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Interoceptive empathy and emotion regulation: the contribution of neuroscience

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ABSTRACT

Sensory and cognitive processes connected to emotions are perceived as changes in body conditions and are encoded as affective feelings, also thanks to the contribution of interoception pathways. Interoception refers to the perception of internal body signals and has been previously related to emotion regulation processes and empathic response, even in the clinical neuroscience domain concerning emotional and social disorders. It is worth to note that interoception shares brain circuits, such as the anterior insula and portions of the prefrontal cortex, and physiological correlates involved in the empathic behavior, especially in response to pain perception. Thus, given the highly connoted emotional and sensory characteristics of the pain experience, empathy for pain studies represent an interesting ground for deepening the effects of an intentional interoceptive focus on the brain-and-body physiological response. In this context, a multi-method neuroscientific research protocol was recently developed, and its potential will be here discussed in the light of future application fields.

Keywords: interoception; emotion regulation; empathy for pain; BIO-fNIRS-EEG co-registration

1. The common thread between interoception, emotions, and empathy

This short contribution aims to suggest that, in the study of emotions, it is necessary to dedicate a space to the contribution of a specific type of perception related to the internal bodily information that contributes to the formation of an emotional experience, that is interoception.

Interoception refers conventionally to the afferent processing of signals that originate within the body and refer to the state of the body (Craig, 2002). Interoception differs both from proprioception (the perception of the position or movement of the body) and from the sensory perception of the environment through the five senses. It includes most of the body signals, such as information that is relevant for homeostatic control and physiological needs (hunger, thirst, heat, pain), the signals processed at the level of the central nervous system that provide information on the general state of the body (that is, on the state of health and disease), as well as the neural and mental representation of the internal changes of the body.

Taking a step back, Aristotle was perhaps the first who in ancient Greece postulated the presence of sensations - *aisthêseis* - and passions - *pathê* - defined as "affects" of the perceptive soul, in all beings endowed with sense organs and perceptive systems (Oppedisano, 2009). And, since ancient Greece, human beings have been wondering what are the mechanisms that allow them to perceive the world and experience an emotion, as a condition capable of suddenly changing and influencing behavior.

These questions begin to find some plausible answers from the conceptualizations of James and Lange (1922) onwards, up to the more recent peripheral emotional theories, which suggest how internal physiological sensations are able to evoke emotional responses and affective states in individuals influencing their behavioral response. Emotions are configured as characterized by psychophysiological processes that mark and direct the allocation of physiological and psychological resources to adapt the behavior of individuals to the external environment. Furthermore, the physiological expression of emotion includes changes within internal organ systems, which are driven by autonomic nerve responses usually independent of conscious control. In this domain, the study of interceptive signals is closely connected to the study of emotions, behavioral motivational systems and the regulation of emotions, since interoceptive cues vary in terms of motivational imminence (from the urge to feel thirsty to the perception of acute pain) and also include feedback from physiological changes induced by emotions (Critchley et al., 2004).

Given these premises, it is possible to state that interoception is configured as the way through which the sensory and cognitive processes connected to emotions are perceived as changes in body conditions and are encoded in affective feelings (Tsakiris & Critchley, 2016). These bodily processes have also been intimately linked to socio-cognitive and affective functions, such as empathy. Indeed, awareness of one's bodily processes also influences social awareness. Empathy is configured as a multidimensional concept and refers, respectively, to the ability to share another person's emotional states and to infer that person's experiential states (Balconi & Canavesio, 2013; Balconi & Vanutelli, 2016; de Vignemont & Singer, 2006). The latter inferential ability is closely related to the constructs of the theory of mind and can adopt a probabilistic inference cycle (which includes a feedback prediction error) similar to what has been proposed for cognitive, perceptual and emotional abilities (Wu & Schulz, 2018).

Evidence from previous empirical studies suggests that there may be interdependence between interceptive sensitivity (SI) and affective or cognitive empathic responses (Ernst et al., 2013; Fukushima et al., 2011; Handford et al., 2013; Terasawa et al., 2014). Accurate perception of one's bodily states and their representation shape both affective and cognitive empathic experience, and feedback from visceral activity can contribute to inferences about the affective state of others.

As recently suggested, this interoceptive ability allows us to be more empathetic and to evaluate the bodily experience that other people experience (Grynberg & Pollatos, 2015). This hypothesis is also consistent with the idea that impaired access to one's emotional state and feelings is directly associated with the altered simulation of the emotional state and feelings of the other, leading to less empathic experience (Balconi et al., 2011; Balconi & Bortolotti, 2012b, 2012a, 2014; Balconi & Canavesio, 2013, 2016).

In addition, people's interoceptive capacity is not static and there are individual differences in the extent to which interoceptive signals reach awareness. This aspect is configured as a trait component, which can modulate both the subjective experience of emotion and the ability of subjects to distinguish "self" from "other" in multisensory contexts (Ainley et al., 2014).

In particular, it has been shown that, when visual stimuli describing other people in suffering conditions were observed, a higher Interoceptive Sensitivity (IS) (determined by a heartbeat perception task) is associated with a greater estimated degree of pain (result interpreted as representative cognitive empathy), as well as a greater state of arousal and feelings of compassion (evidence indicating the activation of the affective component of empathy) (Grynberg & Pollatos, 2015). Sharing the activation of these circuits at a neurophysiological level also allows individuals to activate their body's representations of pain when they observe someone who suffers, leading to more intense empathic responses (Singer & Lamm, 2009).

Besides, IS contributes to emotional experience and psychophysiological response in terms of arousal: a higher SI has been associated with higher physiological activation and a greater deceleration of heart rate in response to emotional stimuli that can induce an empathic experience (Pollatos et al., 2007). To confirm this, IS, the subjective experience of emotions and cardiovascular arousal are associated with the activation of similar brain regions (such as the anterior insula and the anterior cingulate cortex) at the neural level (Critchley et al., 2004; Ernst et al., 2013). Clinically, higher IS has been shown to be associated with lower levels of alexithymia (Herbert et al., 2011). Greater activation in the brain regions mentioned above could explain the associations between high IS, low levels of alexithymia and a more intense emotional experience.

Finally, the potential impact of interceptive awareness on the distinction between self and others was also considered in the motor domain, as a specific form of "empathic resonance of action", with particular reference to the observation of the action and the behavior of the imitation (Ainley et al., 2014). In fact, in automatic imitation, the inhibition of imitation is an indicator of an individual's success in distinguishing internally generated motor representations from those triggered by observing the action of another person. Potentially, a high IS implies more accurate interceptive representations of the consequences of an action, implying greater empathy, greater motor reactivity in response to the observed action and therefore a greater tendency to imitate.

Recent research suggested that people more sensitive to interoceptive signals may experience more intense emotions or better emotional control.

Individual differences in interceptive ability were quantified using behavioral questionnaires and tests that exploit the natural fluctuations of internal physiological signals (such as applying tasks such as the Heartbeat Detection Task, which measures the ability to estimate one's heart rate cardiac, under stress; Garfinkel & Critchley, 2016). Hence, individuals with higher interoceptive sensitivity can experience more intense emotional experiences (Wiens et al., 2000) and show greater activation of brain areas that are believed to play a key role in emotional processing [insular cortex, dorsolateral prefrontal cortex (DLPFC), Anterior Cingulate Cortex (ACC) and ventromedial prefrontal cortex (vmPFC)] and somatosensory processing (somatosensory cortex) (Critchley et al., 2004).

2. Interoception and emotion regulation: insights from clinical neuroscience studies

The present paragraph focuses on clinical neuroscience research suggesting a connection between interoception, emotion regulation process, and empathy also from a clinical perspective. Indeed, previous studies showed a close association between impaired interoception and the development of psychopathologies, even supposing that the first may be a precursor of the disorders and their effects on emotion regulation (Murphy et al., 2017).

Firstly, impaired interoception could also have consequences on the ability to develop an empathic response and to interact and get into a relationship with others. Indeed, interoception provides a path through which the physiological state, the integrity and the physical health of the body condition the repertoire of emotions and motivational behaviors that an individual could experience and implement towards other individuals (Pace-Schott et al., 2019).

As confirmation of the strict link between interception and regulation of emotions, a wide variety of disorders related to emotions, such as depression (Furman et al., 2013) and alexithymia (Herbert et al., 2011), have been associated firstly with anomalies of interoceptive sensitivity and, secondly, with altered activation of the brain structures involved in the processing of interoceptive signals (Berthoz et al., 2002). An increase in interoceptive sensitivity has been widely documented in patients with panic disorder and euphoric manic state or emotional lability of borderline personality disorder (De Cort et al., 2017). Furthermore, the interoceptive signals are the main reinforcements (positive and negative) that perpetuate the disturbances from substance use (Paulus & Stewart, 2014). Finally, anomalies at the level of interoceptive skills have also been detected in psychosis and obsessive-compulsive disorder (Yoris et al., 2015) and chronic psychosomatic pathologies, such as fibromyalgia.

Specifically, fibromyalgia (FM) has been considered an "amplification syndrome" due to the increased attention that patients turn to the interceptive signals that arise within the body and which have been shown to negatively influence affective aspects of pain (Borg et al., 2015). However, FM is not only characterized as a chronic pain disorder and intensified interceptive ability, but also by a possible mood regulation deficit (Rost et al., 2017). Specifically, previous studies showed firstly a strong positive correlation between intensity of pain and interoceptive awareness, and secondly an increased vigilance to internal bodily cues (Martínez et al., 2018).

Furthermore, regarding the life span, previous studies have suggested that anomalies in the interoceptive ability can determine (as an endophenotype) the onset of mental illness and risky behavior in adolescence and the consequent reduced socio-emotional capacity detected in late adulthood (Murphy et al., 2017). Indeed, failure to recognize interoceptive signals can contribute to a lack of empathy in antisocial personality disorder (Nentjes et al., 2013).

3. "Interoceptive empathy" for pain? A new research protocol

Regarding the large body of research exploring pain, a fertile example of what we are discussing concerns empathy for pain. Indeed, it has been suggested that there may be a correspondence between the observation of pain experienced by another person and the activation of an empathic response that evokes the sensation of self-reported pain.

The evidence from fMRI studies underlines that observing another person who experiences pain activates neural circuits involved in the painful condition experienced in the first person, involving regions specialized in the affective-motivational dimension of pain, for example, the Anterior Insula (AI) and the ACC (Lamm et al., 2007), the activation of which is related to the test scores that measure empathy as a dispositional trait (Gu et al., 2010; Singer et al., 2004). Furthermore, also the areas of the brain specialized in the elaboration of the emotional qualities of pain and in coding the position and intensity of pain seem to be activated. Above all, the primary and secondary somatosensory areas (S1 and S2) are activated, showing a somatomotor preparation of pain relief. While, when participants focused on the intensity of the observed stimulus, S1 activation increases, similarly to when the pain situation is somatosensory perceived (Osborn & Derbyshire, 2010). Therefore, in line with this evidence, it has been suggested that the empathic response to the observation of pain may involve sharing the effect of pain (Lamm et al., 2016).

In an fMRI study, Danziger and colleagues (2009) demonstrated that patients with rare Congenital Insensitivity to Pain (CIP), showed the activation of the anterior MidCingulated Cortex (aMCC) and AI when observing other people in painful situations (Danziger et al., 2009). However, given their syndrome, they have never experienced pain before. Accordingly, a question might arise spontaneously. Can we share a pain that we have never "experienced"? It seems so.

The theories of empathy differ in the contribution of the automatic resonance mechanism and the perspective-taking mechanism in understanding the emotions of others. For example, patients with the rare aforementioned syndrome, CIP, cannot rely on mirror matching mechanisms to understand others' pain. However, as anticipated, normal neurophysiological responses have been shown, during the observation of pain experienced by other people, in the aMCC and the AI, two key regions of the so-called "shared circuits" for the pain experienced on oneself and the other-selves. In these patients (but not in healthy controls), trait empathy appears to predict vmPFC responses to somatosensory representations of others 'pain and posterior cingulate responses to emotional representations of others' pain. These results underline the main role of prefrontal structures in emotional perspective-taking and in understanding other people's emotions despite the lack of previous personal experiences connected to them. This embodiment process is an empathic challenge often raised in studies that explore human social interactions.

In the empathy for pain field of study, it has been suggested that empathy for pain matures from an exteroceptive process based on sensory input from the environment (during childhood) to an interoceptive mechanism supported by representations of one's own bodily experiences in adulthood (Levy et al., 2018). Authors' found this progression involves the gradual orchestration of several brain rhythms (alpha, beta and gamma frequency bands), distinct neural networks (involving bilateral S1 and the central sulcus for children and adolescents vs. bilateral S1, the parietal cortex and left visceromotor cortex for adults), and mechanisms of enhancement (beta and gamma) with those of suppression (alpha) (Levy et al., 2018).

Interestingly, in this study, visceromotor gamma activity was found in a network supporting interoceptive representations, result that may reflect firstly, the understanding that the other, not the self is in pain and, secondly, the recruitment of embodiment and affective salience mechanisms to evaluate and "take part in" others' emotions. Specifically, this band activity in frontal cortex may track the shift from sensory self-based to interoceptive representational other-focused empathy and it may mirror human developmental stages, since it was detected in adults (Levy et al. 2018). Also previous authors supposed that in the case of empathy for pain, gamma oscillations fine-tune the affective sharing and cognitive processing of another human's pain on the basis of one's own bodily self (Shipp et al., 2013). This is in line with recent advances in the study of interoception suggesting that the agranular visceromotor cortex generates predictions about the expected state of the body on the base of sensory input (Feldmann Barrett & Simmons, 2016).

Since bodily sensations underlie most if not all of our emotional feelings, the ability to identify, access, understand, and respond appropriately to the patterns of internal signals, that is interoceptive awareness, provides a distinct advantage to engage in life challenges and on-going social and emotional adjustments (Craig, 2002). From an embodiment perspective, the accurate detection and evaluation of cues related to personal physiological reactions is accompanied by appropriate regulation strategies that temper and influence the emotional response toward others. Therefore, interoception has a role in supporting regulated response to sensations related to the state of the body (e.g., sensations of hunger and pain) as well as emotion sensations (i.e., emotion regulation) directed at social bonding (e.g., positive emotion, intimacy and empathy response) (Price & Hooven, 2018).

Higher order social functions, such as empathic response to pain, were previously shown to elicit increased brain responses within the prefrontal cortex (specifically DLPFC; Rêgo et al., 2015; Wang et al., 2014). The abilities to monitor and regulate emotional processes are parts of a functional psychophysiological model of empathic behavior (Chauhan, Mathias, & Critchley, 2008) which includes processes of emotional resonance. These are constituted by an affective response to another person, which often entails knowing what another person is feeling; sharing that person's emotional state; and, in some cases, having the intention to respond compassionately to another person's distress (Cacioppo & Cacioppo, 2020). Specifically, the emotional behavior, in addition to the cognitive ability to share mental representations, constitute the basic components of empathy (Decety & Svetlova, 2012). However, limited previous studies explored empathy by using stimuli consisting of real interpersonal situations and found increased PFC activation and skin conductance response when subjects empathized with the interpersonal scenario, together with an hemispheric lateralization effect according to the valence of the interpersonal stimuli (left for positive and righ for negative; Balconi & Vanutelli, 2017). Moreover, these previous studies did not manipulate participants interoceptive awareness linked to their neural and psychophysiological response implicit response, neither they tested if this manipulation may have an impact on their body-brain response features.

Thus recently, to deepen the link between interoception and empathy by adopting a neuroscientific perspective, we developed a research protocol with the main aim of observing and analyzing how a direct focus on one's bodily sensations and interoceptive signals can increase the empathic and sensory responses of the healthy participants involved in the experiment. For these reasons, our study also aims to investigate the relationship between individuals' interceptive capacities and empathy for pain. The decision to explore the dimension of empathy for pain from an interoceptive point of view is based on at least three key reasons: i) the highly connoted emotional characteristics of the pain response, ii) the marked neurophysiological and psychophysiological activation traceable following the exposure of a stimulus evoking empathy for pain, and iii) the involvement of strictly sensorial and affective cortical areas.

Is a greater interoceptive sensitivity connected to an affective and cognitive empathic experience experienced both at a neurophysiological and psychophysiological level?

To what extent do increased interoceptive sensitivity and interoceptive awareness allow one to deduce the subjective experience of pain experienced by another individual?

To find an answer to these questions, an experiment was conducted in which healthy adult individuals observed complex social images related to the issue of pain while focusing or not on their internal sensations. Individuals were randomly divided in two different groups: the experimental group was requested to pay attention on its bodily and neural changes, thus being assigned to the “direct interoception” condition, while the control group did not receive any explicit instruction regarding interoception, therefore being assigned to the “indirect interoception” condition. In this way we strived to manipulate participants interoceptive focus.

At the same time, their brain neurophysiological (electrophysiological and hemodynamic) and psychophysiological response to stimuli were detected, thanks to the application of tools such as electroencephalography (EEG), functional near-infrared spectroscopy (fNIRS) and autonomic measurements. The multidimensional feature of the construct of empathy, previously explored by taking into consideration peripheral autonomic activity, it less intelligible with traditional study and investigation methods only (Balconi & Bortolotti, 2012b). For this reason, here it was decided to use a multimethod protocol that involves the use of different and complementary neuroscientific techniques. An EEG system has been used to detect the electrical activity of the brain, meanwhile adapted with fNIRS co-registration in order to record the hemodynamic activity of PFC and the somatosensory cortex (Balconi et al., 2015).

A meta-analysis study conducted by Lamm and colleagues (2011) underlined how, after the presentation of an emotional pain stimulus, activation of the bilateral inferior parietal cortex and somatosensory primary parietal cortex, of the bilateral inferior gyrus, of the anterior insula, of the mPFC and DLPFC was detected. In particular, the DLPFC has been identified as a key region for the experience and regulation of emotional responses (Balconi & Bortolotti, 2012b). For these reasons, we decided to investigate the effect of interoceptive ability on the activation of the prefrontal and somatosensory areas (located in the Broadmann areas BA1, BA2, BA3) during the observation of stimuli related to empathy for pain. Moreover, at the end of the experiment we explicitly asked participants to provide answers regarding their internal sensations, including emotions experienced while observing the wide set of stimuli (manipulation checks phase). In addition, both groups underwent the Heartbeat Detection Task (Schandry, 1981) to test individuals' basic interoceptive sensitivity.

To date, experimental data are still undergoing the processing phase. However, this protocol could allow us to test the experimental evidence derived from previous studies according to which a greater interoceptive sensitivity measured with the heartbeat detection task proves to be related to greater levels of empathy (measured by questionnaires). Secondly, a direct focus on one's own interoceptive experiences while observing individuals who receive painful stimulation during the experimental task can influence the marked activation of physiological correlates and somatosensory brain areas and/or frontal areas connected to emotions and empathic response (such as the prefrontal cortex, in the specific dorsolateral portion). Thirdly, we suppose this body-brain empathic effect is possibly amplified by a complex and relatively ecological scenario that involves a social interaction between two individuals, instead of an image representing a single person (receiving painful or nonpainful situation). One of the main strengths of this research consists in the integration of data deriving from neurophysiological detections with behavioral results, obtained at the Heartbeat detection task, and self-report, detected by the scores of the questionnaires that evaluate empathy (affective and cognitive), body perception, perceived pain level, motivational systems of the participants involved in the study.

This neuroscientific research will not be limited to the study of empathy for pain, but it could be considered as an assessment protocol that could be applied to the study of the link between a direct and intentional interoceptive focus and its effect on emotion regulation and empathic response in a wide variety of contexts, both in the clinical and health domains. On one hand, it could be applied to orientate clinical interventions in enhancing the interoceptive awareness or diminishing the interoceptive sensitivity of clinical populations (such as addictions and the disorders abovementioned), in order to support the person in restoring the functional connection between its physiological state, self-perception and emotional regulation. Regarding future intervention protocols, neuroscientific techniques such as biofeedback and neurofeedback devices could be adopted to train individuals' interoceptive skills (both at the physiological and neural level). On the other hand, this study could interestingly stimulate the development of training focused on interoceptive ability and dedicated to functional empowerment or enhancement of the brain-and-body system self-awareness. Also, these training could benefit of the abovementioned neuroscientific devices and could be applied in several well-being contexts, where the knowledge and awareness of one's psychophysiological correlates in complex social situations can improve one's performance, such as sports, organizational relations, strategic decision-making, and real-world high-stakes risk-taking (such as financial trading).

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