus onset over occipito-temporal sites (P1, N1). The posterior P1 component is associated with early activity in the extrastriate cortex and known to be enhanced for attended than unattended stimuli (e.g., Hillyard & Anllo-Vento, 1998; Luck & Hillyard, 1994). The subsequent posterior negativity (N1) is elicited between 130 and 200 ms after the onset of visual stimuli, reflecting higher-order visual processes while also being sensitive to attention. It is worth noting that other researchers (e.g., Eimer & Holmes, 2002) found an earlier peaking anterior negativity (120 ms) to be smaller for attention-capturing, salient emotional than neutral stimuli that undergo automatic processing (e.g., Öhman, 2002). Also, the early posterior negativity (EPN) between 200 and 300 ms after stimulus onset reflects such automatic emotion-related influences on information processing (e.g., Olofsson et al., 2008; Schupp, Junghöfer, Weike, & Hamm, 2004). In addition, emotional stimuli have also been found to elicit an augmented, centro-parietally distributed late posterior positivity (P3) that is taken to reflect task-dependent stimulus classification processes (e.g., Donchin, 1981; Polich, 2007).

A prominent ERP study addressing the time course of empathic processing was conducted by Fan and Han (2008). They presented pictures showing one or two hands in neutral or painful situations (e.g., cutting vegetables vs. cutting oneself). Participants were instructed to either judge the pictures as neutral versus painful or to count the number of hands displayed in the pictures. In the pain judgment task, they found more positive ERP amplitudes for painful than neutral stimuli in an early and a late time interval. More specifically, the ERP waveform at 140–200 ms (P180) and 200–280 ms (N240) over fronto-central regions reflected the task-independent, early pain effect. By contrast, the centro-parietal P3 component (360–800 ms) indicated the task-dependent, late pain effect, that is, P3 amplitude was influenced by painful versus neutral stimuli only in the pain judgment but not the counting task. These findings indicate that distinct early-automatic and late-controlled processes contribute to empathy for pain, hence providing evidence for the late appraisal model of de Vignemont and Singer (2006). However, as will be outlined next, subsequent ERP-studies using similar stimulus materials and tasks revealed discrepant results.

![Figure 1](image-url)  
*Figure 1.* Model of information processing including encoding, categorization, response selection, and motor processing stages as well as an energetic arousal pathway. See main text for further details.
For instance, using different stimuli and tasks, Meng, Hu et al. (2012) and Decety, Yang, and Cheng (2010) found early (N1, P2) and late (P3) ERP components to be influenced by empathy as in Fan and Han’s (2008) study. However, other studies could only replicate the empathy for pain influence on the P3 component (Lyu, Meng, & Jackson, 2014; Sessa, Meconi, Castelli, & Dell’Acqua, 2013). Interestingly, using Fan and Han’s (2008) stimuli and tasks, Mella, Studer, Gilet, and Labouvie-Vief (2012) found an early ERP effect only in adolescents but not adults, and it was opposite in direction to that reported by Fan and Han (2008).

Empathy-related influences on sensorimotor and late motor processes have been examined in studies analyzing either oscillatory EEG activity or motor evoked potentials (MEPs) triggered by transcranial magnetic stimulation (TMS). Thus, in a study of Valentini, Liang, Aglioti, and Iannetti (2012) participants watched video clips of hands while receiving simultaneous nociceptive stimulation. EEG time–frequency analysis showed for painful compared to neutral video clips reduced event-related desynchronization (ERDs) in the beta-band (21.5–26.5 Hz) over central and frontal electrodes contralateral to the stimulated hand. The authors suggest that experiencing the pain of others reduces the sensorimotor cortex activity in the observer, triggered by nociceptive stimulation. Regarding late motor-related influences of empathy, Riečansky, Paul, Kölble, Stieger, and Lamm (2014) found that video clips depicting needle injections into hands compared to hands touched by a cotton swab triggered stronger ERDs of beta oscillations (13–30 Hz) over the sensorimotor cortex while watching the dynamic stimuli, and of mu oscillations (7–12 Hz) during the static phase at the end of the video. They interpreted these findings in terms of increased motor readiness. It is worth mentioning, however, that Avenanti and colleagues (Avenanti, Bueti, Galati, & Aglioti, 2005; Avenanti, Sirigu, & Aglioti, 2010) reported smaller MEP amplitudes when participants attended video clips presenting needle injections compared to touches with a cotton swab, suggesting motor inhibition in line with the beta-band ERD findings of Valentini et al. (2012). Crucially, Avenanti, Minio-Paluello, Sforza, and Aglioti (2009) found that corticospinal inhibition of motor activity was limited to the hand being penetrated, whereas corticospinal excitability was increased for the other hand, as indicated by larger MEPs when TMS-stimulation was applied to the motor cortex ipsilateral to the hand shown in the video.

Taken together, previous research concerned with the effects of empathy on information processing produced mixed results, for which it is difficult to come up with a straightforward explanation, because the reviewed studies differ with regard to tasks (e.g., behavioral RT task, pain judgment, pain intensity rating), stimuli (e.g., hands, faces, experience of own pain), ERP analysis approach and empathy measures used. With regard to the latter point, it is worth noting that some studies reported situational empathy, as measured via pain intensity and self-unpleasantness ratings, to underpin the relationship of ERP effects with empathy (e.g., Decety et al., 2010; Fan & Han, 2008), whereas it is less clear whether dispositional empathy, as assessed with the aid of established questionnaires, shows a similar relationship (e.g., Mella et al., 2012; Sessa et al., 2013). Also, some studies did not report behavioral effects (e.g., Decety et al., 2010; Riečansky et al., 2014) or did not test for the automaticity of the observed empathy-related effects (e.g., Lyu et al., 2014; Meng, Hu et al., 2012; Sessa et al., 2013), limiting the interpretation of EEG/ERP results. Additionally, at least to our knowledge, the studies reporting evidence in favor of automatic empathic processes, as indicated by the modulation of early anterior ERP waveforms, did not explicitly check for (pictorial) arousal effects on sensory processing (e.g., Decety et al., 2010; Fan & Han, 2008; Meng, Hu et al., 2012). Finally, the nature and time course of changes in the state of the motor system are not well understood, as well as whether these changes are elicited automatically in response to empathy-evoking stimuli.

Objectives of the current study

It was the main aim to extend previous studies by investigating in the same experiment the chronometry of automatic and controlled perceptual and motor processes underlying empathy for pain, as well as their relationship with dispositional empathy. To this end, we recorded the EEG while participants were watching pictures of hands or feet in painful or neutral situations. Like in the study of Fan and Han (2008), participants were either judging the pain (painful vs. neutral) or counting the body parts depicted in the pictures (one vs. two or more) in order to determine whether empathy for pain depends on attention to pain cues. Various studies (Peng, Hu, Zhang, & Hu, 2012; Sochurková, Brázdil, Jurák, & Rektor, 2006; Toledo, Manzano, Barela, & Kohn, 2016) implied an association between specific ERP components and event-related desynchronization or synchronization (ERD/ERS) in specific frequency bands. Yet, ERPs and ERD/ERS might reflect different neurophysiological phenomena. That is, ERPs are taken to mainly indicate the averaged postsynaptic potential activity that is strictly time-locked to a sensory, motor,
or cognitive event, whereas ERD/ERS represents a decrease/increase in synchrony of the underlying electrophysiological activity (cf. Roach & Mathalon, 2008). Thus, ERD/ERS captures oscillatory brain activity that is not strictly phase-locked to a specific event, and hence eliminated by the averaging procedure involved in calculating ERPs (Gomarus, Althaus, Wijers, & Minderaa, 2006; Pfurtscheller & Lopes da Silva, 1999). Therefore, ERPs and ERD/ERS complement each other in measuring ongoing brain activity. Specifically, concerning the measurement of the empathy-related facilitative or inhibitory influences on the motor system, ERD/ERS is suitable because it can be interpreted as an electrophysiological correlate of activated cortical areas involved in the production of motor behavior (Pfurtscheller, 1992). We additionally assessed behavioral variables, namely RT and RF, to measure motor changes and their relationship with brain activity. Finally, since the experience of situational empathy of persons appears to depend on their individual empathic dispositions (e.g., Eisenberg & Fabes, 1990), we obtained dispositional empathy measures in addition to situational ratings of perceived pain and self-unpleasantness for every picture.

In agreement with former studies, we expected differential ERP amplitudes in the painful than the neutral condition in early (before 300 ms; N1, P1, and EPN) and late (after 300 ms; P3) time intervals (cf. Figure 1). The early ERP effects should be independent of task demands if triggered by automatic empathic processes, whereas the late ERP effects should be present only in the pain judgment task if reflecting the controlled evaluation processes underlying empathy for pain. In addition, if painful situations inhibit the motor system (e.g., Avenanti et al., 2005; Valentini et al., 2012) contingent on the categorization of the situation, we would predict less forceful key presses and reduced ERDs in the mu- and beta-band to painful than neutral stimuli in the pain judgment task. Alternatively, if painful situations activate the motor system (e.g., Riečanský et al., 2014), this higher preparedness should lead to stronger RF and ERDs in the mu- and beta-band in comparison to neutral situations. Of course, it is conceivable that empathy-related activation of the motor system is produced by arousal, for instance, via a direct pathway from perceptual to motor processes (e.g., Miller, Franz, & Ulrich, 1999; cf. Figure 1). In this case, EEG and RF patterns should be present in both the pain judgment and the counting task. Finally, if situational and dispositional empathy are related to the way painful pictures are processed, we would expect early and late ERP amplitudes as well as EEG power changes triggered by painful stimuli to increase with the scores of perceived pain and self-unpleasantness, and with dispositional empathy scores.

Method

Participants

19 students from the University of Tübingen participated voluntarily for payment (8 Euros per hour) or course credits. Two participants were excluded because of technical problems with the EEG recording; another did not appropriately operate the force-sensitive keys. The remaining 16 participants (seven females; 14 right-handed; mean age = 26.81 years) entered data analysis.

Materials and apparatus

Stimuli consisted of Meng, Hu et al.’s (2012) 124 digital color pictures, shot from first-person perspective. The pictures displayed body parts (hands, forearms, or feet) in harmful or neutral (62 pictures each) daily life situations; otherwise the pictures were almost identical. Painful pictures included scenes like a hand being cut by a knife or a foot being pricked by a needle, whereas the non-painful pictures showed the same arrangement of body parts except for the harmful component. That is, there were 62 picture pairs consisting of a painful and its corresponding non-painful picture, matched for their luminance, contrast and color. 62 pictures displayed one and 62 pictures two or more body parts.

Participants were tested in an electrically shielded, low-noise booth with ambient light at low level. Instructions, stimuli, and feedback were presented on a 1100 MB Samsung SyncMaster screen with a resolution of 1280 × 960 pixels and a refresh rate of 60 Hz. A fixed chin rest guaranteed a constant viewing distance of 60 cm and helped to minimize head movements. Dimensions of the stimuli were 354 × 266 pixels. Stimulus presentation and response recording were controlled by a Mac Mini (Apple Inc.) running a MATLAB (The Math Works, Inc., Version R2014b) program using the Psychophysics Toolbox 3.0.12 (Brainard, 1997; Kleiner et al., 2007).

Procedure

Participants were informed about the experiment and the EEG procedure before giving their informed consent. In the pain judgment task, they were asked to decide whether the stimulus depicted a painful or a neutral scene and in the counting task whether one or more body parts were displayed. The experiment consisted of four blocks of 62 stimuli each. Half of the
participants performed the pain judgment task in the first two blocks and the counting task in the last two blocks, whereas the other half received the reverse task order. Each stimulus was presented once per task in randomized order, with the constraint that pictures of the same picture pair were shown in different blocks. The mapping of left and right keys changed after every block and was balanced across participants. In order to get participants used to the task and the S-R mapping, every experimental block was preceded by 20 practice trials. Participants were free to take a short break after each block.

Each individual trial started with the presentation of a fixation cross for 800 ms, followed by the display of the pictorial stimulus for 200 ms. Participants were to respond to this stimulus within 1500 ms following its onset. After the response, and in the case of an incorrect, too fast (RT < 200 ms) or too slow (RT > 1500 ms) trial, feedback was shown at the center of the screen for 1000 ms. A blank screen of 1000 ms followed. If the response was correct, feedback was only shown in the practice trials; in the experimental blocks a blank inter-stimulus-interval of 2000 ms followed the correct response.

RT was recorded using force-sensitive keys, which allowed continuously measuring RF with a sampling rate of 512 Hz for the index fingers of both hands (for details, see Leuthold, Sommer, & Ulrich, 1996). Participants pressed this key with the left or right index finger; the forearm rested comfortably on a supporting panel. RT was measured as the interval between the onset of the stimulus and the point in time when RF displayed a change of about 100 cN relative to the mean baseline activity within the preceding 100 ms.

After the EEG recording all painful stimuli were presented again. Participants were asked to rate on a 6-point scale (1 = very low, 6 = very high) the intensity of the pain supposedly experienced by the person in the picture and their own self-unpleasantness while watching the pictures. Then, as measures of dispositional empathy, participants completed a German version (de Haen, 2006) of the Empathy Quotient (EQ, Baron-Cohen & Wheelwright, 2004) and the German version of the Interpersonal Reactivity Index (IRI, Davis, 1983) that is called the Saarbrücker Persönlichkeitsfragebogen (SPF, Paulus, 2009).

**Electrophysiological measures**

EEG activity was recorded continuously with a sampling rate of 256 Hz from 72 Ag–AgCl electrodes using a BIOSEMI Active-Two amplifier system (for details, see Filik, Leuthold, Wallington, & Page, 2014). Using a procedure similar to that described by Nolan, Whelan, and Reilly (2010), all EEG channels were recalcuated off-line to an average reference, (ocular) artifacts were removed, and EEG data were corrected and high-pass filtered (0.1 Hz, 36 dB/oct) (for details, see Filik et al., 2014). Following this procedure and after removing trials with incorrect response, there remained on average 51.14 trials (out of 62; range = 37–61, median = 49–56) per condition.

**Data analysis**

Peak force (PF) for the responding hand was determined in each correct trial at the time point where RF was maximal within a 200–1500 ms time interval after stimulus onset.

Separately for each experimental condition, ERPs were averaged for the analysis epoch that started 200 ms prior to stimulus onset and lasted for 1400 ms. The averaged ERPs were low-pass filtered (40 Hz, 36 dB/oct) and aligned to a 200 ms pre-stimulus baseline. Mean ERP amplitudes were measured in ERP waveforms within time intervals during which specific ERP deflections were found to be most pronounced, similar to previous studies (e.g., Fan & Han, 2008): 90–130 ms (P1), 140–180 ms (N1), 200–300 ms (N240, EPN), and 300–500 ms (rising P3) and 500–800 ms (P3) relative to stimulus onset.

ERP amplitudes at midline and lateral electrode sites were separately analyzed. Lateral electrodes were pooled to form eight regions of interest (ROIs), divided along left-right, anterior-posterior, and dorsal-ventral dimensions. The four ROIs over the left hemisphere were defined as follows: left-anterior-ventral (AF7, F5, F7, FT7, FC5, C5, T7, F9), left-anterior-dorsal (AF3, F1, F3, FC1, FC3, C1, C3), left-posterior-ventral (TP7, CP5, P5, P7, PO9, P7, O9), left-posterior-dorsal (CP3, CP1, P1, P3, PO3, O1). Four analogous ROIs were defined for homolog electrodes located over the right hemisphere. Additionally, analyses were calculated for frontal (Fz, FCz, F3, F4, FC3, FC4) and central ROIs (Cz, CPz, C3, C4, CP3, CP4) as defined by Fan and Han (2008). EPN amplitudes were determined for two ROIs (left hemisphere: P5, P7, PO9, right hemisphere: homolog sites) (cf. Scott, O’Donnell, Leuthold, & Sereno, 2009).

Oscillatory brain activity was analyzed to reveal decreases versus increases in the synchrony of oscillatory brain activity that is not strongly phase-locked to a specific sensory or motor event, and hence might not be reflected by averaged ERPs (cf. Roach & Mathalon, 2008; Tallon-Baudry & Bertrand, 1999). The analysis epoch started 500 ms prior to the stimulus and lasted until 1500 ms.
after stimulus onset. Power was analyzed from 4 to 30 Hz in 1-Hz frequency steps during the analysis epoch for successive 50-ms time steps. For the time–frequency decomposition, we used Morlet wavelets with a five-cycle width (e.g., Tallon-Baudry & Bertrand, 1999). The averaged power values in the analysis windows between 300 and 600 ms and between 700 and 1500 ms were subsequently converted to a percentage change scale relative to a pre-stimulus baseline from −200 to 0 ms within mu (7–12 Hz) and beta (13–18 Hz) frequency bands for left- and right-hemispheric ROIs over the somatosensory cortex (left hemisphere: C1, FC1, C3, CP1, right hemisphere: homolog sites) (cf. Riečanský et al., 2014).

Statistical analyses were performed by means of repeated measures analysis of variance (ANOVA). Bonferroni-adjusted planned comparisons were performed in order to decompose the interaction effect of condition and task. The specific ANOVA designs will be described in the respective result sections.

**Results**

**Ratings and questionnaires**

Across participants, ratings of perceived pain ($M = 3.99$) and self-unpleasantness ($M = 3.58$) correlated positively as indicated by the Kendall rank coefficient, $\tau = .73$, $p < .001$. SPF scores ranged from 33 to 52 ($M = 43.4$) and EQ scores from 31 to 63 ($M = 42.5$). Internal consistency was good for the EQ (Cronbach’s $\alpha = .86$) and the different subscales of the SPF: Cronbach’s $\alpha = .82$ (Empathic Concern), .87 (Perspective Taking), .82 (Fantasy), .89 (Personal Distress).

**Behavioral performance**

For accuracy, RT, and PF, repeated measures ANOVAs with variables condition (neutral, painful) and task (pain judgment, counting) were conducted.

**Accuracy**

The ANOVA showed a main effect of condition, $F (1, 15) = 5.55$, MSE = 9.50, $p < .05$, and a significant Task × Condition interaction, $F (1, 15) = 94.03$, MSE = 4.20, $p < .001$. Response accuracy was higher for painful than neutral stimuli in the pain judgment task (89.11% vs. 85.99%), $F (1, 15) = 5.55$, MSE = 9.50, $p < .05$, but lower in the counting task (79.64% vs. 86.39%), $F (1, 15) = 80.26$, MSE = 4.50, $p < .001$ (cf. Figure 2).

**Reaction time**

Responses were faster in the counting than the pain judgment task (652 vs. 723 ms), $F (1, 15) = 11.68$, MSE = 691.00, $p < .01$, and for painful than neutral stimuli (681 vs. 694 ms), $F (1, 15) = 5.73$, MSE = 454.60, $p < .05$. The Task × Condition interaction was significant, $F (1, 15) = 46.39$, MSE = 834.00, $p < .001$, indicating shorter RTs to painful than neutral stimuli in the pain judgment task (695 vs. 751 ms), $F (1, 15) = 36.59$, MSE = 691.00, $p < .001$, but longer RTs in the counting task (667 vs. 636 ms), $F (1, 15) = 12.64$, MSE = 597.00, $p < .01$ (cf. Figure 2).

**Response force**

The ANOVA of PF revealed a significant Condition × Task interaction, $F (1, 15) = 6.78$, MSE = 2102.00, $p < .05$. Further tests indicated higher PF in the painful
than the neutral condition of the pain judgment task (787 vs. 733 cN), \( F(1, 15) = 7.91, \text{MSE} = 2954.00, p < .05 \), but not the counting task (840 vs. 845 cN), \( F(1, 15) = 0.09, \text{MSE} = 2915.60, p = .77 \) (cf. Figure 2).

**Event-related potentials**

As can be seen in Figure 3, the ERP waveform was characterized over posterior-ventral ROIs by a first positive deflection (P1), peaking at about 120 ms, followed by a negative deflection (N1) maximal at about 160 ms. After 200 ms a rising positivity appeared, leading to the P3, which was most pronounced over posterior midline sites between 300 and 700 ms and larger in the pain judgment task for painful stimuli in comparison to the other three conditions.

ERP amplitudes measured at midline electrode sites were subjected to ANOVA with variables condition (neutral, painful), task (pain judgment, counting) and electrode (AFz, Fz, FCz, Cz, CPz, Pz, POz, Oz). ERP data from lateral electrodes were submitted to ANOVA with variables condition (neutral, painful), task (pain judgment, counting), hemisphere (left, right), anterior-posterior (anterior, posterior), and laterality (ventral, dorsal). Additionally, like Fan and Han (2008), ERP amplitudes over frontal and central ROIs and in time intervals up to 300 ms were subjected to ANOVA with variables condition (neutral, painful), task (pain judgment, counting), and ROI (frontal, central). For the EPN, ANOVA with variables condition (neutral, painful), task (pain judgment, counting), and hemisphere (left, right) was conducted.

**Time interval 90–130 ms (P1)**

The lateral ROI analysis of this time window yielded a significant Condition × Hemisphere × Anterior-Posterior × Laterality interaction, \( F(1, 15) = 10.06, \text{MSE} = 0.05, p < .01 \). Separate tests for the different ROIs only revealed a significant Condition × Hemisphere × Anterior-Posterior interaction over ventral ROIs, \( F(1, 15) = 9.24, \text{MSE} = 0.11, p < .01 \), but further tests did not produce any significant main effect of condition, Condition × Hemisphere, or Condition × Anterior-Posterior interaction, all \( F_s \leq 4.65, p > .05 \).

The analysis including only frontal and central ROIs analogously to Fan and Han (2008) revealed no significant main effects or Condition × Task interaction, all \( F_s \leq 1.63, p > .22 \).

**Time interval 140–180 ms (N1)**

The lateral ROI analysis revealed a significant main effect of task, \( F(1, 15) = 9.54, \text{MSE} = 0.09, p < .01 \), and a reliable Task × Anterior-Posterior interaction, \( F(1, 15) = 6.51, \text{MSE} = 2.34, p < .05 \), indicating more positive ERP amplitudes for the pain judgment than the counting task over posterior ROIs (0.64 vs. 0.21 µV), \( F(1, 15) = 7.37, \text{MSE} = 1.57, p < .05 \), but not over anterior ROIs (−0.57 vs. −0.30 µV), \( F(1, 15) = 5.23, \text{MSE} = 0.86 \).

![Figure 3](https://example.com/figure3.png)

**Figure 3.** Grand average ERP waveforms recorded over different ROIs (left anterior, Fz, right anterior, Cz, left posterior, Pz, right posterior) time-locked to the presentation of the stimuli as a function of stimulus condition (painful vs. neutral) and task (pain judgment vs. counting).
p = .04 (Bonferroni-corrected α-level = .025). Additionally, the Task × Condition × Hemisphere interaction was significant, $F (1, 15) = 5.5, \text{MSE} = 0.34, p < .05$. Separate tests for the two tasks did not reveal any significant main effect or Condition × Hemisphere interaction, all $F$s ≤ 3.53, $ps > .08$.

The Fan and Han (2008) analysis revealed a significant difference between the pain judgment and the counting task ($−0.56$ vs. $−0.30 \mu V$), $F (1, 15) = 5.5, \text{MSE} = 0.42, p < .05$, but no significant condition or interaction effects, all $F$s ≤ 2.90, $ps > .11$.

**Time interval 200–300 ms (N240, EPN)**
The midline analysis of this time window did not produce significant main effects or a reliable Task × Condition interaction, all $F$s ≤ 1.84, $ps > .20$. The lateral analysis yielded a significant Condition × Anterior-Posterior × Laterality interaction, $F (1, 15) = 5.35, \text{MSE} = 0.10, p < .05$, but subsequent tests revealed no significant condition effect, all $F$s ≤ 5.11, $ps > .04$ (Bonferroni-corrected α-level = .0125). Further analyses of the Task × Laterality interaction, $F (1, 15) = 4.71, \text{MSE} = 1.74, p < .05$, revealed no significant task effects over ventral and dorsal ROIs, all $F$s ≤ 5.11, $ps > .04$ (Bonferroni-corrected α-level = .025). Likewise, follow-up analyses for the significant Task × Hemisphere × Anterior-Posterior interaction, $F (1, 15) = 4.62, \text{MSE} = 0.28, p < .05$, did not reveal any significant task effect, all $F$s ≤ 1.16, $ps > .30$. The same held true for the Condition × Anterior-Posterior × Laterality interaction, $F (1, 15) = 5.35, \text{MSE} = 0.10, p < .05$, for which further tests did not reveal any significant condition effects, all $F$s ≤ 5.11, $ps > .04$ (Bonferroni-corrected α-level = .0125). In line with that, the analysis of frontal and central ROIs revealed no effect of condition or task, all $F$s ≤ 2.16, $ps > .16$.

By contrast, the analysis of EPN amplitudes produced a significant main effect of condition, $F (1, 15) = 9.02, p < .01$, indicating more negative-going EPN amplitudes in the painful than the neutral condition over posterior ROIs for both tasks ($6.2$ vs. $6.6 \mu V$), as can be seen in Figure 4.

**Time interval 300–500 ms (rising P3)**
The analysis of ERP amplitudes in the rising P3 time range over midline electrodes revealed a significant main effect of condition, $F (1, 15) = 7.02, \text{MSE} = 3.32, p < .05$, due to larger ERP amplitudes in the painful than the neutral condition ($0.94$ vs. $0.51 \mu V$). In addition, the Task × Condition interaction, $F (1, 15) = 26.55, \text{MSE} = 1.16, p < .001$, and the Task × Condition × Electrode interaction were significant, $F (7, 105) = 3.22, \text{MSE} = 1.01, p < .01$. Further analyses for the pain judgment task showed a significant main effect of condition, $F (1, 15) = 28.59, \text{MSE} = 1.88, p < .001$, due to larger ERP amplitudes in the painful than the neutral condition ($1.34$ vs. $0.42 \mu V$), and a Condition × Electrode interaction, $F (7, 105) = 4.83, \text{MSE} = 0.93, p < .001$, indicating this condition effect to be most pronounced over parietal electrodes. By contrast, analyses of the counting task did not reveal any significant main effect of condition ($0.53$ vs. $0.60 \mu V$) or Condition × Electrode interaction, all $F$s ≤ 0.57, $ps > .78$.

The lateral analysis corroborated the midline findings as indicated by the significant Task × Condition × Anterior-Posterior interaction, $F (1, 15) = 7.97, \text{MSE} = 1.72, p < .05$. Separate tests for the pain judgment task indicated larger amplitudes in the painful than the neutral condition over posterior ROIs ($4.23$ vs. $3.66 \mu V$), $F (1, 15) = 8.03, \text{MSE} = 1.27, p < .05$, but no significant reverse effect over anterior ROIs ($−2.86$ vs. $−2.53 \mu V$), $F (1, 15) = 7.30, \text{MSE} = 0.49, p = .02$ (Bonferroni-corrected α-level = .0125). No reliable condition effects were found in the counting task ($0.57$ vs. $0.57 \mu V$), all $F$s ≤ 1.65, $ps > .22$. In addition, there was a significant Task × Condition × Laterality interaction, $F (1, 15) = 20.02, \text{MSE} = 0.32, p < .001$, indicating in the pain judgment task a numerically more pronounced condition effect over dorsal ROIs (painful vs. neutral = $1.49$ vs. $0.88 \mu V$), $F (1, 15) = 16.89, \text{MSE} = 0.70, p < .001$, as compared to ventral ROIs ($−0.12$ vs. $0.25 \mu V$), $F (1, 15) = 16.46, \text{MSE} = 0.28, p < .01$. The condition effect was not reliable in the counting task, all $F$s ≤ 0.24, $ps > .63$.

**Time interval 500–800 ms (P3)**
The midline analysis in this time window yielded a significant main effect of condition, $F (1, 15) = 7.62, \text{MSE} = 3.66, p < .05$, due to larger ERP amplitudes in the painful than the neutral condition ($1.09$ vs. $0.63 \mu V$). Furthermore, the Task × Condition interaction was significant, $F (1, 15) = 9.51, \text{MSE} = 1.14, p < .01$. Separate tests
for the tasks implied larger amplitudes in the painful than the neutral condition in the pain judgment task ($M = 1.56$ vs. $0.80\,\mu V$), $F(1, 15) = 14.72$, MSE = $2.50$, $p < .01$, but not in the counting task ($M = 0.63$ vs. $0.45\,\mu V$), $F(1, 15) = 0.86$, MSE = $2.31$, $p = .37$. The condition effect and the Task × Condition interaction were further qualified by electrode, $F(7, 105) = 3.66$, MSE = $1.79$, $p < .01$ and $F(7, 105) = 4.84$, MSE = $1.49$, $p < .001$, respectively, indicating the previously reported effects to be maximal over Pz. The significant main effect of task, $F(1, 15) = 5.53$, MSE = $9.41$, $p < .05$, indicated larger amplitudes for the pain judgment than for the counting task ($M = 1.18$ vs. $0.54\,\mu V$).

The lateral analysis corroborated the midline findings by revealing a significant Task × Condition interaction, $F(1, 15) = 10.37$, MSE = $0.19$, $p < .01$, indicating for the pain judgment task larger ERP amplitudes in the painful than the neutral condition ($M = 0.82$ vs. $0.54\,\mu V$), $F(1, 15) = 20.04$, MSE = $0.24$, $p < .001$, whereas there was no such difference in amplitudes in the counting task ($M = 0.52$ vs. $0.50\,\mu V$), $F(1, 15) = 0.18$, MSE = $0.18$, $p = .68$. The Task × Condition interaction was further qualified by Anterior-Posterior, $F(1, 15) = 10.49$, MSE = $3.12$, $p < .01$, and Laterality, $F(1, 15) = 6.32$, MSE = $0.45$, $p < .05$.

Separate analyses revealed that over anterior ROIs, no condition effect was found, neither in the pain judgment, $F(1, 15) = 8.02$, MSE = $1.00$, $p = .013$, nor in the counting task, $F(1, 15) = 1.86$, MSE = $1.18$, $p = .19$, whereas over posterior ROIs, ERP amplitudes were more positive in the painful than the neutral condition for the pain judgment task ($M = 3.10$ vs. $2.06\,\mu V$), $F(1, 15) = 14.62$, MSE = $2.39$, $p < .01$, but not for the counting task ($M = 1.94$ vs. $2.15\,\mu V$), $F(1, 15) = 0.85$, MSE = $1.77$, $p = .37$. Over dorsal ROIs, ERP amplitudes were larger in the painful than the neutral condition for the pain judgment task ($M = 1.95$ vs. $1.16\,\mu V$), $F(1, 15) = 22.57$, MSE = $0.88$, $p < .001$, but not for the counting task ($M = 1.10$ vs. $0.85\,\mu V$), $F(1, 15) = 1.69$, MSE = $2.71$, $p = .21$, whereas there was no significant main effect or Task × Condition interaction over ventral ROIs, all $Fs < 5.04$, $ps = .04$ (Bonferroni-corrected $\alpha$-level = .025).

The significant main effect of task, $F(1, 15) = 10.93$, MSE = $0.34$, $p < .01$, was due to larger amplitudes in the pain judgment than the counting task ($M = 0.68$ vs. $0.51\,\mu V$). Furthermore, there were significant interactions of Task × Anterior-Posterior, $F(1, 15) = 4.55$, MSE = $3.72$, $p < .05$, Task × Laterality, $F(1, 15) = 6.63$, MSE = $3.39$, $p < .05$, and Task × Anterior-Posterior × Laterality, $F(1, 15) = 6.07$, MSE = $0.48$, $p < .05$. Further analyses revealed that there was no task effect over anterior ROIs ($M = -1.21$ vs. $-1.02\,\mu V$), $F(1, 15) = 1.52$, MSE = $1.56$, $p = .24$, but over posterior ROIs, amplitudes of the pain judgment task were larger than those of the counting task ($M = 2.58$ vs. $2.04\,\mu V$), $F(1, 15) = 7.30$, MSE = $2.51$, $p < .05$. A significant main effect of task was further found over dorsal ($M = 1.56$ vs. $0.97\,\mu V$), $F(1, 15) = 9.11$, MSE = $2.45$, $p < .01$, but not over ventral ROIs, $F(1, 15) = 5.04$, MSE = $0.61$, $p = .04$ (Bonferroni-corrected $\alpha$-level = .025).

**Correlational analyses**

We performed correlational analyses to test the relationship between mean ERP amplitudes measured in different time intervals for the painful condition of the pain judgment task and scores of perceived pain, self-unpleasantness and the dispositional empathy scores of the EQ and the SPF. ERP amplitudes for ROIs where ERP components were found to be most pronounced in previous studies were entered into the correlational analyses: ventral-posterior ROIs for time intervals 90–130 ms and 140–180 ms, fronto-central (N240) and lateral-posterior ROIs (EPN) for the 200–300 ms interval, and centro-parietal ROIs for the P3 time ranges (300–500 ms and 500–800 ms). Similarly, correlational tests were calculated between EQ scores and mu- and beta-band power change values over the left and right somatosensory cortex of the painful condition. The same correlational tests were conducted for the neutral condition to reveal empathy-unspecific correlations. The significance level (alpha) was Bonferroni adjusted in order to control for the problem of multiple comparisons.

There were no significant correlations between scores of perceived pain or self-unpleasantness and ERP amplitudes of the painful condition, $−.39 < r < .23$, all $ps ≥ .14$. The correlations between the SPF empathy score and ERP amplitudes of the painful condition were not significant either, $−.33 < r < .06$, all $ps ≥ .21$. Concerning EQ scores (cf. Figure 5), we found a negative correlation with P1 amplitudes at left posterior-ventral ROIs of the painful condition, $r = −.62$, $p < .05$, and of the neutral condition, $r = −.61$, $p < .05$. N1 amplitudes of painful and neutral conditions did not significantly correlate with EQ scores, $−.38 < r < −.11$, all $ps ≥ .14$. ERP amplitudes at FCz between 200 and 300 ms (N240) correlated positively with EQ scores for the painful condition, $r = .57$, $p < .05$ (cf. Figure 5), but not for the neutral condition, $r = .50$, $p = .05$ (Bonferroni-corrected $\alpha$-level = .025).

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1Correlational analyses of ERP amplitudes of the painful condition and all subscales of the SPF only revealed one significant correlation between the subscale Personal Distress and ERP amplitudes over left posterior ventral ROIs from 90 to 130 ms, $r = .58$, $p = .017$. 
whereas there were no significant correlations for posterior ROIs (EPN), $-0.49 < r < -0.42$, all $p_s \geq .05$. Additionally, amplitudes of the rising P3 at Pz between 300 and 500 ms did not significantly correlate with EQ scores neither in the painful condition, $r = -0.55$, $p = .027$ (Bonferroni-corrected $\alpha$-level = .025), nor in the neutral condition, $r = -0.53$, $p = .03$. Between 500 and 800 ms, there was a correlation between EQ scores and the P3 amplitudes of the painful condition, $r = -0.59$, $p < .05$, as well as the neutral condition, $r = -0.72$, $p < .01$ (cf. Figure 5).

Oscillatory EEG activity

Percentage power change values were subjected to ANOVA with variables condition (neutral, painful), task (pain judgment, counting), and hemisphere (left, right).

Time interval 300–600 ms

The analysis of mu-band (7–12 Hz) power in this time window revealed an ERD ($-7.43\%$) that was not significantly different from zero, $t (15) = -1.06$, $p = .31$, and did not produce any significant effects including the factors task or condition, all $F_s \leq 2.29$, $p_s > .15$. In contrast, the analysis of beta-band (13–18 Hz) power in the time interval from 300 to 600 ms after stimulus presentation revealed an ERD ($-25.70\%$) significantly different from zero, $t (15) = -7.77$, $p < .001$, but did not reveal any significant main effect or Task × Condition interaction, all $F_s \leq 1.57$, $p_s > .23$ (cf. Figure 6).

Time interval 700–1500 ms

The analysis of mu-band (7–12 Hz) power yielded an overall ERD ($-10.15\%$) significantly different from zero, $t (15) = -2.15$, $p < .05$, a main effect of condition, $F (1, 15) = 11.15$, MSE = 273.90, $p < .01$, due to larger ERDs in the painful than the neutral condition ($-15.04\%$ vs. $-5.27\%$) (Figure 6), and a main effect of task, $F (1, 15) = 5.50$, MSE = 550.70, $p < .05$, due to larger ERDs in the pain judgment than the counting task ($-15.02\%$ vs. $-5.29\%$).

The overall ERD ($-1.61\%$) of beta-band (13–18 Hz) power in this time interval did not significantly differ from zero, $t (15) = -0.29$, $p = .78$, but the analysis yielded a significant main effect of condition, $F (1,
15) = 15.92, MSE = 180.80, p < .01, indicating a decrease in power in the painful compared to the neutral condition (−6.36% vs. 3.13%) (Figure 6). The main effect of task, F (1, 15) = 6.37, MSE = 518.00, p < .05, indicated decreased power in the pain judgment compared to the counting task (−6.69% vs. 3.46%). The reliable Condition × Task × Hemisphere interaction, F (1, 15) = 4.94, MSE = 32.71, p < .05, reflected a decrease in power in the painful compared to the neutral condition in the counting task (−2.57% vs. 9.50%), F (1, 15) = 11.23, MSE = 207.40, p < .01, and a Condition × Hemisphere interaction in the pain judgment task, F (1, 15) = 6.88, MSE = 30.87, p < .05. Further tests for the pain judgment task revealed a numerically larger, but non-significant condition effect over the left hemisphere (−7.46% vs. 3.09%), F (1, 15) = 5.88, MSE = 151.50, p = .03 (Bonferroni-corrected α-level = .0125), compared to the right hemisphere (−12.83% vs. −9.56%), F (1, 15) = 1.15, MSE = 73.91, p = .30.

**Correlational analyses**

There were no significant correlations between EQ or SPF scores and power change values in the mu- or beta-band for the 300–600 ms time interval, −.15 < r < .48, all ps ≥ .06. However, for the mu-band we found a significant correlation between EQ scores and power change values between 700 and 1500 ms for the painful condition over the right, r = .58, p < .05, but not the left sensorimotor cortex, r = .50, p = .05 (Figure 5), whereas those for the neutral condition were not significant, r = .40, p = .12 and r = .31, p = .25. There were no significant correlations between SPF scores and power change values in the mu-band in this time interval, .22 < r < .41, all ps ≥ .11.

The correlational analyses of beta-band oscillations over the left and right somatosensory cortex in the late time interval did not reveal any significant correlation between EQ scores and power change values of the two conditions, .21 < r < .39, all ps ≥ .13. For the SPF score, there were no reliable correlations with power change values in the beta-band either, .27 < r < .46, all ps ≥ .07.

**Discussion**

In this study, compared to similar others, we used a more comprehensive set of behavioral and brain-based measures to investigate the time course of empathy-related influences on information processing (cf. Figure 1). The main novel findings of this study concerned (a) the EPN, which indicated an early automatic component of empathy for pain, (b) empathy-related and task-dependent facilitation of the motor system by painful stimuli, and (c) that motor readiness was generally increased for both tasks after the response to painful stimuli. In the following, these and other findings will be discussed in more detail.

First, it is worth noting that the present experiment produced the expected behavioral effects. Thus, the relatively high scores in ratings of perceived pain and self-unpleasantness, as well as the positive correlation between the two measures, suggest that painful stimuli...
indeed influenced participants' affective state. In addition, response accuracy was generally high in both tasks and for all participants. More specifically, responses were more accurate for painful than neutral stimuli when pain judgments were required, most likely indicating that painful stimuli automatically capture attention in contrast to neutral stimuli. This assumption is also supported by the finding that for the counting task, responses to neutral stimuli were more accurate than to painful stimuli. Here, attention is attracted by task-irrelevant pain-related stimulus features, away from task-relevant ones, thereby obstructing processing of painful stimuli in the counting task. The latter conjecture is corroborated by faster responses to painful than neutral stimuli in the pain judgment task and a reverse RT effect in the counting task.

Second, and more importantly, present results provide novel insights regarding the time course of automatic and controlled processes of empathy for pain. In the following, we discuss key findings with regard to the information processing model depicted in Figure 1. Concerning early perceptual processes, it is instructive that painful compared to neutral stimuli did not differentially influence P1 and N1 amplitudes over lateral posterior regions, speaking against the possibility that pictorial (physical) differences influence information processing. Moreover, it is worth noting that, despite the fact that we used the same picture set, we could not replicate the early fronto-central empathy-related ERP effect of Meng, Hu and colleagues (2012) who reported more positive-going ERP amplitudes to painful than neutral stimuli like others (Decety et al., 2010; Fan & Han, 2008). However, the present absence of early empathy-related effects over fronto-central ROIs accords with similar zero effects reported previously (Lyu et al., 2014; Mella et al., 2012; Sessa et al., 2013). In the 200–300 ms time interval, again, we did not find any empathy-related ERP amplitude effects over fronto-central regions, in contrast to some previous reports (Fan & Han, 2008; Meng, Hu et al., 2012). Unfortunately, we do not have a straightforward explanation for these discrepancies, except that our study differed from others with regard to the sample (e.g., young Asian vs. slightly older German participants), task (e.g., pain intensity rating vs. pain judgment), and the EEG recording (e.g., right mastoid reference vs. average reference). Future studies should test participants with different cultural background and age using the same stimulus, task, EEG recording and analysis procedures to reveal potential causes underlying the varied ERP amplitude findings across studies. Also, it should be examined whether possible attentional influences on early perceptual processing as indicated by early posterior ERP components are related to fronto-central empathy-related ERP effects. Furthermore, a final limitation of our study concerns the sample size, since we tested only 16 participants, which might limit the statistical power of the present study.

Crucially, in line with the assumption of an automatic empathic response within information processing, we found painful compared to neutral stimuli to trigger a more negative, task-independent EPN component. We take this finding to reflect the selective processing of affectively arousing stimuli (cf. Olofsson et al., 2008), following initial perceptual encoding as reflected by P1 and N1. Given the fact that the EPN is triggered by salient emotional stimuli (cf. Olofsson et al., 2008), we assume that the influence of painful stimuli on information processing is of affective but empathy-unspecific nature.

In line with previous studies (e.g., Fan & Han, 2008; Mella et al., 2012), P3 amplitudes over posterior regions were larger for painful than neutral stimuli in the pain judgment task but not in the counting task. We take this P3 amplitude effect to reflect a late empathic influence on the categorization stage (Donchin, 1981; for a review, see Polich, 2007). More specifically, like Fan and Han (2008) we interpret the P3 effect in our study as reflecting the controlled, top-down empathic response on information processing. Together, present EPN and P3 amplitude findings provide converging evidence for the late appraisal model (de Vignemont & Singer, 2006), which assumes that empathic cues influence processing before their cognitive appraisal, the latter only modulating late empathic responses as indicated by the P3 component.

Importantly, the present study offers novel insights regarding empathic influences on late motor processing stages (cf. Figure 1). Thus, the analysis of RF showed that participants responded more forcefully to painful than neutral stimuli in the pain judgment but not the counting task. This finding supports the idea that motor responses are facilitated when watching others experiencing pain, contingent on the controlled categorization stage because of the task-dependence. The faster responses to painful than neutral stimuli when attending the pain dimension can also be explained by motor facilitation. Thus, in line with the RT results of Meng, Shen et al. (2012) and Grecucci, Koch, and Rumiati (2011), we assume that the readiness of a reactive movement is increased by the task-relevant observation of another individual in pain, leading

2After re-referencing to the right mastoid as reference, we did not find any early fronto-central ERP condition effect either.
Somewhat surprisingly, though, we did not find these motor system changes being reflected by mu- and beta-band power ERD in the time interval close to the response (300–600 ms). In this respect, our ERD results contrast with those of Riečanský et al. (2014), who found increased beta ERD when participants were watching videos of moving needles and increased mu ERD when participants were watching the static endpoint of the painful video. A possible explanation for the discrepant results is that participants watched dynamic painful versus neutral stimuli in the study of Riečanský and colleagues, whereas in the current study participants performed a choice response task to static stimuli. Static stimuli may exert a weaker influence on the motor system than dynamic stimuli, as indicated by Riečanský et al.’s finding of smaller beta-band ERD effects during the static treatment-endpoint of the videos. Since overt responses are preceded by large beta-ERDs (e.g., Androulidakis et al., 2007; Neuper & Pfurtscheller, 2001), as observed here too, it is further conceivable that present strong choice-response-related ERD effects masked the much smaller differential beta-ERDs induced by static painful versus neutral stimuli which become visible in a passive viewing task. Future studies should examine whether the nature of stimulation, response demands, or both factors play a role in producing the beta-ERD effects, and further test for condition-specific mu-ERD effects, which were absent in the present study. Also, since Avenanti et al. (2009) found that the muscle of the hand corresponding to the one penetrated in the stimuli was inhibited, whereas the corticospinal excitability of the muscles of the other hand was increased, future studies should separately measure RF of participants responding to painful and neutral stimuli that depict the corresponding finger versus a finger of the opposite hand.

In contrast to ERDs in the response-related analysis interval, we observed larger ERDs in the painful than the neutral condition in the mu- and beta-band in the late time interval preceding the presentation of the next stimulus (700–1500 ms). Since this ERD effect was found for both the pain judgment and the counting task, it appears to reflect an automatic activation of the motor system following the response to empathy-evoking stimuli, thereby increasing motor readiness to forthcoming events. Similarly, the larger ERD in the pain judgment than the counting task in the late time interval indicates an enhanced preparedness for processing the forthcoming stimulus. Since tasks changed between blocks, participants might be more attentive in processing the pain-related than the counting-related stimulus dimension. In line with this attentional account, P1 amplitudes tended to be more positive in the pain judgment than the counting task.

Finally, concerning the relationship between individual empathic dispositions and brain-based measures of situational-empathic influences on information processing (e.g., Decety, Lewis, & Cowell, 2015), we obtained some unexpected results. Before discussing these results in more detail, it is first worth noting that both SPF and EQ showed high internal consistency and were therefore considered as reliable measures of dispositional empathy. Whereas the SPF scores did not reliably correlate with ERP amplitudes or changes in the power of oscillatory brain activity, we found a negative correlation between EQ scores and P1 amplitudes over left posterior-ventral regions, as well as P3 amplitudes over Pz for painful stimuli in the pain judgment task, such that participants with increasing trait empathy showed increasingly smaller P1 and P3 amplitudes. Of course, it must also be mentioned that neutral stimuli produced similar correlations, suggesting a stimulus-unspecific effect. In line with Ikezawa, Corbera, and Wexler (2014), one possible account for the direction of the correlation is that persons with high trait empathy down-regulate the sensory and affective processing of incoming stimuli in order to avoid being overwhelmed by their empathic feelings in the case of painful stimuli. As a result of such emotion regulation, P3 amplitudes would decrease (see also Hajcak, MacNamara, & Olvet, 2010). In line with this assumption, Decety et al. (2010) found smaller P3 amplitudes in physicians who have to regulate their empathic responses in their everyday working life. Additionally, there were positive correlations between EQ scores and N240 amplitudes over FCz in the painful but not the neutral condition. Crucially, the positive correlations between EQ scores and mu-band activity over the right somatosensory cortex in the post-response interval (700–1500 ms) were specific for painful stimuli, supporting the relationship between late motor changes and empathy-evoking stimuli. Again, the direction of the correlation might indicate the down-regulation of the motor system with increasing dispositional empathy.

In conclusion, the present study extended our understanding of empathy for pain influences on perception, decision, and motor processing by the combined recording and analysis of RT, RF, ERPs, and oscillatory brain activity (ERD). Thus, the EPN component demonstrated
the automatic and enhanced perceptual processing of empathy-evoking stimuli. In line with previous reports, the subsequent P3 component indicated top-down controlled empathic influences on stimulus categorization. RF and RT findings suggested that the observation of others in pain activates the motor system, an effect that was task-dependent and not mediated by arousal. Finally, empathy-evoking stimuli differentially influenced oscillatory EEG activity following response execution, indexing increased motor readiness. Taken together, while being generally in line with the late appraisal model of empathy (de Vignemont & Singer, 2006), our findings also indicate that empathy-provoking stimuli produce automatic and controlled effects within the motor system at different time points.

Acknowledgments

We wish to thank Jing Meng for providing the pictorial stimuli. Sarah Fabi was supported by a doctoral scholarship of the Federal State Baden-Württemberg (LGFG).

Disclosure statement

All authors report no financial interests or potential conflicts of interest.

Funding

Sarah Fabi was supported by a doctoral scholarship of the Federal State Baden-Württemberg (LGFG).

References


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