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Reading others' emotions: Evidence from event-related potentials

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Abstract (English)

This Thesis aimed at investigating, by using the event-related potentials (ERPs) technique, some relevant aspects involved in human ability to read others' emotions and in empathizing with others' affective states. Social and affective neuroscience has largely studied faces and facial expressions since they represent relevant "pieces of information" in guiding individuals during interaction. Their importance is strictly related to the fact that they provide unique information about identity, gender, age, trustworthiness, and attractiveness, but they also convey emotions.

In Chapter 1, I have introduced the reader to the contents of this Thesis, in particular the ability to "read" others' facial expressions and to empathize with others' affective states.

In Chapter 2, I have offered an overview of knowledge available today on how humans process faces in general and facial expressions in particular. I have proposed a theoretical *excursus* starting from Bruce and Young's cognitive model (1986) to a recent simulative model of recognition of emotional facial expressions by Wood and colleagues (2016), which considers facial mimicry helpful in discriminating between subtle emotions.

In Chapter 3 and 4, I have presented two different studies (Experiments 1 and 2, respectively) strongly related to each other, since they aimed both at testing a functional link between the visual system and facial mimicry/sensorimotor simulation during the processing of facial expressions of emotions. I have described two different studies in which ERPs, by virtue of its high temporal resolution, allowed to track the time-course of the hypothesized influence of mimicry/simulation on the stages of visual analysis of facial expressions. The aim of Experiment 1 was to explore the potential connection between facial mimicry and the early stage of the construction of visual percepts of facial expressions; while the Experiment 2 investigated whether and how facial mimicry could

interact with later stages of visual processing focusing on the construction of visual working memory representations of facial expressions of emotions, by also monitoring whether this process could depend on the degree of the observers' empathy. For both studies, the results strongly suggest that mimicry may influence early and later stages of visual processing of faces and facial expressions.

In the second part of my Thesis, I introduced the reader to the construct of empathy, dealing with its multifaceted nature and the role of different factors in the modulation of an empathic response, especially to others' pain (Chapter 5).

In Chapter 6 and 7, I have discussed two ERP studies (Experiments 3 and 4a) with one behavioral study included as a control study (Experiment 4b) to investigate the empathic reaction to others' pain as a function of different variables that could play a role in daily life. Experiment 3 investigated the role of prosodic information in neural empathic responses to others' pain. Results from this study demonstrated that prosodic information can enhance human ability to share others' pain by acting transversely on the two main empathy components, the experience sharing and the mentalizing. The aim of Experiment 4a was to study whether the physical distance between an observer and an individual in a particular affective state, induced by a painful stimulation, is a critical factor in modulating the magnitude of an empathic neural reaction in the observer. Thus, by manipulating the perceived physical distance of face stimuli, I observed a moderating effect on empathic ERP reactions as a function of the perceived physical distance of faces. Results of Experiment 4b clarified that the critical factor triggering differential empathic reactions in the two groups in Experiment 4a was not related to the likelihood of identifying the faces of the two sizes but to the perceived physical distance.

Finally, in Chapter 8, a general discussion highlights the main findings presented in this Thesis, by also providing future suggestions to extend the research on this topics debated in the previous Chapters.

Abstract (Italiano)

Questo elaborato ha l’obiettivo di indagare, tramite l’utilizzo della tecnica dei potenziali evento-relati (ERPs, Event-Related Potentials), alcuni aspetti che caratterizzano e guidano l’interazione sociale umana, come l’abilità di leggere e comprendere le emozioni altrui. Le neuroscienze sociali hanno studiato nel dettaglio volti ed espressioni facciali, in quanto stimoli che, oltre a fornire informazioni uniche circa l’identità, il genere, l’età, l’affidabilità, l’attrattività e la direzione dello sguardo, tramettono indicazioni circa gli stati emotivi dell’altro.

Il Capitolo 1 fornisce una panoramica teorica, *primum*, rispetto al processamento dei volti e delle espressioni facciali, *deinde*, sull’empatia, in particolare al dolore, intesa come capacità umana di comprendere l’altrui stato affettivo.

Nel Capitolo 2 è proposto un *excursus* teorico sul processamento dei volti e delle emozioni da essi veicolate, partendo dal modello cognitivo di Bruce e Young (1986) ai recenti modelli simulativi, fino a quello più attuale di Wood e colleghi (2016), che considera il ruolo della mimica facciale nella discriminazione di emozioni sottili.

Nei Capitoli 3 e 4, sono presentati due studi strettamente interconnessi (rispettivamente, Esperimento 1 e 2). Entrambi hanno come obiettivo lo studio di un collegamento funzionale tra il sistema visivo e la mimica facciale/simulazione senso-motoria, nel processamento di emozioni tramite l’osservazione di espressioni facciali. Nei due studi è stata utilizzata la tecnica degli ERPs che, data la sua alta risoluzione temporale, ha permesso di tracciare una dinamica temporale chiarendo il ruolo della mimica/simulazione sugli stadi di analisi visiva coinvolti nell’elaborazione di espressioni facciali.

L’obiettivo dell’Esperimento 1 era di indagare una possibile connessione tra la mimica facciale e uno dei primi stadi di costruzione del percetto visivo del volto; mentre l’Esperimento 2, indagava se e come la mimica facciale interagisse con uno stadio

più tardivo legato alla costruzione di una rappresentazione in memoria di lavoro visiva e se questo processo dipendesse dal grado di empatia dell'osservatore. I risultati dei due Esperimenti suggeriscono come la mimica facciale influenzi sia gli stadi precoci che tardivi del processamento di emozioni tramite l'osservazione di espressioni facciali.

Nella seconda parte della Tesi, viene affrontato il tema dell'empatia, con particolare riferimento alla sua natura sfaccettata e al come variabili diverse possano modulare la risposta empatica stessa, specialmente al dolore altrui (Capitolo 5).

All'interno dei Capitoli 6 e 7 sono presentati due studi ERPs (Esperimento 3 e 4a) e un'indagine comportamentale (Esperimento 4b) con l'obiettivo di indagare la risposta empatica, elicitata nell'osservatore, quando si trova di fronte a qualcuno che sta provando dolore. L'esperimento 3 vuole studiare il ruolo della prosodia nel modulare la risposta neurale empatica nell'osservatore. I risultati dimostrano che l'informazione prosodica può aumentare la risposta empatica, agendo trasversalmente sulle due grandi componenti dell'empatia, experience sharing e mentalizing. Nell'Esperimento 4a, l'obiettivo era di comprendere se la distanza fisica tra l'osservatore e un individuo in una situazione dolorosa, potesse rappresentare un fattore importante nel modulare la grandezza della risposta empatica. Questo studio, attraverso la manipolazione della distanza fisica percepita di volti, ha mostrato una riduzione della risposta empatica rilevata nell'osservatore, in funzione della distanza fisica percepita. Il risultato dell'Esperimento 4b, invece, ha chiarito che il fattore critico nella generazione della risposta empatica (studio 4°) fosse la distanza fisica percepita e non quanto fossero discriminabili i volti tra loro.

In conclusione, nel Capitolo 8, è fornita una discussione generale che integri i risultati più importanti ottenuti negli studi descritti, cercando di delineare risvolti e prospettive future.

Chapter 1 – General Introduction

Humans are inherently social. Understanding the intentions and actions of other individuals is a basic human need. In human relationships and interactions, non-verbal communication plays a major role, and in this context, two particular aspects are central, if not even vital, for humans: the ability to "read" others' facial expressions and the ability to empathize with others' affective states. In the present Thesis, I will describe four studies that I conducted in order to provide answers to important questions in this field of investigation, and for this reason, a general introduction is necessary.

As human beings, decoding others' emotions and understanding others' (affective) states represent an important goal during social interactions and this allows individuals to act in adaptive ways and enhances the quality of social relationships, which represent an essential aspect of the overall quality of life. In this context, others' faces are elements of paramount importance, because by observing others' faces it is possible to extract most of the useful information that is necessary to appropriately interact with others.

From a general point of view, there are no doubts that faces are special, since they provide unique information about expression, identity, gender, age, trustworthiness, attractiveness and gaze direction (e.g., McKone & Robbins, 2011; see also Theeuwes & Van Der Stigchel, 2006). In particular, faces occupy a place of first order among the stimuli that convey emotions. These stimuli in general, together with facial expressions, are extremely important for humans considering their ability to provide immediate sources of social and emotional information since birth. Evidence in favor of this is the fact that attention is frequently deployed to faces, to the detriment of other visual objects, in particular when they convey emotions (Theeuwes & Van Der Stigchel, 2006; Vuilleumier, 2000; Vuilleumier, Armony, Driver, & Dolan, 2001). Humans appear to have a preference for facelike patterns over non-facelike patterns (Valenza, Simion, Macchi Cassia, & Umiltà, 1996). Furthermore, 5-month-olds babies are able to discriminate between different emotional expressions (Schwartz, Izard, & Ansul, 1985).

An aspect related to facial expressions processing and to the understanding of others' affective states refers to the ability to empathize with others. As I will discuss later in the next Chapter, this ability is complex and consists of several sub-components, which is why empathy is defined in psychology and social and affective neuroscience as a multi-componential construct.

As briefly mentioned above, the experiments I will describe in this Thesis have attempted to answer some central questions about how humans process facial expressions by assigning them a meaning and how some variables are central in modulating empathic neural responses when an individual observes another individual experiencing a condition of physical pain. However, before going into the description and discussion of these studies, I will try to provide the reader with a thorough introduction of the knowledge available today on how humans process faces in general and facial expressions in particular, and on how they empathize with others' affective states, especially pain.

Chapter 2 – Perceiving faces and facial expressions

Faces of conspecifics are stimuli of paramount importance for humans: they convey a large amount of social and emotional information and represent the main source in order to identify other individuals. When exposed to a face, individuals quickly categorize that face in a social group by stable (i.e., structural) face cues, such as race, age and sex (e.g., Crisp & Hewstone, 2007; Tajfel, 1981; Tajfel, Billig, Bundy, & Flament, 1971; Taylor, Fiske, Etcoff, & Ruderman, 1978) and also process dynamic face dimensions that may provide critical information on others' mental states and intentions, such as emotional expression and eye-gaze direction (e.g., Bruce & Young, 1986; Haxby, Hoffman, & Gobbini, 2002). Notably, a huge body of work has established that both stable and transient face dimensions influence face processing in cascade.

One singular aspect of face processing when compared with the processing of other object stimuli, is that faces are recognized by the use of a form of configural processing, as opposed to feature-based processing, which results in the whole face being recognized without any explicit recognition of face parts (e.g., Tanaka & Farah, 1993 see also Maurer, Le Grand, & Mondloch, 2002). This last observation strongly suggests that faces are special for humans and for this reason humans might have developed a specialized module or brain network for their processing. This aspect will be discussed at length in the following paragraphs together with another central aspect of face processing consisting of facial expressions, one of the main subjects of this Thesis.

The centrality of facial expressions of emotions for humans has always been known, but we owe to Charles Darwin their first systematic exploration. Darwin claimed in his famous book "The Expression of Emotions in Man and Animals" (1872) that a specific set of facial expressions is universal. Later, in the 1970s, Paul Ekman and Wallace V. Friesen provided a comprehensive taxonomy of human facial expressions over time, called *Facial Action Coding System* (FACS). Starting from this taxonomy, these researches have deepened their research by using the electromyography (EMG) technique, in order to identify the activation of facial muscles as accurately and distinctly as possible in relation to the different facial expressions of emotions. As an example − and only to anticipate to the reader some topics that will be explored later in this Thesis − the authors discovered that there are facial muscles universally involved regardless of the culture and individual differences; the production of an expression of happiness, for instance, evokes increased activity in the *zygomatic major* muscle (which raises the corners of the mouth during smiling), whereas the production of an expression of anger leads to increased activity in the *corrugator supercilii* muscle (which is associated with frowning).

In the following paragraphs I will present two of the main models of face processing, still relevant and up-to-date and widely cited.

2.1 A cognitive model of face processing

One well-known functional model to account for face processing has been developed by Bruce and Young (1986). Interestingly, this model has been derived from an extensive study of documented everyday failures in face recognition process (Young, Hay, McWeeny, Flude, & Ellis, 1985). The innovative aspect of this model was the emphasis given to the functional components involved in the face processing system without taking into account whether or not these functional components were localized in specific brain areas. The model therefore focuses on the functional cognitive architecture of facial processing rather than the architecture in neural terms. Figure 1 depicts Bruce and Young’s model and illustrates the different stages involved in face processing. This model assumes the existence of different face attributes processed in a sequence of discrete processing stages. This feature of the model is based on the several observations collected by the authors about the type of deficits that may occur in face processing. The model assumes that it is possible to extract different types of information from faces that are named *codes*. The first stage of processing involves structural encoding of the face by which it is possible to process facial features and their configuration. This structural encoding is the first fundamental stage that allows humans to construct a three-dimensional representation of a particular face (together with the extraction of low level features such as lighting, grain and flaws) so that it can be subsequently discriminated by other faces and, eventually, recognized. At this point, through an operation of comparison with the representations stored in a specific store (*face recognition units*), it is possible for the observer to determine if the face is familiar or not. A familiar face is successfully recognized when the representation obtained in the structural encoding stage matches the face recognition unit in long-term memory. Following this match it is also possible to retrieve semantic information about faces recognized as familiar at the level of a subsequent stage named *person identity nodes*, which contains all the semantic knowledge about the observed person, except for the name that could be retrieved in a following stage (*name generation*).

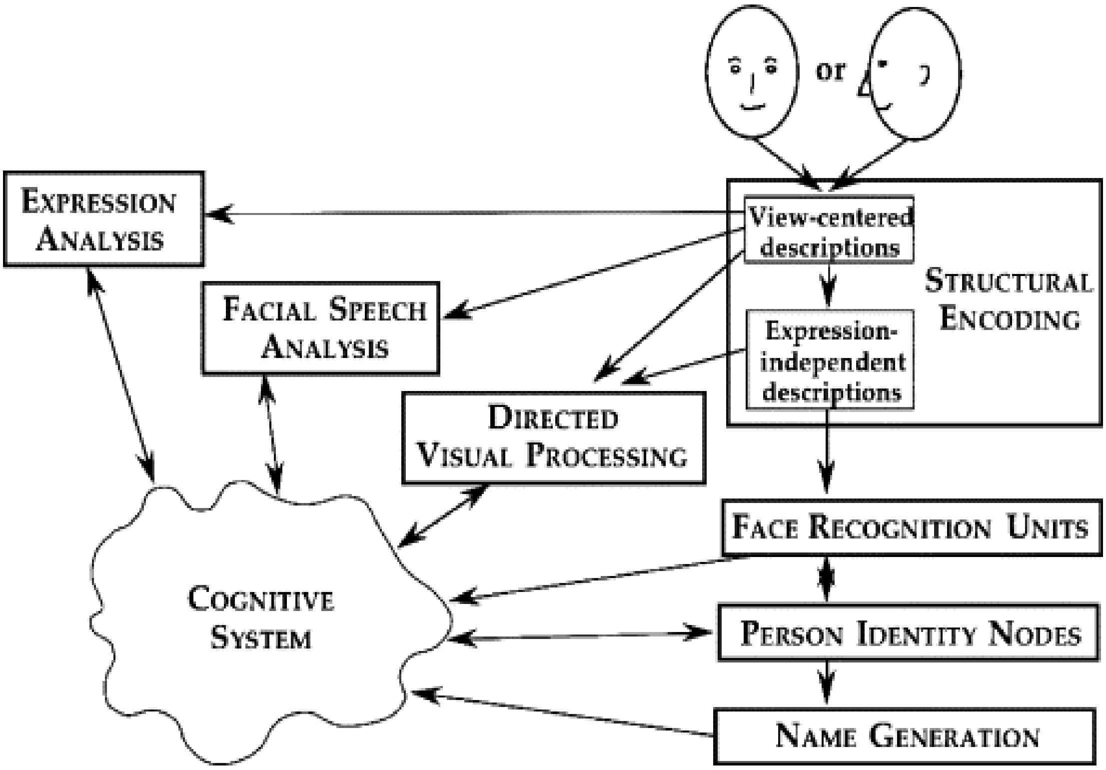

Figure 1 The Bruce and Young (1986) model of face processing.

The model proposes that the access to the *person identity* could occur *via* different kinds of inputs, such as the face, but also the voice, the accent, the name or even a particular object. Therefore, this unit is defined as a cross-modal unit.

To date, Bruce and Young's model (1986) is the prevalent cognitive account of the face recognition architecture. Even though it is highly influential, there is still debate concerning where these "modules" are localized in the brain and how these processes interact with each other.

The model also proposes the existence of a second pathway for the processing of facial expressions, including the movements of the lips during speech, and the processing of the direction of others' gaze. However, this second pathway of processing is not central to the model and is not widely described by the authors.

2.2 A distributed neural model of face processing

As previously mentioned, the interest of researchers about neuroanatomical localization of “modules” involved in face processing is rapidly improving in the last decades. For a neural point of view, single-cell recordings in non-human primates proved the existence of a class of neurons that selectively respond to faces but not to other objects categories. Desimone (1991) has provided evidence in favor of the existence of such face-selective neurons in the temporal cortex of the monkey. Further, several studies demonstrated a certain degree of selectivity in the response of these neurons such that they fire in response to certain aspects of faces more than others (Rolls & Toove, 1995). For example, a particularly interesting distinction in the context of this Thesis refers to the observation that some neurons tend to respond selectively to changes in facial identity while others to changes in expression (see Hasselmo, Rolls, & Baylis, 1989, for a first evidence on this in monkeys). It is well known from several functional magnetic resonance imaging (fMRI) studies that the majority of these face-selective neurons are located in the human visual cortex. Within these brain areas it is possible to distinguish two visual pathways for the processing of all kind of objects; a *ventral pathway*, through which it is possible to identify them, regardless of their spatial location, and a *dorsal pathway*, specifically involved in localizing objects, in spite of “what” they are (Mishkin & Ungerleider, 1982). Face perception seems to depend more on the former. In particular, an area named *fusiform face area* (FFA; Grill-Spector, Knouf, & Kanwisher, 2004; Kanwisher, McDermott, & Chun, 1997) might represent a specific anatomical module for human face perception (Kanwisher, 2000).

Nevertheless, this region alone is not sufficient to process the complex information conveyed by faces and some researchers proposed the existence of a distributed neural network including multiple cortical regions involved in face perception (see, e.g., Haxby, Hoffman, & Gobbini, 2002; Ishai, Schmidt, & Boesiger, 2005).

According to this view, multiple brain areas are differently engaged during face processing, each in analyzing a particular aspect of faces.

Haxby & Gobbini (2010) presented a neuroanatomical face perception model establishing a link between different functional sub-processes of face perception to different cortical areas. This model introduces a sequential stream of processing where different brain regions are involved explicitly in extracting early perceptual and subsequent semantic information from faces (see Figure 2). The authors propose the existence of two different systems, dissociated at the neuroanatomical and functional levels, named *core system* and *extended system* that I will describe in detail in the following paragraphs.

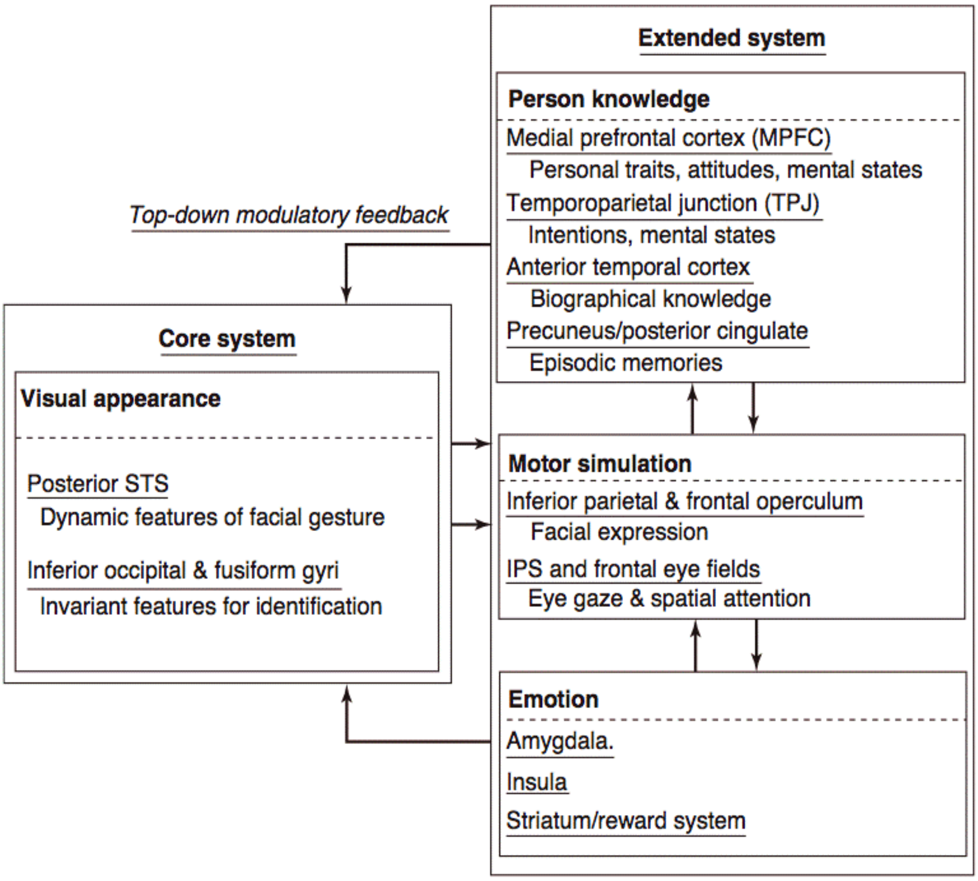

Figure 2 The distributed neural system for face perception (Haxby & Gobbini, 2010).

2.2.1 The core system

The *core system* consists of visual extrastriate areas for the visual analysis of faces. It is composed of three extrastriate regions, the inferior occipital gyrus, including the occipital gyrus face area (OFA; Gauthier, Skudlarski, Gore, & Anderson, 2000) and the lateral fusiform gyrus, including the face fusiform area (FFA) and the posterior superior temporal sulcus (STS; Haxby, Hoffman, & Gobbini, 2002; Hoffman & Haxby, 2000). Figure 3 presents a schematic representation of the brain areas involved in this system.

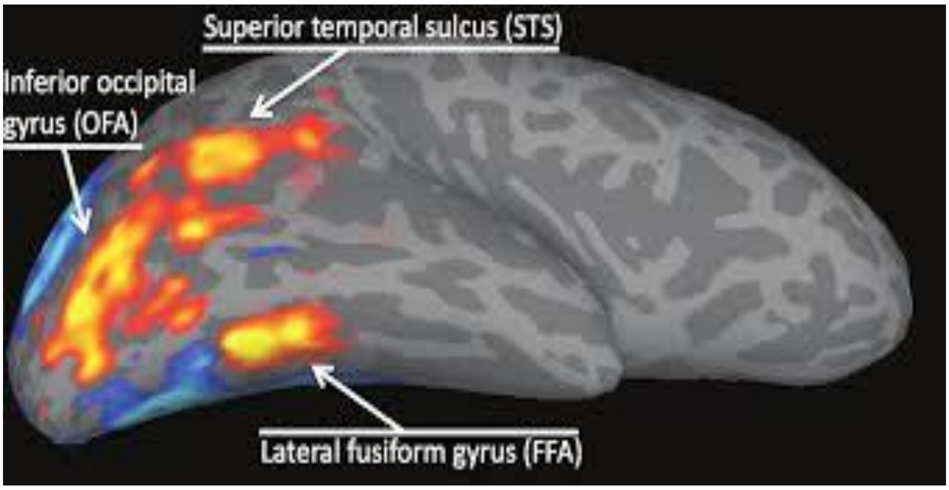

Figure 3 The three core extrastriate regions activated during face perception in the human visual cortex (Haxby & Gobbini, 2010).

Moreover, other neighboring regions in the ventral occipital-temporal cortices are also engaged in face perception responding significantly but not maximally to human faces (e.g., Ishai et al., 2005). The core system is involved in the processing of both static and dynamic faces characteristics. When a person is processing another individual's identity, it results in a stronger activation of the FFA (e.g., Gauthier et al., 2000; Grill-Spector et al., 2004). Even though some overlap in brain activity has been observed between FFA and posterior STS, there is neuroanatomical evidence that has shown quantitatively that in monkeys one specific population of neurons responds to facial identity independently of expression, and a separate population responds to facial expression independently of identity (Hasselmo et al., 1989). Therefore, person identity processing occurs independently of dynamic facial cues and is mostly – but not entirely – due to the activation of one specific brain region. This ability is vital since it allows humans to "perceive" the same identity of the observed person even when some changes in expression and gaze direction occur (Haxby, Hoffman, & Gobbini, 2000).

Thus, at the heart of both models I have presented in these paragraphs, is the idea that facial expression and identity recognition are two functionally and anatomically dissociable and independent systems. Several proofs have supported this idea; for example, brain lesions might result in selective impairment in recognition of facial identity and vice-versa (Bruyer et al., 1983; Etcoff, 1984; Hornak, Rolls, & Wade, 1996; Tranel, Damasio, & Damasio, 1988; Young, Newcombe, de Haan, Small, & Hay, 1993).

In this field of investigation, it is worth mentioning that studies using the Principal Component Analysis (PCA) approach, have supported the idea that the facial identity route might "bifurcate" from the facial expression route after processing at the level of a *universal representational system* that codes both facial identity and expression (Cottrell, Branson, & Calder, 2002; for a review see also Calder & Young, 2005). Results from an fMRI study conducted by Baseler and colleagues (Baseler, Harris, Young, & Andrews, 2014) support the general claim that posterior STS is involved in representing changeable aspects of faces (Haxby et al., 2000), but also offer a novel perspective on the neural processing in this area. Neurons in the posterior STS are particularly sensitive to changeable aspects of the same face, suggesting that the face-selective posterior STS could represent the invariant aspects of a face that are necessary for the perception of facial expressions. Indeed, the authors found that the connectivity between the posterior STS and the FFA increases for sequences of faces in which the identity was unchanged compared with sequences when the identity changed. Of particular interest is also that the posterior STS responds to emotion information, not only from faces but also from other modalities, such as human voice (Charest et al., 2009; Phillips et al., 1998).

2.2.2 The extended system

At the conclusion of the purely visual analysis of faces, face processing continues recruiting additional brain areas that are part to that distributed system that Haxby and colleagues have named *extended system*. This system would act in concert with the regions of the core system. This extended system plays a fundamental role in face processing because it assigns “meaning” to the cues and signals processed within the core system. For instance it allows retrieving semantic information about the person identity, interpreting facial expressions assigning specific emotions and assigning specific mental states and intentions to an individual showing a particular gaze direction.

The regions that are part of this second system, “beyond” the extrastriate visual cortex, play a fundamental role in the recognition of familiar faces, especially in the automatic recovery of personal knowledge and emotional response, as well as in the processing of other people's eye gaze. These aspects, although extremely interesting, are not central for the present discussion and I invite the reader to refer to the chapter by Haxby and Gobbini (2010) which presents a rich bibliography in this regard.

This paragraph will focus instead on the portions of the extended system that are crucial to the present discussion, i.e. those involved in the processing of facial expressions.

As discussed above, visual analysis of facial expressions mainly involves the posterior STS; the extraction of what Haxby and colleagues call the “facial expression meaning” involves also other brain areas that are part of the extended system, such as the brain areas underlying the mirror neuron system (MNS), the premotor cortex (PMC), the inferior parietal lobe (IPL) and the frontal operculum (FO); all these regions are believed to be involved in understanding others’ emotions and actions (see, e.g., Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Montgomery & Haxby, 2008; Montgomery, Seeherman, & Haxby, 2009). More specifically, these cortical areas seem to trigger motor representations to produce the observed facial expression, with the aim of understanding the meaning of the emotion itself (Haxby & Gobbini, 2010). Montgomery and Haxby (2008), moreover, observed that the FO is more active during the vision of dynamic facial expressions in individuals with high empathic skills.

Beyond the motor representation triggered within the areas of the extended system when viewing facial expressions, the perception of these expressions involves also the cerebral areas associated with the processing of emotions, such as the anterior insula (AI) and the amygdala. Specifically, the amygdala responds primarily to the expressions of pain and to different types of fear-relevant stimuli (it responds both to the potential threat of stimuli and specifically fear-related stimuli; Öhman, 2005); AI, on the other hand, is mainly activated by expressions of disgust (Breiter et al., 1996; Morris et al., 1998; Whalen, 1998; Whalen et al., 1998; Whalen et al., 2004). Furthermore, activity of the insula is triggered by both the exposition to facial expressions of disgust, and by the emotion of disgust experienced in first person (Wicker et al., 2003).

This evidence seems to suggest that the mechanism used by humans to recognize others’ emotions expressed by their faces might be based on an internal simulation mechanism. Therefore, observers would recognize joy, disgust, fear in others by activating the motor representations (or better, the sensorimotor representations) and the affective circuitry associated with those emotions. This view is certainly fascinating, and, as we will see in the next section, there is evidence that strongly supports it. Moreover, as we shall see later in this chapter, this mechanism seems to be at the basis of one of the most important aspects of empathy, that is, the vicarious experience of others’ affective states. However, this is not the only possible mechanism. Goldman and Sripada

(2005), in their influential work on the different possible models able to explain how humans recognize others' emotions, discuss four possible simulation models and an alternative mechanism, different from simulation, and substantially based on higher level cognitive skills. I start the discussion in the next paragraphs describing this latter mechanism, and subsequently I will introduce the reader to simulation models.

2.3 Theory-Theory and Simulation models

From a philosophical perspective, our understanding of other people's emotions could be based on the so-called, exquisitely human, mind-reading ability (Goldman & Sripada, 2005). Humans can understand others' emotions by inferring mental states based on the knowledge they have on a specific individual and on specific contexts. In this vein, a "facial expression" would be recognized as a particular "emotion" by linking the observed expression to a repertoire of known emotion categories.

According to Baron-Cohen and colleagues' mind-reading definition (Baron-Cohen, Leslie, & Frith, 1985), this is a "*mechanism which underlies a crucial aspect of social skills, namely being able to conceive of mental states: that is, knowing that other people know, want, feel, or believe things; in short, having what Premack & Woodruff, (1978) termed a 'theory of mind' "* (p. 38). Several studies have indeed demonstrated a relationship between impaired emotion recognition and Theory of Mind (ToM) deficits, such as in autistic children (e.g., Baron-Cohen et al., 1985; Heerey, Keltner, & Capps, 2003) or in schizophrenic patients (e.g., Brüne, 2005). It is already well known that ToM abilities are associated with activity in the medial prefrontal cortex (Gallagher et al., 2000). Goldman and Sripada (2005) use the term Theory-Theory (TT) to refer to this mind-reading ability that is that ability by which humans, by using their knowledge, can infer others' beliefs, thoughts, goals and emotional states. This approach is essentially based on a naïve psychological theory, which promotes the existence of a module, innate and dedicated, or acquirable by domain-general learning (i.e., in the developmental psychology field, see Gopnik & Meltzoff, 1997; Leslie, 1994; Premack & Woodruff, 1978).

On the other hand, Simulation Theories (ST) describe emotion recognition as a process of simulating and replicating others' affective states in oneself. According to Goldman and Sripada (2005) individuals observing others' emotions can "reproduce" the target emotion in their corresponding brain areas. Consequently, a deficit in emotion production is often linked with a deficit in emotion recognition in others. One important observation in order to disentangle between these two different views on how humans recognize others' emotions is the evidence that others' facial expressions are represented, at least partly, within motor brain structures of the observer's brain. The motor system engagement would reflect a process of simulation, or automatic imitation, of others' emotions, supporting then the simulative view (Goldman & Sripada, 2005; Moody, McIntosh, Mann, & Weisser, 2007; Niedenthal, Mermillod, Maringer, & Hess, 2010; Oberman, Winkielman, & Ramachandran, 2007; Rychlowska et al., 2014; Sato, Fujimura, Kochiyama, & Suzuki, 2013). In line with this view, a dysfunction of the right somatosensory cortex[1] has been associated with a variety of emotion processing impairment within faces (Adolphs, Damasio, Tranel, Cooper, & Damasio, 2000; Pitcher, Garrido, Walsh, & Duchaine, 2008) as well as in voices (Banissy et al., 2011). Lesion studies suggested that impairment of right somatosensory cortices was associated with a deficit in forming neural representations of the observed emotion which in turn disabled simulation as well as recognition of the emotion expressed by others (Adolphs et al., 2000; Wood, Lupyan, Sherrin, & Niedenthal, 2016). Furthermore, facial feedback has a

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[1] Somatosensory representations is a useful mechanism that helps to understand how another person is feeling by internal simulation of facial expressions in brain regions of the right somatosensory cortex (Adolphs et al., 2000).

vital role in emotion recognition task as demonstrated by several studies: dampening face expressions by Botulin Toxin injections reduced in turn subjective experience of emotions as the muscle feedback from faces was limited (Neal & Chartrand, 2011) and altering facial feedback as a consequence of wearing a constrictive gel facemask decreased participants' ability to detect small differences between facial expressions (Wood et al., 2016). Indeed, it was found that accuracy level in facial expressions discrimination was worse for the participants that were wearing the facemask compared to those that could freely move their facial muscles.

Starting from Fadiga et al.'s study (Fadiga, Fogassi, Pavesi, & Rizzolatti, 1995), in which it has been proved that in humans there is a system matching action observation and execution, the recent neuroscientific research has investigated the human MNS as a plausible neural mechanism of simulation, also involved, in emotion recognition tasks. These neurons are mainly located within motor areas and are for example active during the observation of others’ actions. This activation, in turn, would allow the observer to understand others’ actions and intentions (Fabbri-Destro & Rizzolatti, 2008; Giacomo Rizzolatti, 2005). When seeing another individual performing a behavior, the observer does not overtly execute the same action, but rather the activation of motor cortices would be a correlate of simulation leading to a better insight into what the observed individual must feel at that moment of time (Gallese & Goldman, 1998). This idea is in line with the so-called *embodied cognition* approach, and in particular with *embodied simulation* which postulates that the sensorimotor activity triggered during the observation of others’ actions and facial expressions is probably the neural correlate of simulation (Gallese, 2003, 2005; Gallese & Sinigaglia, 2011). It is well known that structures involved in the subjective experience of emotions are also active, through this mechanism, when people recognize these sensations in others.

Although the debate between SS and TT approaches is still open, clinical and experimental findings confirmed a strong connection between production and recognition of emotions; a body of evidence supports indeed a remarkable pattern of paired deficits between emotion production and face-based recognition processes (Goldman and Sripada, 2005). For example, bilateral damage of amygdala causes both impairments in fear production and recognition (Adolphs et al., 1999). The current empirical evidence seems to support ST as the best account on how humans recognize others' facial expressions in a real social interaction context. What remains unclear is how exactly this simulation is implemented at cognitive, functional and neuroanatomical levels. Goldman and Sripada (2005) proposed four possible models of simulation involved in face-based emotion recognition that I will describe in the next paragraphs.

2.3.1 How many possible simulation mechanisms?

Over ten years ago, within the context of simulationist models of face-based emotion recognition, Goldman and Sripada (2005) formalized the role that mimicry and simulation may have in this process. In this review, the authors in particular referred to the humans' ability to attribute affective states to others based just on their facial expressions.

The authors proposed four potential simulation models in emotion recognition in which two individuals are involved, the *observer*, who would carry out the simulation process, and a *target*, that is a second individual who is observed while producing a facial expression.

The first model (see Figure 4) would see the observer at first intent in generating a hypothesis on the possible emotion associated with the target's facial expression and would proceed with the implementation (enactment) of the emotion in him/herself. The emotion experienced in first person would then elicit the facial expression typically associated with it. At this point, in the case of a match between the expression produced by the observer and that observed in the target, the originally hypothesized emotion is confirmed and, therefore, attributed to the target. On the contrary, the process would resume from the generation of a new hypothesis until the match was valid. Two of the most important weaknesses of this model is that this trial-and-error method could take several attempts before hitting on the right facial expression and it postulated an association between the generate proprioceptive representation of the specific facial expression and visual target, which has not been proved. A possible consequence is that the entire process would be too slow to account for actual covert mimicry of displayed facial expressions, which occurs at approximately 300 ms from the onset of the stimulus (Dimberg & Thunberg, 1998; Goldman & Sripada, 2005; Lundqvist & Dimberg, 1995).

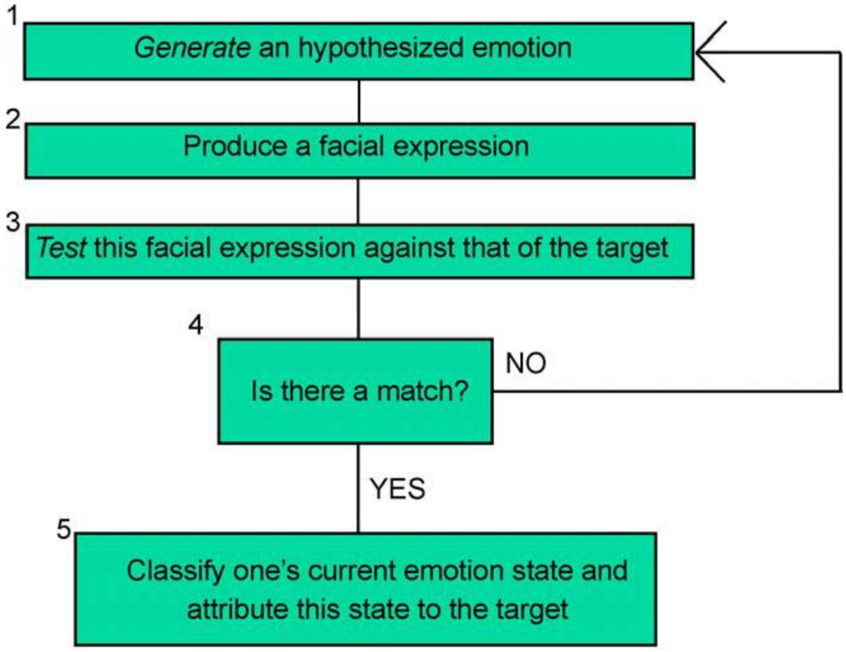

Figure 4 Flow chart of the generate and test simulation model.

A second alternative model, endorsed by several experts in the field, is a *reverse simulation heuristic*. Here, the observer would activate his/her facial mimicry when observing the target’s facial expression, which may result in the experience of that same emotion (i.e., emotion contagion) in the observer. In this perspective, the experienced emotion is then attributed to the target, contributing to emotional facial expression recognition (Goldman & Sripada, 2005). Therefore, an observer would mimic the target’s facial expression using his/her own facial muscles, allegedly more subtle and in an attenuated fashion than the original observed expression. In this vein, the observer will classify his/her own emotional state based on the experienced emotion and would attribute the same emotional state to the target.

This model is supported by studies in which observers’ facial muscles activity was recorded during the presentation of facial expressions (Dimberg & Thunberg, 1998; Lundqvist & Dimberg, 1995) and it was found that muscular activation is often subtle, but is detectable by electromyography and occurs extremely rapidly (Goldman and Sripada, 2005). This evidence is in line with the reverse simulation model, in which a potential attributor who sees an emotion-expressive face starts by mimicking the facial expression she/he observes, thus the generated emotion state is a consequence of facial mimicry’ activation (Goldman & Sripada, 2005). While there is evidence in support of this theory, other studies provide evidence that individuals can experience emotional contagion without facial mimicry (Goldman & Sripada, 2005; Hess & Blairy, 2001). Consistent with this idea, Keillor and colleagues (Keillor, Barrett, Crucian, & Kortenkamp, 2002), reported no differences in accuracy in a face-based emotion recognition task between a group of patients with bilateral facial paralysis and a control group. This evidence suggests that facial mimicry might accompany – but not facilitate – emotion recognition. However, it should also be noted that in favor of the link between mimicry and simulative processes, emotional mimicry has been associated with the activation of the mirror neuron system such that congruent facial reactions to angry and happy expressions correlate significantly with activations in the inferior frontal gyrus, supplementary motor area and cerebellum (see Likowski et al., 2012).

Adolphs and colleagues (Adolphs et al., 2000) hypothesized a third model called *reverse simulation with 'as if' loop*. These authors postulated the possibility of a visual-somatosensory pathway activated directly by emotional simulation in the observer. In this case, observing emotion in others may trigger a somatosensory activity of the expressed emotion "as if" the observer was experiencing the same emotion as the target. Through this activation, and the consequent retrieval of knowledge about the emotion, it will be possible for the observer to recognize and understand the target's emotional state (Adolphs, Tranel, & Damasio, 2003).

A fourth model termed *unmediated resonance model*, instead, is based on the idea that the observation of the target's face will directly activate the same neural substrate associated with the other's emotion, without any mediation as proposed by the previous models presented in this section. In this vein, the observer's facial mimicry could be present or not, but the model does not clarify what its contribution can be in emotion recognition. The idea behind this model comes from the hypothesis of an automatic sharing, by the observer, of the displayed emotion (Gallese, 2001; Wicker et al., 2003) *via* MNS. This system allows an internal action representation during the observation of, or listening to, someone, analogous to the one that occurs when an action is produced (Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Goldman & Sripada, 2005; Kohler et al., 2002; Rizzolatti, Fogassi, & Gallese, 2001) (see Figure 5). According to this model, the reproduction of an emotion in the observer would be transmitted to some cognitive centers that "recognize" the experimented activation, leading to its explicit classification (usually in a verbal format).

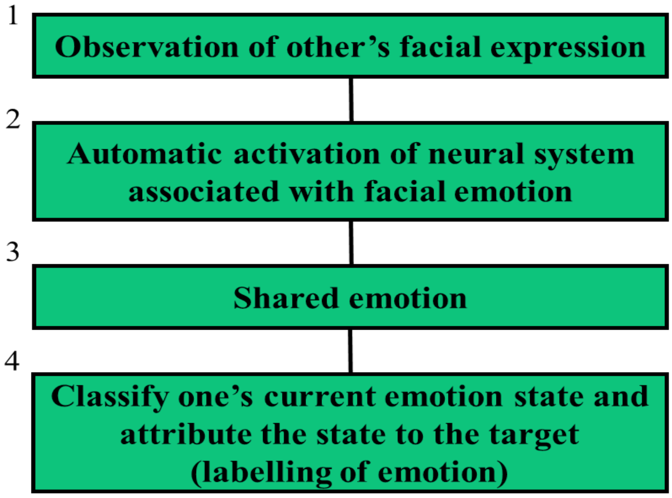

Figure 5 Flow chart of the *unmediated resonance model.*

2.3.2 A recent simulation model

As described in the previous paragraph, current models aimed at explaining how face recognition occurs, in order to understand others' emotions expressed through their faces, propose the existence of a simulation mechanism within the observer of the emotion observed in the target (Carr et al., 2003; Caruana & Borghi, 2013; Gallese & Sinigaglia, 2011; Goldman & de Vignemont, 2009; Goldman & Sripada, 2005; Niedenthal, 2007; Pitcher, Garrido et al., 2008; Wicker et al., 2003; see also Mastrella & Sessa, 2017, for a review on this topic). This simulation process would also involve the facial mimicry of the observer, although the different simulation models consider mimicry to be more or less relevant. As previously argued, some models assign to mimicry an absolutely central role in this process, while others indicate it as a fundamentally accessory element (see Goldman & Sripada, 2005 for a review of different simulation models; see also Hess & Fischer, 2014 for a report on emotional mimicry) or a sort of spillover of simulation by sensorimotor areas (Wood et al., 2016). This aspect will be further explored in the following paragraph. In this section, I would like instead to present a very recent simulation model of others' facial expressions.

This model has been proposed by Wood and colleagues (2016) and has made a step forward by suggesting that the exposure to a facial expression triggers in parallel the visual system (for the construction of a percept) and the simulation system (for the construction of sensorimotor and somatovisceral representation(s)) that, according to the authors, may or may not include the observer's facial mimicry, which is conceived as spillover of the sensorimotor simulation.

Furthermore, based on the model, the simulation process would recursively modulate the clarity of the visual percept and would contribute to the recognition of facial expressions and the attribution of an affective state to the observed individual. The sensorimotor simulation would also play a fundamental role in the activation of the limbic system and other brain regions involved in the processing of emotions. The authors underline the distributed and recursive nature of the model, which iteratively recruits visual, somatosensory, motor and premotor cortex, as well as the subcortical regions of the limbic system and the encephalic trunk (Fullana et al., 2016).

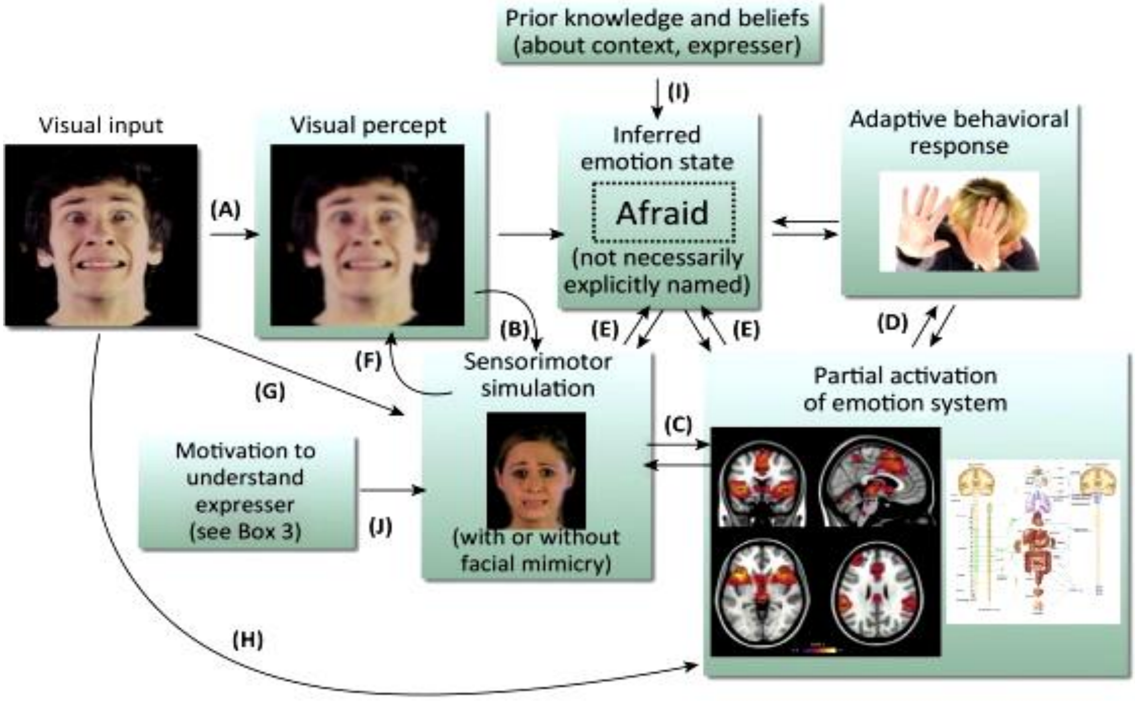

Figure 6 Simulation and recognition model of facial expression in the human being (Wood et al., 2016).

Figure 6 describes the model in detail. When a person is exposed to a facial expression (a fearful face, as in Figure 6), this will generate a visual percept (that would modulate the face region of the sensorimotor cortices and other motor control areas), and would also directly activate sensorimotor regions, possibly leading to facial mimicry. On the basis of the model, after the activation of these posterior regions of facial analysis and sensorimotor regions, the activity would extend to other regions of the brain involved in emotion processing (in the flow-chart depicted in Figure 6, the fear) possibly resulting in overt cognitive, behavioral, and physiological changes. This whole process seems to be modulated by affiliation with and motivation to understand the expresser. Further, it has been suggested that this partial activation of the emotion state would allow the perceiver to explicitly or implicitly recognize the emotion of the expresser. Recent evidence, such as that provided by Wood's et al. (2016) in a behavioral study, has suggested that sensorimotor simulation recursively modulates the clarity of the visual percept. In this between-subjects study Wood and colleagues used a facial gel that hardening was able of blocking/altering the participants' facial mimicry during a fine discrimination task of facial expressions selected from a morphing continuum of a face from an expression of 100% anger to an expression of 100% sadness (Wood et al., 2016). Importantly, the design also included a control condition in which participants had to discriminate images of animals selected from a morphing continuum from the image of a horse (100%) to the image of a cow (100%). The results showed that blocking/altering facial mimicry (using the gel) had a selective negative impact on discrimination of facial expressions (but not on discrimination of animal images). The authors then proposed that this selective decrease in accuracy in the subtle discrimination of emotions was due to a selective effect of the alteration of facial mimicry and to an interference with the simulation process that in turn would not have contributed/or would have to a small extent to the construction of the visual percept.

2.3.3 Evidence in support of the role of facial mimicry in emotion recognition

After discussing the main simulation models, I would like to draw the reader's attention to the role that mimicry could have in recognizing facial expressions, since, as seen in the previous paragraphs, the different simulation models assign a more or less central role to the mimicry in the process of recognition/discrimination of facial expressions.

A large body of studies supports a central role of the observer's facial mimicry indeed. For instance, Dimberg, Thunberg and Elmehed (2000) demonstrated that facial muscle responses increase during the subliminal exposure to emotional expressions. On this same line, other studies have instead suggested that the mechanical (Baumeister, Rumiati, & Foroni, 2015; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman et al., 2007; Stel & van Knippenberg, 2008) or chemical (for example by the botulinum toxin A-BTX; Baumeister, Papa, & Foroni, 2016) alteration of mimicry may have a substantial effect on the recognition of emotions. Neal and Chartrand (2011) conducted a study on a sample of females who underwent botulinum toxin Type A treatment comparing that with a paired females sample who received Restylane injections[2], that contains an active ingredient called hyaluronic acid. This study supports the hypothesis that facial mimicry is part of the facial emotion recognition process since lower accuracy rates were found in the Botox group compared to the Restylane one. In this context, another promising approach is the study of patients with partial/total mimic inability, as in the case of patients with facial paralysis (Keillor, Barrett, Crucian, Kortenkamp, & Heilman, 2002; Korb et al., 2016). For instance, Korb and colleagues (2016) studied the ability of patients with partial facial paralysis (right or left unilateral facial paralysis) to recognize emotional facial expressions showing that patients with right hemiparesis are more at risk of developing an inability in understanding emotions.

2.3.4 Beyond the classic view on emotional mimicry

In the “classic” view, usually termed Matched Motor Hypothesis, emotional mimicry[3] is definable as the imitation of the emotional expression of another person (Hess, Philippot, & Blairy, 1999; Hess & Fischer, 2013) and it is based on a perception-behaviour link (Chartrand & Bargh, 1999; Preston & de Wall, 2002). As it has been already discussed in the previous paragraphs, within this framework, facial mimicry

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[2] Botox injection causes a block in the release of the neurotransmitter acetylcholine. This neurotransmitter needs to be released through to send signals to the brain and vice versa. Hence, the muscle is paralysed (Hennenlotter et al., 2009). Restylane, in contrast, is effective under the skin, not in the muscle. Thus it does not block muscles activity.

[3] Emotional mimicry is the imitation of the emotional expressions of others. It can be differentiated from behavioural mimicry, which is the imitation of non-emotional behaviours, such as face touching or foot tapping. The crucial difference between those two mimicries is that emotional displays are not neutral and always intrinsically meaningful within the relationship with another individual. Therefore, emotional mimicry is more restricted by the social relational context than behavioural mimicry (Hess & Fischer, 2014).

phenomenon could occur automatically and rapidly in the observer just as soon as the observer perceives a facial expression in the target.

Hess and Fischer (2014) postulated four critical features for mimicry, which can be applied to facial mimicry in particular. The first trait is related to the motor matched hypothesis based on which it is necessary that the expressions of two individuals are congruent, which means that the same facial muscles are activated in both the observer and the target. However, most of the research on emotional mimicry focused on specific emotions, such as happiness and anger, and only occasionally on sadness, showing an increasing activity in Zygomaticus Major to happiness and increasing activity in Corrugator Supercillii for anger and sadness (see Hess & Fischer, 2013, for a review of these specific muscles activity). In this sense it is not clear how much emotional mimicry response can be selective based on the observed facial expression. These muscles activity, indeed, has been found to differentiate between positive and negative mood (Larsen, Norris, & Cacioppo, 2003) and, for this reason, it does not seem that their activity is highly specific and therefore selectively sensitive to specific facial expressions.

The authors have proposed a second limitation related to the assumption that mimicry would occur to the same degree in reaction to all facial expressions. Instead there is evidence that the likelihood that a mimicry response can be triggered in the observer depends on the observed facial expression. As an example, people tend to simulate a smile more than a frown (Hess & Fischer, 2013). This exciting effect is illustrated in a qualitative research by Hinsz & Tomhave (1991) in which have been reported the reactions to smiles and frowns in people in shopping centres, stores, or libraries. They found that 53% of smiles but only 7% of the frowns evoked a matching expression in the observers.

Similarly, smiles are generally mimicked more because they have a meagre social cost since no immediate action is required. When people imitate sadness, for example, they are communicating empathy and comprehension to the other person.

The third issue is related to the existence of a dependency between the mimicking individual on the mimicked one, which means that the emerging facial mimicry is dependent on what is observed. Hess and Fisher (2014) provided evidence, from a cross-modal mimicry, where facial expressions were elicited by vocal stimuli (Hawk, Fischer, & Van Kleef, 2012; Verona, Patrick, Curtin, Bradley, & Lang, 2004), clarifying that the physical presence is not an indispensable prerequisite for facial mimicry. Indeed, emotional sounds can elicit a congruent emotional state as well. Stel (2016) demonstrated that mimicry is not just an automatic motor reaction, but also “a social reaction” because it is modulated by the social context. Indeed, the authors provided evidence that social context information is crucial for the elicitation of mimicry and that mimicry mainly serves to communicate affiliation between individuals or group members. In this context, facial mimicry reflects predominately not what the observer sees, but rather the observers’ knowledge on the others’ emotional states.

Hess, Houde and Fischer (2014) reported a study where participants had to passively observe neutral facial expressions accompanied by an emotion label and showed that mimicry could be elicited by facial stimuli with a neutral expression.

This evidence suggests that observers mimic interpretations of facial expressions and/or emotional signals, indicating that facial mimicry is not just the copy of the movements seen in the observed face. The last point discussed by the authors regarding the “classic” view on mimicry has been already mentioned in this paragraph: facial mimicry has mainly the role of communicating affiliation between individuals or group members. Thus, it becomes even more important whether the relationship between the two individuals is cooperative or competitive (Lanzetta & Englis, 1989; Weyers, Mühlberger, Kund, Hess,

& Pauli, 2009) and, by contrast, in a competitive or hostile interaction, facial reactions are likely to be a reaction to rather than with the emotion displayed by the other person. A negative attitude toward the target tends to inhibit facial mimicry or to display that are incongruent with the observed expression, such as smiling when seeing the pain or fear display of a competitor or a disliked out-group member (Lanzetta & Englis, 1989).

In conclusion, when a person is observing an angry facial expression and will react with an angry facial expression based on cognitive evaluation of the observed anger (e.g., as being inappropriate) or intentional imitation of the observed facial expression, this does not constitute facial mimicry. This imitation is definable instead as “emotional contagion”. Thus, emotional mimicry could be defined as a conscious or automatic imitation of a nonverbal emotional expression of another person, with whom one has an affiliative link (Hess et al., 2014).

2.4 A theoretical introduction to Experiment 1 and Experiment 2

As I have already discussed in the previous paragraphs, a large body of studies supports a central role of the observer's facial mimicry. In spite of the abundant evidence on the importance of simulative processes and facial mimicry in emotion recognition, the work that has directly investigated the relationship between the visual system for facial expressions processing and the simulation system (including mimicry) is minimal (Wood et al., 2016). Nonetheless, the understanding of how these two systems contribute to the processing of others’ emotions and communicate with each other is mandatory for the delineation of a theoretical model that describes in its entirety the process of recognizing others’ emotions.

The model I have previously described by Wood and colleagues (2016) considers the recognition/discrimination of others' emotions as a complex process involving the parallel activation of two different systems, one for the visual analysis of faces and facial expressions, and the second one for sensorimotor simulation of facial expressions. This second system would trigger the activation of the emotion system, that is the whole of those additional brain regions involved in the emotional processing, including the limbic areas. The combination of these processing steps, in continuous iterative interaction with each other, would allow us to understand the emotion expressed by others' faces, assigning an affective state to the others, and possibly producing appropriate behavioral responses. Although this stimulating model proposes that sensorimotor simulation feeds back to shape the visual percept itself, the experimental evidence in this regard is very limited and primarily based on an interesting between-subjects study by Wood et al. (2016) on a large sample of participants (N = 122) that has used a facial gel that hardening was able of blocking/altering the participants' facial mimicry during a fine discrimination task of facial expressions. The behavioural results showed that blocking/altering facial mimicry (through the gel) had a selective negative impact on discrimination of facial expressions. The authors then proposed that this selective decrease in accuracy in the fine discrimination of emotions was due to a selective effect of the alteration of facial mimicry and to an interference with the simulation process that in turn would not have contributed/or would have to a small extent to the construction of the visual percept. However, this evidence is indirect and does not allow to reach these interesting conclusions with certainty. In particular, these findings do not allow to directly attribute the decrease in the accuracy of fine facial expressions discrimination to the impact of the block of mimicry on the construction of the facial expressions percept. For instance, the possibility remains that the blockage/alteration of mimicry may have an effect on the activation of the emotion system (see also Price & Harmon-Jones, 2015) or directly on the ability to infer an affective state from a facial expression that in turn would cause a decrease in discrimination accuracy. Wood's et al.' (2016) results do not inform on the specific stage of percept construction that would be affected by the block of facial mimicry. In other words, these results do not allow to state clearly whether the mimicry plays a role in the construction of the visual percept of facial expressions, and even less during which specific stage of visual processing this occurs. To answer these questions, I conducted two experiments to provide a direct test of some fundamental aspect of this model. In the two experiments I have explored the impact of an alteration of the participants' mimicry on the visual processing of facial expressions, monitoring early stages relative to the structural encoding of faces and facial expressions (Experiment 1) and later stages relative to the maintenance of visual working memory representations of faces and facial expressions (Experiment 2).

These experiments will be described in detail in the chapters dedicated to them (Chapter 3 and Chapter 4).

Chapter 3

Experiment 1: Exploring the effect of observers' facial mimicry on early stage of visual perception

The present study investigated the role of the observer's facial mimicry on the early stages of visual analysis of faces with negative facial expressions (i.e., anger and sadness) in order to test the hypothesis that the observer's facial mimicry is a critical element for the construction of a visual percept of the observed facial expression.

As I discussed at great length in Chapter 1, recognizing an emotion by looking at another person's facial expression would likely require additional and fundamental processing other than visual, possibly involving brain areas underlying embodiment and neural resonance mechanisms (see, e.g., Carr et al., 2003; Gallese & Sinigaglia, 2011; Niedenthal, 2007; Wicker et al., 2003). Experimental evidence in this field suggests that emotion recognition of a subtle emotion may also involve the right portion of the somatosensory cortex (rSC; Adolphs et al., 2000; Hussey & Safford, 2009). Furthermore, it seems plausible that the overlap between neural activity associated with the emotion experienced in first person vs. observed in others is not limited to the sensorimotor component of the emotion itself, but would also include portions of the limbic system such as the AI and the amygdala (see, e.g. Breiter et al., 1996; Morris et al., 1998; Whalen, 1998; Whalen et al., 1998; Whalen et al., 2004; Wicker et al., 2003). This rich empirical evidence supports the theoretical framework according to which at least the most subtle emotions could be interpreted and understood by internally simulating the expression itself.

Although there is evidence of a connection between motor representation of the observed facial expressions, encompassing the MNS, the PMC, the IPL and the FO (see, e.g., Banissy et al., 2011; Carr et al., 2003; Montgomery & Haxby, 2008; Montgomery et al., 2009) and the extraction of the "meaning” of that specific facial expression, the evidence on the role of facial mimicry in the construction of facial expressions percept is not conclusive and largely indirect.

Patients with inability to feel and express fear, disgust and anger tend to be deficient in recognizing these same emotions (Hussey & Safford, 2009); a meta-analysis, conducted on patients with focal brain lesions, revealed that damage to rSC is associated with deficits in the recognition of observed expressions (Adolphs et al., 2000); behavioral studies have proved that mimicking facial expressions of emotions facilitates their recognition (e.g. Lewis & Dunn, 2017). Consistently to this view, over ten years ago Goldman and Sripada (2005) formalized the role that mimicry and simulation could have in emotion recognition in the context of alternative versions of simulationist models of face-based emotion recognition. Simulationist models reviewed by Goldman and Sripada have been discussed at great length in Chapter 1. Here I want to underline that two of these models (i.e., Generate-and-test model, Reverse simulation model) support a central role for the observer’s facial mimicry in the recognition and discrimination of the facial expressions in others. Another simulationist model reported by the authors, the Unmediated resonance model (Gallese, 2001, 2003; Gallese et al., 1996; Kohler et al., 2002; Rizzolatti et al., 2001; Wicker et al., 2003) proposes that observation of a facial expression would instead directly trigger the activation (at the sub-threshold level) of the same neural substrates associated with that emotion in the observer, without any sort of mediation and, in this vein, the observer’s facial mimicry could be present or not, but the model does not clarify what its contribution can be in emotion recognition.

In spite the rich evidence on the importance of simulative processes and facial mimicry in emotion recognition, there are no direct evidence of a direct relationship between the visual system for facial expressions processing and the simulation system (including mimicry). Nonetheless, the understanding of how these two systems contribute to the processing of others' emotions and eventually communicate with each other is mandatory for the delineation of a theoretical model that describes in its entirety the process of recognizing the emotions in others. As it has been already discussed in Chapter 1, Wood et al. (2016) explained the selective decrease in accuracy they observed in the fine discrimination of emotions to the alteration of facial mimicry that would have interfered with the simulation process and, in turn, would not have contributed/or would have to a small extent to the construction of the visual percept of the facial expressions stimuli presented in their task. However, this evidence is indirect and do not allow to reach these intriguing conclusions with certainty. In particular, these findings do not allow to directly attribute the decrease in the accuracy of fine facial expressions discrimination to the impact of the block of mimicry on the construction of the facial expressions percepts. For instance, the possibility remains that the blockage of the mimicry might have affected the activation of the emotion system (see also Price & Harmon-Jones, 2015) or the ability to infer an affective state from a facial expression causing, as a consequence, a decrease in the discrimination accuracy. Further, Wood et al.'s (2016) results do not inform on the specific stage of percept construction that would be affected by blocking observers' facial mimicry. In other words, these results do not allow to state clearly whether the mimicry plays a role in the construction of the visual percept of facial expressions, and even less during which specific stage of visual processing this would occur.

Starting from all these promises, the first aim of the Experiment 1 was to directly test the hypothesis of a direct link between mimicry (*via* simulation) and the construction of visual percepts of facial expressions. For this purpose we used the ERP technique in a within-subjects design in which we administered our participants a task similar to that used by Wood et al. (2015), including both a condition of fine discrimination of facial expressions and a control condition of fine discrimination of animal images. Importantly, we adopted Wood's et al. stimuli in the context of a very similar paradigm. We then manipulated the participants' facial mimicry, who performed the discrimination task with a hardening facial gel in half of the experiment (with counterbalanced order). By means of ERPs we were able to trace the timecourse of the potential effects of mimicry on fine facial expressions discrimination focusing on an early component of ERP associated with face and facial expressions processing, i.e. N170 ERP component[4]. This component classically indexes low-level visual perception and categorization of face stimuli, and under certain circumstances it is sensitive to facial expressions (Bentin, Allison, Puce, Perez, & McCarthy, 1996; Eimer & McCarthy, 1999). It is generally thought to reflect the structural encoding of faces for recognition and identification (e.g., Achaibou, Pourtois, Schwartz, & Vuilleumier, 2008). The N170 is a negative-going component detected at the lateral occipito-temporal electrodes observed in the 120 to 220 ms range and peaking at around 170 ms post-stimulus. Several studied have shown that this face-sensitive component may be considered as an index of the configural processing of the face, since it clearly distinguishes faces from non-face visual stimuli (e.g., Bentin et al., 1996; Rossion, Joyce, Cottrell, & Tarr, 2003). It has been demonstrated that this component has a shorter latency and larger amplitude in the right hemisphere than the left hemisphere (Bentin et al., 1996). Its neural generators have been localized using dipole source models in the fusiform gyrus, in particular in "fusiform face area" (Schweinberger, Pickering, Jentzsch, Burton, & Kaufmann, 2002), and in the STS

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[4] The capital letter is related to the polarity of the components: "N" is for negative and "P" for positive. The number can be related to the serial number in which the oscillation occurs within the waveforms (e.g. the N1 is the first negative oscillation after the presentation of an event) or rather can be related to the latency, expressed in milliseconds, of the component (e.g. N100).

(Rossion et al., 2003). We did not expect any difference in terms of amplitude in the earlier ERP components, i.e. P1, because it mainly reflects the processing of low-level visual features, such as color and contrast (Rossion & Caharel, 2011). P1 face effects, starting shortly before 100 ms, are much less consistent than the N170 face effects (Tanaka, 2018).

Based on all these observations and evidence, if facial mimicry plays a role in the construction of facial expressions visual percepts, by altering/blocking it I expected to observe a modulation of the N170 amplitude.

3.1 Method

Participants

Data were then collected from 20 volunteer healthy students (6 males) from the University of Padova. Data from four participants were discarded from analyses due to excessive electrophysiological artifacts. All reported normal or corrected-to-normal and no history of neurological disorders. The final sample included 16 participants (mean age: 23.8 years, SD =; 4.28, 4 left-handed). All participants signed a consent form according to the ethical principles approved by the University of Padova.

Stimuli

The facial expressions stimuli consisted of images of a female model (we adopted the original images developed by Niedenthal, Halberstadt, & Margolin, 2000) expressing various morphed combinations of sadness and anger. Because our analyses required many trials for each stimulus, we used only one actor’s images, acknowledging the limitations of this approach. The face images were selected from a morph of anger and sadness¸ while the non-face control images were selected from a morph of a horse and a cow that had maximally similar postures (Figure 7). All images were resized to subtend a visual angle between 10 and 12 deg. Participants were seated about 60 cm away from the screen.

Figure 7 Stimuli utilized in the XAB perceptual discrimination task.

Procedure

The XAB discrimination task required participants to discriminate a target from a perceptually similar distractor. Participants performed twelve practice trials using morphed images followed by the horse–cow and angry–sad versions of the task, in that order, in separate blocks of trials. Each trial (Figure 8) shows the trial structure of the XAB discrimination task) began with a 500 ms fixation cross, followed by the target image (X) for 750 ms, The target was then followed by a 350 ms noise mask. Every trial was interleaved by a variable blank interval (Inter-stimulus Interval, ISI: 800-900 ms). The target image reappeared alongside a distractor, with left–right locations counterbalanced across trials. The target and distractor images were at 20 % apart on the morph continuum, yielding nine image pairs for each continuum. The trial order was randomized across participants. The target and distractor remained on the screen until participants had made a response. The 350 ms noise mask inserted between the target and test images limited the processing of the target faces, thus controlling for the potential effects of iconic memory representations. Participants 'task was to press a key (F = left; J = right) to indicate which image matched the target image. The participants performed 4 experimental blocks, each of 144 trials (i.e., 432 trials in total).

As in the study by (Wood et al., 2016), at the beginning of the experimental session participants were told that the experiment involved "the role of skin conductance in perception" and that they would be asked to spread a gel on their face in order to "block skin conductance" before completing a computer task.

Each participant has performed the task in two different conditions (counterbalanced order across the participants); in the gel condition a mask gel was applied on the participant's whole face, so as to create a thick and uniform layer, excluding the areas near the eyes and upper lip. The product used as a gel was a removable cosmetic mask (BlackMask Gabrini©) that dries in 10 minutes from application and becomes a sort of plasticized and rigid mask. The participants perceived that the gel prevented the wider movements of face muscles (see Figure 8). In the other half of the experiment (no-gel condition) nothing was applied to the participants' faces.

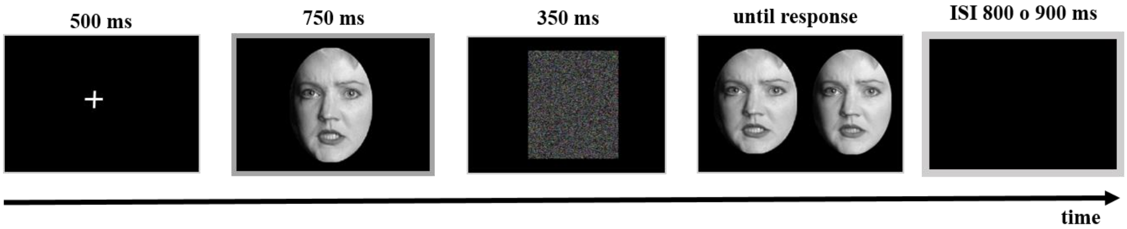

Figure 8 Sample trials depicting the perceptual discrimination XAB task.

Figure 9 Two pictures depict the result of the application of the gel on participants' face. The participants in the blocked/altered mimicry conditions were asked to apply the product to their entire faces in a thick layer. The experimenter instructed all the participants to do not move their facial muscles during the application of the gel. The experiment usually started 10 minutes after the gel application but – before starting the computer task – the compactness and duress of the facial gel was always checked.

EEG/ERP recording

The EEG was recorded during the task by means of 64 active electrodes distributed on the scalp according to the extended 10/20 system, positioning an elastic Acti-Cap with reference to the left ear lobe. The high viscosity of the gel used has allowed the impedance to be kept below 10 KΩ. The EEG was segmented into 1200-ms epochs starting 200 ms prior to the onset of the faces. The epochs were baseline-corrected based on the mean activity during the 200-ms pre-stimulus period, for each electrode site. The ocular correction was performed using Gratton (Gratton, Coles, & Donchin, 1983). Separate average waveforms for each condition were then generated time-locked to the presentation of the target face stimuli. Based on the experiment's aim, statistical analyses of ERP mean amplitude focused on N170 (150-190 ms). Mean ERPs amplitude values were measured at pooled electrode sites selected from occipito-parietal (PO10, PO9, PO8, PO7) electrodes according to visual inspection and previous work (Boehm, Dering, & Thierry, 2011). All electrodes were referenced to the right mastoid and re-referenced to the average reference off-line.

At the end of the EEG session involving the XAB discrimination task, the participants were given the Empathy Quotient questionnaire (Baron-Cohen & Wheelwright, 2004) and TAS-20 (Toronto Alexithymia Scale, Bagby, Parker, & Taylor, 1994; Caretti, La Barbera, & Craparo, 2005, for an italian version). The EQ measures the empathic skills of the individual through 80 items (20 of which are control items). Individuals have to express their agreement on a 4-point Likert scale: "very much agree", "partially agree", "partially disagree" and "very much in disagreement". The analysis of the scores is carried out on the basis of a scale ranging from 0 (almost null empathy) to 80 (exceptional empathy). The TAS-20 is a 20-item instrument that is one of the most commonly used measures of alexithymia. Items are rated using a 5-point Likert scale: “strongly disagree”, “moderately disagree”, “neither disagree nor agree”, “moderately agree” and “strongly agree”.

3.2 Results

Behavior

For the behavioral data, the analysis was conducted using the R environment (R Development Core Team, 2014; all package versions used were from Dec. 2014 or earlier) and the lme4 package (Bates, Mächler, Bolker, & Walker, 2015). We estimated generalized linear mixed-effect binomial model (since the outcome variable – correct/incorrect response – was dichotomous) including participants’ responses as dependent variable and stimuli (facial expressions vs. animals), mimicry condition (free vs. blocked/altered by the presence of the gel) and as fixed effects while subject as random effect. No significant differences emerged as a function of the mimicry condition; participants were equally accurate for facial expressions and animals stimuli regardless of the mimicry condition, b = -0.156, SE = 0.117, z = 1.339, p = .181.

ERPs

A repeated measure analyses of variance (ANOVA) was conducted on N170 amplitude values including stimuli (facial expressions vs. animals) and mimicry condition (free vs. blocked/altered by the presence of the gel) as within-subjects factors. Exact *p* values, mean square errors (i.e., MS_e) and effect sizes (i.e., partial eta-squared, ηp^2) are reported. Confidence intervals (i.e., *CIs*, set at 99%) are defined only for paired t-tests and referred to difference of means (i.e., M_{diff}, as suggested by Cumming, 2012). Planned comparisons relevant to test the hypotheses of the present experiment are reported.

Figure 10 shows grand averages of ERPs locked on face onset recorded at pooled occipito-parietal electrodes facial expressions/free mimicry condition, facial expressions/altered-blocked mimicry condition, animals/free mimicry condition, animals/altered-blocked mimicry condition.

The ANOVA revealed a significant main effect of both stimuli, $F(1,15) = 60.76$, $p < .001$, $\eta p^2 = .802$, and mimicry condition, $F(1,15) = 4.632$, $p = .048$, $\eta p^2 = .236$. The interaction between the mimicry condition and the stimuli reached significance, $F(1,15) = 9.405$, $p = .008$, $\eta p^2 = .385$. Planned comparisons revealed that the N170 amplitude was significantly increased for facial expressions in the blocked/altered mimicry when compared to the free mimicry condition, $t = - 2.638$ $p = .019$; *Mdiff* = -

.715 [.-1.37, -1.29]). This modulation of the N170 amplitude as a function of the mimicry conditions was not observed for animals, *t* = - .891 *p* = 3.87; *Mdiff* = -.061 [.-2.07, -.85])[5].

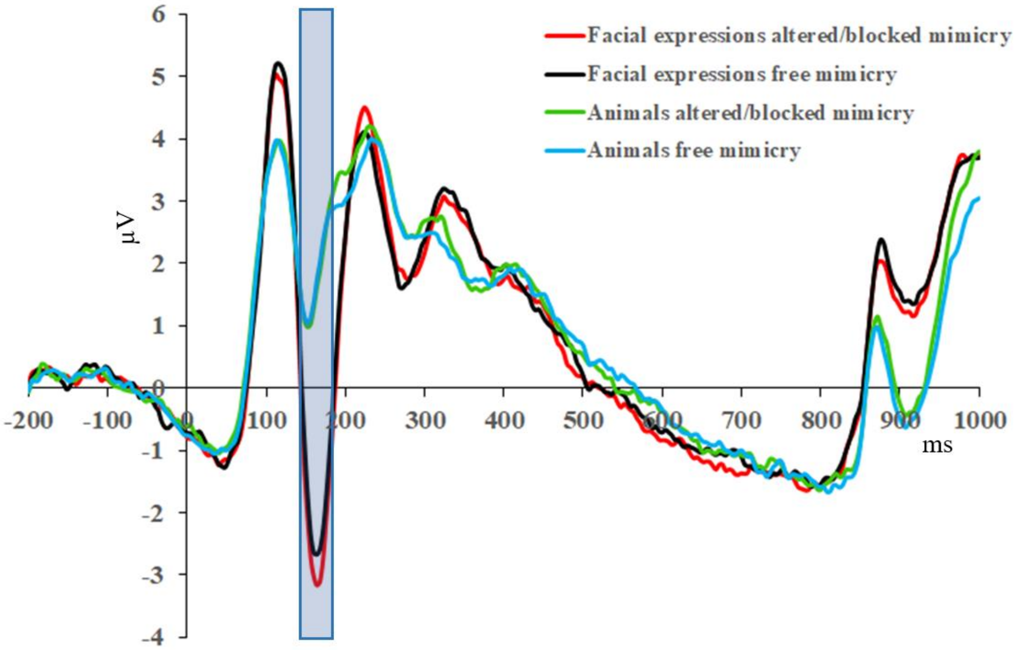

Figure 10 Grand averages of the face-locked ERP waveforms time-locked to the presentation of the target stimuli (facial expressions vs. animals) as a function of the mimicry conditions (free vs. altered/blocked).

3.3 Discussion

The present experimental investigation, based on the theoretical background offered by the simulation models of facial expressions and, more specifically, on the model recently proposed by Wood and colleagues (2016), had the aim of testing whether

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[5] I performed an ANOVA of the N170 amplitude values, including the same factors already mentioned in the Paragraph - stimuli (facial expressions vs. animals), mimicry condition (free vs. blocked/altered by the presence of the gel) as within-subjects factors- but adding the between-subjects factor EQ (medium-low EQ, medium-high EQ). No significant interaction emerges between these factors and EQ level (*F* (1,14) = 1.607, *p* = .226, ηp^2 = .103). Furthermore, I performed the ANOVA with the same within factors but including the between-subject factor TAS (medium-low TAS, medium-high TAS). No significant interaction emerges (*F* (1,14) = 3.557, *p* = .08, ηp^2 = .203). I also performed an ANOVA, including in one case participants EQ and in another case subjects TAS levels as covariates. Again, no significant differences were found between these factors (EQ: *F* (1,14) = 0.487, *p* = .497, ηp^2 = .034; TAS: *F* (1,4) = 3.697, *p* = .914, ηp^2 = .504).

the facial mimicry of an observer could be an element able to modulate the clarity of the visual percept. This idea is based on Wood and colleagues' model (2016) which proposed a feedback from simulation in sensorimotor areas to the extrastriate areas, able to increase the clarity of visual representations of facial expressions. The main goal of this experiment was to provide an evidence of whether the mimicry plays a role in the construction of the visual percept of facial expressions, and in particular, during which specific stage of visual processing this occurs. To test this hypothesis, I implemented the same XAB discrimination task paradigm as Wood et al.' study (2016) to monitor the N170 ERP component in two different experimental conditions (free mimicry vs. altered/blocked mimicry) and in a within-subject design. N170 is an early face-sensitive ERP component; it is typically much larger in response to faces than to non-face objects. This amplitude difference between face and non-face stimuli together with its characteristic scalp topography is thought to reflect the activation of face-selective brain areas (Eimer, 2011). By means of ERPs, I was able to track the timecourse of the potential effects of mimicry on fine facial expressions discrimination focusing on the N170 ERP component associated with face and facial expressions processing. In one experimental condition, the participants performed the facial expression discrimination task while being able to use their facial mimicry freely; in a different experimental condition, critical to test the main hypothesis of the present investigation, the participants performed the same task but their facial mimicry was blocked/altered by a facial gel that, hardening, greatly limited their facial movements. To ensure that the alteration of facial feedback affects the N170 ERP component, but selectively for facial expressions, I used as a control condition non-face stimuli (images of animals) that were not expected to elicit facial mimicry. Thus, I expected that the facial gel would have modulated the N170 ERP component elicited in the visual-matching task specifically for facial expressions stimuli, but not for the control animals' images.

In line with the hypotheses, the results with regard to the gel manipulation showed a modulation of the N170 ERP component amplitude values as a function of the mimicry condition. In particular, the N170 amplitude was larger for the face stimuli when participants wore the facial gel compared to when their mimicry was not blocked/altered. This finding might at first seems unexpected; however, it is in line with at least three plausible explanations. The first one is based on the vast literature on the impact of configural processing on the N170 amplitude, that strongly suggests that whenever configural processing is compromised this results in larger N170 amplitude (Boehm et al., 2011; Dering, Martin, Moro, Pegna, & Thierry, 2011). In line with this previous evidence, it is possible that observers' mimicry plays a role in configural processing of facial expressions stimuli. On the other hand, another interesting possibility is that in the absence of a useful feedback from simulative processes, larger visual resources must to be recruited for a correct construction of visual percepts of facial expressions. This view is supported by fascinating previous evidence described below.

In a very interesting study Achaibou et al. (2008), where EEG and facial EMG were concurrently recorded in participants while they were watching short movie clips displaying either happy or angry facial expressions, the authors replicated earlier EMG studies in which a correspondence between EMG activity and the observed facial expression was found (e.g., Dimberg & Thunberg, 1998). These results are also in accordance with current models of emotion simulation that propose that visual processing of facial expressions is followed by a mimicry response of the observed emotion, resulting in facial electromyography response (Halberstadt, Winkielman, Niedenthal, & Dalle, 2009; Niedenthal, 2007). In Achaibou and colleagues' study (Achaibou et al., 2008), EEG results indicated that when higher-order visual processes are strongly recruited for face processing – i.e. corresponding to larger N170 amplitudes – less mimicry is needed to process and recognize the emotion displayed in faces. The authors reasoned that a reduction in mimicry on trials with larger N170 amplitudes might result from some indirect effect of proprioceptive facial feedback during face processing. This idea is in line with Tourangeau & Ellsworth's proposal (1979) that facial mimicry plays a pivotal role in enhancing recognition of expression in other people *via* somatosensory feedback.

A very recent study by de la Rosa, Fademrecht, Bülthoff, Giese, and Curio (2018) challenges the classic view in which facial expression recognition relies on motor-based processes. The authors, using a paradigm of visual and motor adaptations to explore their effects on recognition of facial expressions, showed that visual adaptation (through the repeated visual presentation of facial expressions) and motor adaptation (through the repeated execution of facial expressions) had an opposite effect on expression recognition. These findings support a dual system for the recognition of others' facial expressions, one 'purely' visual and one based on simulation. The results I presented in this Chapter regarding Experiment 1 seems to suggest that, despite this dissociability, the two systems influence each other, at least as regards the effect of the simulation system on the visual system. But at the same time, in line with de la Rosa et al.'s findings (2018), our findings seem to demonstrate that, in cases in which simulation could not contribute to visual percept construction, additional visual resources are recruited indexing the existence of two systems for facial expressions recognition that might communicate but might also work in isolation.

The third explanation regarding the N170 modulation only for the face stimuli when participants wore the facial gel compared to when their mimicry was not blocked/altered is that facial mimicry might increase to accomplish the task when it finds a resistance. Indeed, there is evidence (Neal & Chartrand, 2011) demonstrating that afferent muscle signals are amplified when the initiating muscle meets resistance or load during contraction (e.g., Vallbo, 1974). In the proprioceptive literature, this resistance is created by adding small weights to a contracting muscle or by taping the skin overlying a muscle such that the skin provides a subjective experience of resistance when the muscle contracts (for a review, see Gandevia, McCloskey, & Burke, 1992). In the case of this experiment, the “amplified” feedback from the face due to the gel mask application adds noise that could interfere with the perception of the target expression that sensorimotor processes might be facilitating. In this case, the sensorimotor system would not function optimally since the gel mask may cause a mismatch between sensorimotor predictions and feedback, inducing an actively recruitment of visual resources for face processing – i.e. corresponding to larger N170 amplitudes.

To clarify which is the effect on facial mimicry due to the gel application, further studied should consider electromyography recordings to investigate muscle activity in the free and blocked/altered mimicry conditions.

In conclusion, I want to examine the lack of an impact of the mimicry manipulation on overt behavior. This discrepancy between the neural and behavioral levels of our investigation could be due to the fact that neural measure might be more sensitive to the mimicry manipulation than accuracy (e.g., examples of this discrepancy between neural and behavioral findings Heil, Rolke, and Pecchinenda, 2004; Luck, Vogel, and Shapiro, 1996). Moreover, the effects related to mimicry tend to be very small and usually require, in behavioral studies, rather large samples (with *N* even larger than 100) to be observed (e.g., Wood et al., 2016). Alternatively, and on the basis of the evidence described above, when simulation is compromised, the additional visual resources recruited for the discrimination task might compensate it, resulting in a correct response at the behavioral (overt) level.

Chapter 4

Part of the content presented in this chapter has been described in the following published article:

Sessa, P., Schiano Lomoriello, A., & Luria, R. (2018). Neural measures of causal role of observers' facial mimicry on visual working memory for facial expressions. *Social Cognitive and Affective Neuroscience*, nsy095, https://doi.org/10.1093/scan/nsy095

Experiment 2: Investigating the role of observers' facial mimicry on visual working memory for facial expressions

The objective of Experiment 2 was to test whether the mimicry of the observer is a critical element for the construction of visual working memory (VWM) representations of facial expressions of emotions, by also monitoring whether this process can depend on the degree of empathy of the observer.

The VWM buffer constitutes a critical hub between the earlier processing stages and the manifest behavior of the individuals (see, e.g., Luck, 2005). Thus, demonstrating that the observer's facial mimicry could have an impact on the functioning of this buffer is of fundamental importance for understanding how facial expressions recognition occurs, and in particular, how the VWM buffer operates when coordinating online behavior.

In this sense, given also the evidence discussed in Chapter 2, it is of fundamental importance to understand if the effect of the observer's mimicry is exhausted in initial stages of construction of the visual representation of a facial expression or if its effect can also manifest in later stages, such that of VWM representations, which, as mentioned above, is critical for further and high-level processing stages.

The concertation of processing stages/activity in different brain regions necessary for an understanding of others' emotions is well delineated by a recent theoretical model proposed by Wood and colleagues (2016), already described in previous paragraphs. Briefly, the model considers the recognition/discrimination of others' emotions as a complex process involving the parallel activation of two different systems, one for the visual analysis of faces and facial expressions, and a second one for sensorimotor simulation of facial expressions. This second system would trigger the activation of the emotion system that is the whole of those additional brain regions involved in the emotional processing, including the limbic areas. The combination of these processing steps, in continuous iterative interaction with each other, would allow us to understand the emotion expressed by others' faces, assigning an affective state to the others, and possibly producing appropriate behavioral responses. A crucial aspect of Wood and colleagues' model (2016) is that the sensorimotor simulation process (which, according to the authors, may or may not involve the facial mimicry of the observer depending on the intensity of the simulation) "feeds back to shape the visual percept itself" (Wood et al., 2016). This aspect of the model therefore implies that interfering with the simulation mechanism may have an effect on the quality of the representation of facial expressions. This hypothesis has been already tested in Experiment 1 described in the previous Chapter 2.

According to Wood and colleagues' simulation and recognition of facial expressions model (2016) participants may build a representation of the target facial expression that is partially grounded in sensorimotor activity, and which extends the otherwise limited working memory capacity of the visual system. They can then refer to this representation during the discrimination stage of the task. The representation generated by the individuals wearing the gel facemask may, however, be distorted and ultimately reduce accuracy.

Experiment 2 aimed at further exploring the aspect of the model by Wood and colleagues (2016) that hypothesized a feedback process from simulation to facial percept representation. In particular, the main research question that led the present study was whether alteration/blocking of facial mimicry by using a hardening gel mask could interfere with VWM representations of emotional facial expressions. This would allow first of all to demonstrate the feedback processing postulated by the model, in which the simulation has an effect on the construction of facial expression representations, and also would allow a better understanding of the functioning of the VWM buffer, since an effect of block/alteration of mimicry on this buffer would demonstrate that the simulation process normally contributes to its functioning in the case faces are represented/stored.

For this purpose, a variant of the classic change detection task (Luria et al., 2010; Meconi et al., 2014; Sessa & Dalmaso, 2016; Sessa et al., 2011; Sessa et al., 2012; Vogel & Machizawa, 2004; Vogel et al., 2005) was implemented in which participants, who wore the gel mask for half of the experiment (manipulation of the gel within-subjects), were asked, in each trial, to memorize a face (*memory array*) with a facial expression of three possible intensities (neutral, subtle, intense) for a short time interval of about 1 sec, and to decide, at the presentation of a *test array,* if the expression of the presented face was the same or different from that of the memorized face. The identity of the faces did not change within the same trial. In order to monitor the ERP component named Sustained Posterior Contralateral Negativity (SPCN; Jolicœur et al., 2007; Luria et al., 2010; Meconi et al., 2014; Sessa & Dalmaso, 2016; Sessa et al., 2011, 2012) or also Contralateral Delay Activity (CDA; Vogel & Machizawa, 2004) the presentation of the stimuli was lateralized in the visual field and a distractor face was presented on the opposite side. An arrow placed in the center of the screen, immediately above the fixation cross, indicated to the participants – for each trial – if they had to memorize the face in left or right side of the memory array. The participants then had to compare this memorized face with the face that appeared in the same position in the test array.

The SPCN/CDA is a well-known marker of VWM representations (see Luria, Balaban, Awh, & Vogel, 2016 for a review). It is defined as the difference between the activity recorded at posterior sites (PO7/PO8, O1/O2, P3/P4) contralaterally to the presentation of one or more to-be-memorized stimuli and the activity recorded ipsilaterally to the presentation of one or more to-be-memorized stimuli. SPCN/CDA amplitude tends to increase as the amount of information to be memorized or the quality (in terms of resolution) of the representation increases (e.g., Sessa et al., 2011, 2012; Vogel & Machizawa, 2004) until an asymptotic limit is reached that corresponds to the saturation of the VWM capacity (e.g., Vogel & Machizawa, 2004). Sessa and colleague's (2011) shown that faces with intense facial expressions (fear) elicit larger SPCN/CDA than faces with the same identity but with neutral expressions. These findings suggest either that emotions are represented in VWM, such that VWM representations may include the emotion information, or that faces with an emotional expression are represented with higher resolution than neutral faces (see also Stout, Shackman, and Larson, 2013, for a replication of these findings).

The SPCN proves therefore to be a very useful marker in the present experimental context, since it offers us the opportunity to test the role of observers' facial mimicry on the construction of facial expression representations in VWM. A secondary goal was also to provide an extension of Sessa et al.'s previous results (2011) to a different negative facial expression (i.e., anger).

I expected to observe lower SPCN/CDA amplitude values for facial expressions memorized when participants wore the hardening gel compared to the condition in which participants' facial mimicry was not blocked/altered, that is, as suggested by Wood and colleagues' model (2016) that mimicry may increase the clarity of visual representations of facial expressions, and as a consequence we expected higher resolution for facial expressions memorized when participants' mimicry could be freely used than when blocked/altered. I also expected larger SPCN/CDA amplitude values for intense expressions of anger when compared to both neutral and moderate expressions of anger (i.e., higher clarity of visual representations for intense angry expressions than for neutral and subtle expressions).

Finally, as I already mentioned, the literature strongly suggests that mimicry is strictly linked to empathy (see Prochazkova & Kret, 2017). On the basis of the evidence provided by the literature on the link between mimicry and empathy, I included the empathy variable in our experimental design by measuring participants' Empathic Quotient (Baron-Cohen & Wheelwright, 2004) in order to evaluate whether the interference on the simulation process by blocking/altering participants' mimicry may affect VWM representations of faces differently in high and low empathic individuals.

4.1 Method

Participants

Before starting with data collection, I decided to proceed with the analysis of a sample of about 30 participants, as the existing literature in the field suggests being an appropriate sample (Sessa et al., 2011).

The analyses were conducted only after completing the data collection. Data were collected from 36 healthy volunteer students of the University of Padova. Due to an excess of electrophysiological artifacts, especially eye movements, data from 7 participants were discarded from the analysis. All participants reported normal or correct vision from lenses and no history of neurological disorders. Twenty-nine participants (18 males, average age in years = 24, SD = 2.73; 2 left handed) were included in the final sample.

Stimuli

The stimuli were grayscale digital photographs of faces of 8 individuals (4 females and 4 males) expressing three different levels of emotional facial expression (neutral, sublte and full). These face stimuli have been modified by Vaidya, Jin, &

Fellows (2014)[6] from the original images taken from the Karolinska database (Lundqvist, Flykt, & Öhman, 1998) that included neutral and angry facial expressions. The subtle facial expressions were generated by a morphing procedure of facial expressions of the neutral and angry expressions of the same individual from Vaidya, Jin, & Fellows, (2014) and were 30-40% along the morph continuum. Figure 11 shows the three levels of facial expressions' intensity for 2 individual faces (one of a female and one of a male). All images have been resized to subtend at a visual angle between 10 and 12 degrees. The participants were seated at 70 cm from the screen. The stimuli were presented on a 7" inch CRT monitor of a computer with E-prime software.

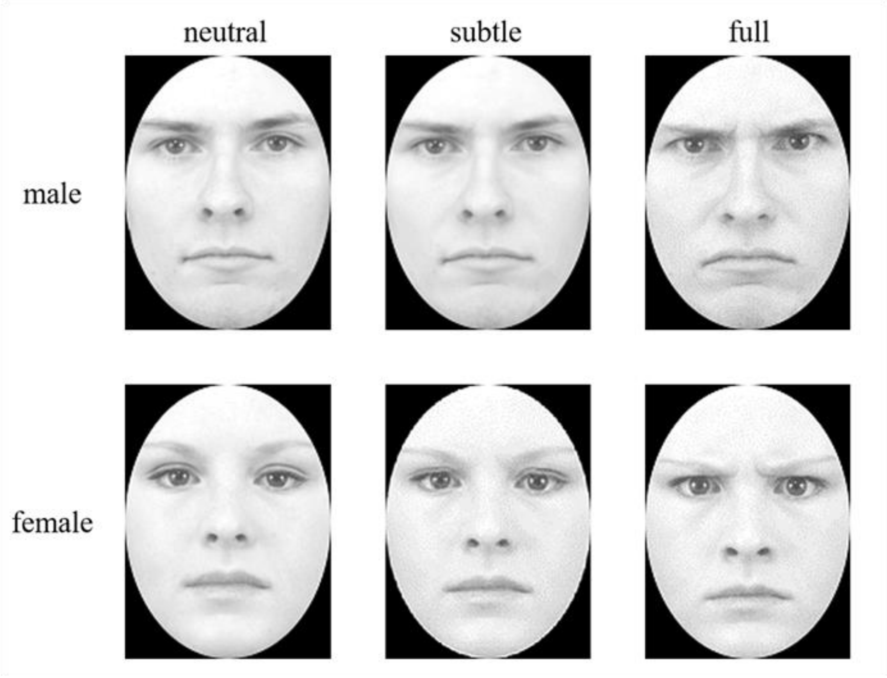

Figure 11 Examples of the stimuli used in the change detection task, one for each three level of facial expression (neutral, intermediate, full) for 2 individual faces (one of a female and one of a male).

Procedure

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[6] In the previous experiment by Vaidya et al. (2014) these stimuli were evaluated on their intensity level in an emotion rating task The emotions represented relatively distinct domains along dimensions of arousal and affect.

I used a variant of the change detection task (e.g., Sessa et al., 2011; Vogel & Machizawa, 2004). Each trial began with a fixation of 500 ms, that remained in the center of the screen throughout the trial, followed by the presentation of two arrows as cues shown for 200 ms one above and one below the fixation cross, both pointing in the same direction (i.e., both on the left or both on the right). The two cues, or the two arrows, were shown for 200 ms and followed by a blank screen of variable duration (200-400 ms). Then a memory array of faces appeared, presented for 500 ms. The memory array consisted of two faces with a neutral, subtle or full emotional facial expression of anger.

Following the memory array, a blank screen with a duration of 900 ms preceded the test array onset, which also contained two faces, one on the right and one on the left of the fixation cross, which was shown until an answer was provided by the participant. In the memory and in the test array, faces of the same identity were presented. Participants were instructed to maintain their gaze on the fixation cross throughout the trial and to memorize only the face of the memory array shown in the side indicated by the arrows and were also explicitly informed that the face shown on the opposite side was not relevant for the task at hand. The task was to compare the memorized face with the one presented on the same side of the test array, in order to indicate if the facial expression of the face had changed or not. In 50% of the trials, the facial expression in the memory array and the test array were identical. In the remaining 50% of the trials, the facial expression was replaced in the test array with a different facial expression. When a change occurred, the face stimulus was replaced with a face stimulus of the same individual but which presented a different intensity of facial expression.

Half of the participants were instructed to press the "F" key to indicate a change between the memory array and the test array and the "J" key to indicate that there was no change between the memory array and the test array. The other half of the participants responded on the basis of an inverted response mapping. The responses had to be given without any time pressure: the participants were informed in this regard that the speed of response would not be taken into account for the evaluation of their performance. Following the response, a variable interval of 1000−1500 ms (in 100 ms steps) elapsed before the presentation of the fixation cross indicating the beginning of the next trial. The experiment started with a block of 12 trial trials. The participants performed 4 experimental blocks, each of 144 trials (i.e., 432 trials in total). Figure 12 shows the trial structure of the change detection task.

Each participant has performed the task in two different conditions (counterbalanced order across the participants); in the gel condition a mask gel was applied on the participant's whole face, so as to create a thick and uniform layer, excluding the areas near the eyes and upper lip. The product used as a gel was a removable cosmetic mask (BlackMask Gabrini©) that dries in 10 minutes from application and becomes a sort of plasticized and rigid mask. The participants perceived that the gel prevented the wider movements of face muscles. In the other half of the experiment (no-gel condition) nothing was applied to the participants' faces[7].

As in the study by Wood et al. (2016), at the beginning of the experimental session participants were told that the experiment involved "the role of skin conductance in perception" and that they would be asked to spread a gel on their face in order to "block skin conductance" before completing a computer task.

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[7] For the facial gel application, I used the same procedure as descripted and depicted in Experiment 1 (see **Errore. L'origine riferimento non è stata trovata.**).

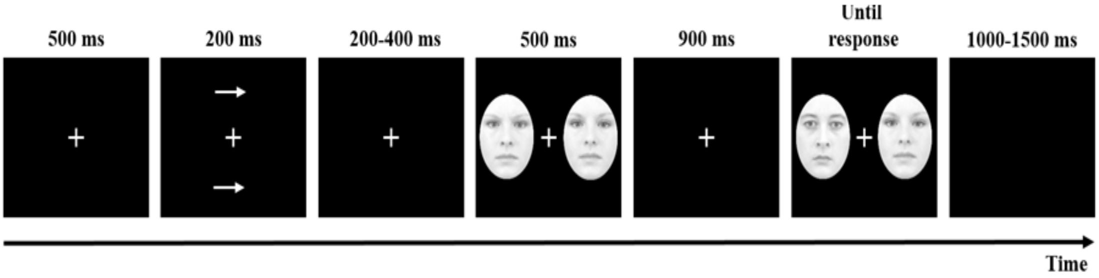

Figure 12 Timeline of each trial of the change detection task.

EEG/ERP recording

The EEG was recorded during the task by means of 64 active electrodes distributed on the scalp according to the extended 10/20 system, positioning an elastic Acti-Cap with reference to the left ear lobe. The high viscosity of the gel used has allowed the impedance to be kept below 10 KΩ. The EEG was re-referenced offline to the mean activity recorded at the left and right ear lobes. The EEG has been segmented into epochs lasting 1600 ms (-200/1400). Following the baseline correction, trials contaminated by ocular artifacts (i.e. those in which the participants blinked or moved the eyes, eliciting activity higher than ± 30 μV or ± 60 μV, respectively) or from other types of artifacts (greater than ± 80 μV) were removed. Finally, the contralateral waveforms were computed by mediating the activity recorded by the electrodes of the right hemisphere when the participants were required to encode and memorize the face stimulus presented on the left side of the memory array (pooling of the electrodes O2, PO8, P4) with the activity recorded by the electrodes positioned on the left when the participants were required to encode and memorize the face stimulus presented on the right side of the memory array (pooling of electrodes O1, PO7, P3). The SPCN was quantified as the difference in mean amplitude between the contralateral and ipsilateral waveforms in a time window of 300-1300 ms time-locked to the presentation of the memory array for each experimental condition (facial expression: neutral, subtle, full; condition: gel and no-gel).

At the end of the EEG session involving the change detection task, the participants were given the Empathy Quotient questionnaire (Baron-Cohen & Wheelwright, 2004). The EQ measures the empathic skills of the individual through 80 items (20 of which are control items). Individuals have to express their agreement on a 4-point Likert scale: "very much agree", "partially agree", "partially disagree" and "very much in disagreement". The analysis of the scores is carried out on the basis of a scale ranging from 0 (almost null empathy) to 80 (exceptional empathy).

The EQ values were then sorted in ascending order and the participants were divided into 2 groups so that a group of participants had a medium-low EQ average value (N = 15) and another group a medium-high EQ average value (N = 14). The rationale for this procedure was based on the assumption that individuals with higher empathic abilities are more likely to use their facial mimicry when recognizing and discriminating other people's facial expressions than individuals with lower empathic abilities (e.g., Sonnby-Borgström, 2002; Sonnby-Borgström, Jönsson, & Svensson, 2003). From this point of view it is possible that the blocking/altering facial mimicry by means of the gel could compromise the representations of facial expressions more in the participants with medium-high EQ than in the participants with medium-low EQ.

4.2 Results

Behavior

The mean proportion of correct responses was submitted to an analysis of variance (ANOVA) considering the within-subject factors emotion (neutral, subtle, full), the mimicry condition (free vs. blocked/altered by the presence of the gel) the between-subjects factor EQ (medium-low EQ, medium-high EQ). The only statistically significant effect was that of emotion, *F*(2,26) = 325.937, p < .001, ηp^2 = .923. Following planned comparisons indicated that participants were more accurate when they had to memorize faces with full expressions than when they had to memorize faces with neutral expressions (p < .001, SE = .008, 95% CI [.123, .163]) or subtle expressions (p < .001, SE = .007, 95% CI [.160, .196]). In addition, the participants were more accurate when they had to memorize faces with neutral expressions than faces with subtle expression (p < .001, SE = .007, 95% CI [.016, .054]). The effect of the mimicry condition and the interaction between emotion and mimicry conditions were not statistically significant (*F* = 1.463, and *F* < 1, respectively). See the Figure 13

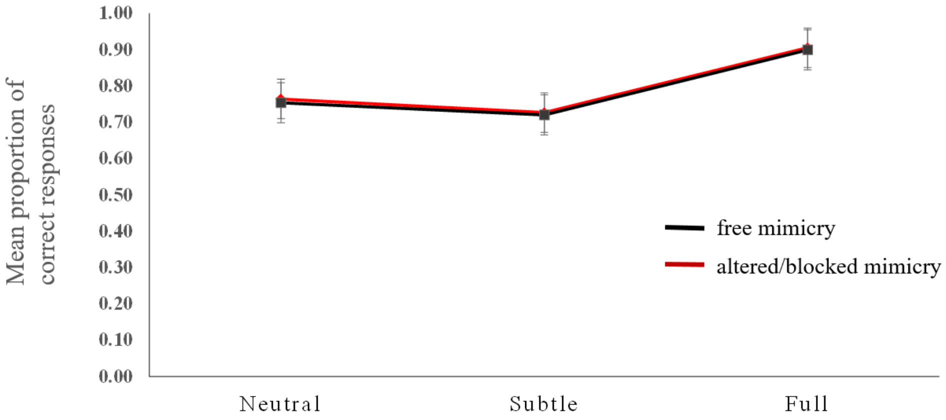

Figure 13 Mean proportion of correct responses in the change detection task for each facial expression condition (neutral, subtle, full).

SPCN

An ANOVA of the mean SPCN amplitude values was performed including the within-subjects factors emotion (neutral, subtle, full) and mimicry condition (free vs.

blocked/altered by the presence of the gel) and the between-subjects factor EQ (medium-low EQ, medium-high EQ). Wherever appropriate the Greenhouse-Geisser correction was used.

The ANOVA revealed a significant main effect of the emotion (*F*(2,26) = 9.841, p = .001, ηp^2 = .267), of the mimicry condition (*F*(1,27) = 5.189, p =. 031, ηp^2 = .161)), and an interaction between the mimicry condition and the EQ (*F*(1,32) = 4.617, p = .041, ηp^2 = .146). The other interactions were not statistically significant ($F < 1$). Pairwise comparisons revealed that facial expressions of full anger elicited larger SPCN amplitude values (mean SPCN amplitude for full expressions = -1.03 µV) when compared to both neutral expressions (p = .004, SE = .104, 95% CI [-.540, -.112] mean SPCN amplitude for neutral expressions = -.71 µV) and subtle expressions (p = .001, SE = .166, 95% CI [.956, -.275]; mean SPCN amplitude for subtle expressions = -.42 µV). Interestingly, subtle expressions produced reduced SPCN amplitude values when compared to neutral expressions (p = .047, SE = .139, 95% CI [.004, .575]). In brief, the whole pattern of SPCN mean amplitudes elicited by the different levels of emotions nicely mirrored participants' accuracy in the change detection task. The differential waveforms (contralateral-minus-ipsilateral) time-locked to the presentation of the memory array for each level of facial expression (neutral, subtle, full) are presented in Figure 14.

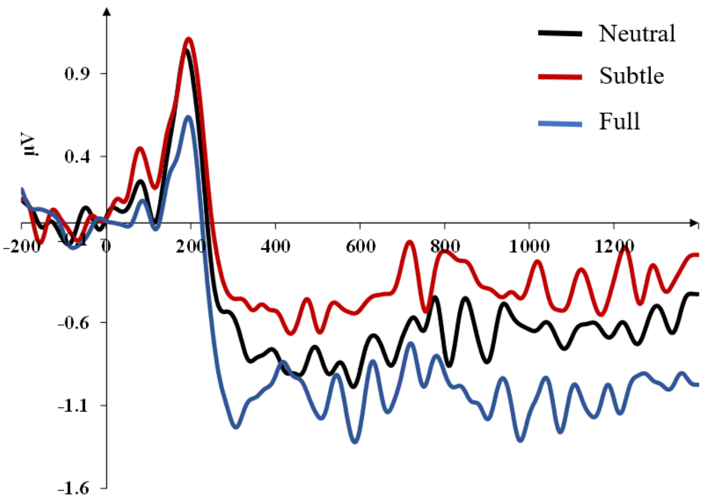

Figure 14 Grand averages of the face-locked ERP waveforms time-locked to the presentation of the memory array as a function of the facial expression conditions (neutral, subtle, full) collapsed across the mimicry conditions (free vs. altered/blocked).

Pairwise comparisons (Bonferroni corrected) for participants with medium-low EQ did not highlight any effect of the mimicry condition ($F < 1$, SE = .183, 95% CI [-.391, .358]; mean SPCN amplitude for the blocked/altered mimicry condition = -.73 µV, for the free mimicry condition = -.75 µV), but, importantly, participants with medium-high EQ showed that the blocked/altered mimicry significantly impacted the SPCN amplitude (= 9.471, p = .005; SE = .189, 95% CI [-.969, .194]; ηp^2 = .260; mean SPCN amplitude for the blocked/altered mimicry condition = -.40 µV, for the free mimicry condition = -.98 µV).

Figure 15 shows the differential waveforms (contralateral-minus-ipsilateral) time-locked to the presentation of the memory array for the two mimicry conditions (free vs. blocked/altered) for medium-low EQ participants (panel A) and medium-high EQ participants (panel B) separately.

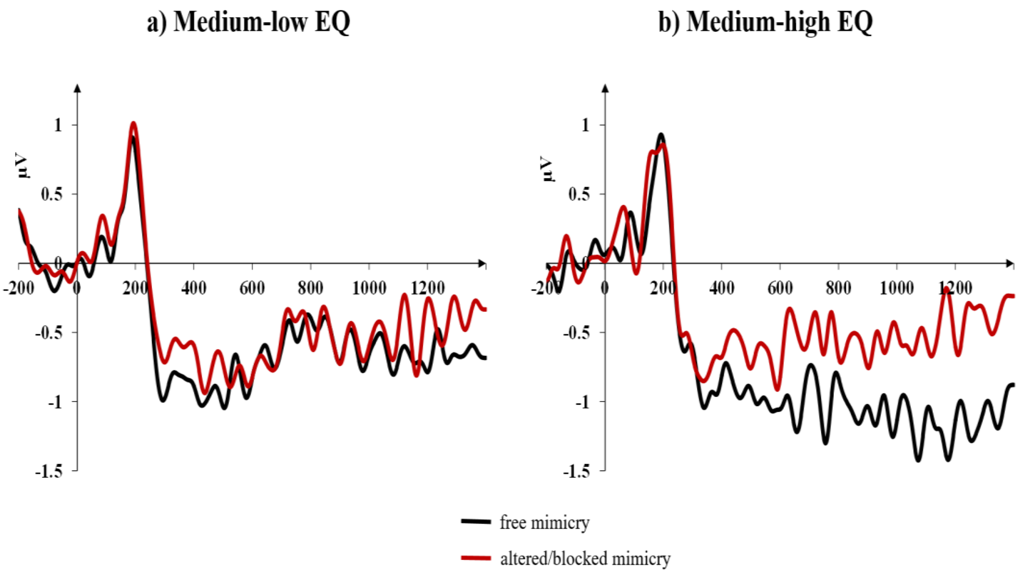

Figure 15 Grand averages of the face-locked ERP waveforms time-locked to the presentation of the memory array as a function of the mimicry conditions (free vs. altered/blocked) and collapsed across facial expression conditions (neutral, subtle, full) for medium-low EQ participants (panel A) and medium-high EQ participants (panel B) separately.

These results therefore suggest that VWM representations of facial expressions appear to be impaired by the gel in the more empathic participants, but not in the less empathic participants.

4.3 Discussion

The present experimental investigation, based on the theoretical background offered by the simulation models of facial expressions and, more specifically, on the model recently proposed by Wood and colleagues (2016), had the objective of testing whether the facial mimicry of an observer could be an element able to modulate the visual representations of facial expressions, as predicted by this latter model that proposes a feedback processing from simulation in sensorimotor areas to processing in the extrastriate areas, such that the simulation process is able to increase the clarity of visual representations of facial expressions.

With the aim to test this hypothesis, we implemented a variant of the classic change detection task in order to monitor the electrophysiological marker of VWM representations, namely the SPCN/CDA ERP component, in two critical experimental conditions in a within-subjects design. In one experimental condition the participants performed the change detection task, that included faces with different intensities of facial expression of anger (neutral, subtle and full) while being able to freely use their facial mimicry during the encoding and VWM maintenance of the face stimuli; in a different experimental condition, critical to test the main hypothesis of the present investigation, the participants performed the same task but their facial mimicry was blocked/altered by a facial gel that, hardening, greatly limited their facial movements.

In line with Sessa et al.'s hypotheses (2011), the results with regard to the gel manipulation showed reduced SPCN/CDA amplitude values for the face representations stored when participants wore the facial gel compared to when their mimicry was not blocked/altered, thus suggesting that the information maintained in VWM under the blocked/altered mimicry condition was poorer than that maintained in the condition in which participants could naturally use their facial muscles during the exposure to facial expressions.

We did not observe differences between the two conditions of anger expressions (subtle vs. full) in terms of modulation of the SPCN amplitude. One possible explanation is that mimicry is not so selectively sensitive to different levels of negative expressions, as for instance it is suggested by a recent study by Fujimura, Sato, & Suzuki, (2010). These authors have indeed provided experimental evidence that the intensity level (arousal) of facial expressions induces in the observers a modulation of their facial mimicry (measured as the electromyography reactions of the zygomatic major and supercilii corrugator muscles) only in the case of expressions with positive valence, but not in the case of negative expressions that instead induced the same level of mimicry in the observers, as indicated by the activity of their supercilii corrugator muscle. On the other hand, another possibility that we cannot disregard is that the statistical power of our study could have been able to allow observing an overall effect of the mimicry but not more subtle modulations related to the different levels of facial expressions.

A second main objective of our work was also to investigate whether the level of empathy of the observer could be an important variable for understanding the role of mimicry on the construction and maintenance of facial expression representations in VWM. The evidence in the literature that guided this hypothesis strongly suggests that individuals with higher levels of empathy are more likely to use their facial mimicry during exposure to facial expressions such as happiness and anger (Dimberg, Andréasson, & Thunberg, 2011; Sonnby-Borgström, 2002; Sonnby-Borgström et al., 2003), and activate their corrugator muscle even when exposed to fear (Balconi & Canavesio, 2016) and disgust (Balconi & Canavesio, 2013; see also Rymarczyk, Zurawski, Jankowiak-Siuda, & Szatkowska, 2018). These findings, together, constitute an important body of knowledge that supports the view that mimicry is an important component of emotional empathy (see, e.g., Preston & de Waal, 2002; Prochazkova & Kret, 2017). These results are very nicely in agreement with this previous evidence; in fact the participants who suffered the most impairment of VWM facial expression representations (in terms of SPCN amplitude) due to the block/alteration of their facial mimicry were those with higher levels of empathy (as measured by the EQ).

A very recent study by de la Rosa, Fademrecht, Bülthoff, Giese, & Curio, 2018) has used a clever paradigm of visual and motor adaptations to explore their effects on recognition of facial expressions. Notably, their results showed that visual adaptation (through the repeated visual presentation of facial expressions) and motor adaptation (through the repeated execution of facial expressions) had an opposite effect on expression recognition. These findings support a dual system for the recognition of others' facial expressions, one 'purely' visual and one based on simulation. Our results, nevertheless, seem to suggest that this dissociability does not imply that the two systems cannot influence each other, at least as regards the effect of the simulation system on the visual system. Furthermore, they suggest that there might be an important inter-individual variability in the connectivity of the two systems, such that this influence of the simulation system on the visual system (in our present work in terms of VWM representations) is particularly relevant for those individuals with higher levels of empathy who likely tend to recognize others' emotional expressions through the synergy of the two systems. Moreover, in the light of these observations, it should probably be emphasized that these findings inform us about the recognition/discrimination of emotions under conditions of interference with simulation, but nothing tells us about the observer's subjective experience that might differ in cases in which facial expressions processing is accomplished on a visual basis, on a simulation basis or through an integration of the two systems. We believe that answering this question is one of the most ambitious challenges that future research will have to face.

The present study also allowed to replicate Sessa and colleague's previous findings (2011) regarding the effect of facial expressions on VWM representations extending those previous findings to a different negative facial expression, i.e. anger. Sessa and colleague (2011) have demonstrated that faces with an intense expression of fear elicit larger SPCN amplitudes than faces with a neutral expression, suggesting that fearful faces are either represented in greater detail (i.e., high-resolution representations) or that the emotion is also represented in VWM in some kind of additional visual format. In the present study, I have replicated these results with angry faces compared to neutral faces: facial expressions of intense anger elicited an SPCN of greater amplitude than neutral and subtle facial expressions and, moreover were associated with greater accuracy in the change detection task when compared to the other two levels of intensity of facial expressions (neutral and subtle). This overall pattern of findings is very well in line with the benefit observed for negative and angry facial expressions in previous studies in terms of behavioral indices of sensitivity (Jackson, Wolf, Johnston, Raymond, & Linden, 2008; Jackson, Linden, & Raymond, 2014; Langeslag, Morgan, Jackson, Linden, & Van Strien, 2009; Simione et al., 2014; Xie & Shang, 2016). An unexpected result refers to the observation that the faces with expression of subtle anger elicited not only an SPCN of lower amplitude than the faces with full expressions of anger, but also an SPCN of lower amplitude than the faces with neutral expressions. This electrophysiological pattern also entirely parallels accuracy in the change detection task, such that accuracy associated with trials subtle faces expressions was lower than accuracy for faces with both full and neutral expressions. A possible account for this result could take into consideration the concept of distinctiveness, originally coined in the context of long-term memory studies (see, e.g., Eysenck, 1979) and later considered a variable of great importance also in the context of short-term memory studies (Hunt, 2006). Distinctiveness refers to the ability of an item to produce a reliable representation in memory relative to the other items in a certain (experimental) context. In relation to the stage of information retrieval, distinctiveness specifies that it is more likely to recover memories/representations that are sparsely represented within the space of representation than memories/representations that are densely represented. In this perspective, neutral and full expressions are two prototypical categories characterized by high distinctiveness, while subtle facial expressions of anger might be characterized by a low distinctiveness and, as a consequence, might elicit smaller SPCN amplitudes and be associated with reduced accuracy in the change detection task when compared to full expressions of anger and neutral expressions.

Finally, I want to examine the lack of an impact of the mimicry manipulation on overt behavior. This discrepancy between the neural and behavioral levels of our investigation could originate from at least two possible sources. On the one hand, it is possible that the neural measure might be more sensitive to the mimicry manipulation than accuracy, at least in the context of the present change detection paradigm. According to this line of reasoning, the effect size of the mimicry effect on SPCN amplitude values was lower than the effect size of the emotion effect (ηp^2 = .161 vs. ηp2 = .267), an observation that could suggest that accuracy captured only the greatest effect in terms of effect size. The literature offers several examples of this discrepancy between neural and behavioral findings (e.g., Heil, Rolke, & Pecchinenda, 2004; Luck, Vogel, & Shapiro, 1996), also in the context of the change detection task (e.g., Sessa et al., 2011, 2012). Moreover, the effects related to mimicry tend to be very small and usually require, in behavioral studies, rather large samples (with N even larger than 100) to be observed (e.g., Wood et al., 2016). An alternative explanation of this incongruity could be that SPCN and accuracy provide estimates of two different aspects of the VWM functioning: while the SPCN can be considered a pure index of VWM representation, accuracy also reflects the processes of retrieval, deployment of attention on the test array stimuli and the comparison between the stored representation and the to-be-compared stimulus in the test array (i.e., comparison process; Awh, Barton, & Vogel, 2007; Dell'Acqua et al., 2010; Hyun et al., 2009). Therefore, in light of these observations, the most relevant result of the present investigation, related to a modulation of the SPCN amplitude as a function of the mimicry manipulation, is entirely reliable.

Chapter 5 – Neuroscience of empathy

Daniel Goleman (1995) describes empathy as one of the basic components of emotional intelligence (EQ). According to his definition, empathy is a critical part of social awareness and a fundamental key to humans' life. Empathy helps us to create interactions and connections with others that are around us, and therefore represents a fundamental humans' skill.

Neuroscientific research mainly focused on understanding how the human brain deals emotions as well as interactions, which both represent the core of our existence as social beings. Thus, the field of social neuroscience has started to investigate the neural mechanisms underlying social cognition and emotions, such as our ability to empathize with others

The term "Empathy" appears for the first time in 1090 when the philosopher Edward Bradfor Tithener translated the German term "Einfühlung".

Empathy is the ability to share and understand other people's emotions both for "prosocial behavior" – definable as the motivation to improve other's experience, such as the relief of someone else's pain (de Waal, 2008) – and for reducing what psychologists generally call "personal distress" – as, for instance, when an observer want to improve his/her own personal experience by reducing other's pain. People can empathize with another individual when they vicariously share their affective state but - at the same time – are aware that it is the other person's emotion, which is causing our response.

In this section, I start by defining empathy, going into more in-depth detail about a neuroscientific definition of this construct, then I will move to examine the theoretical and neural underpinnings of this essential humans' ability, with a specific focus on empathy for pain considering also some relevant factors that could modulate this ability. Subsequently, I will discuss two critical well-know models within this field.

5.1 Defining empathy and related concepts

Empathy is commonly defined as the humans' ability to understand and share others' emotions and affective states (for a general review of this phenomenon see de Vignemont & Singer, 2006; Decety & Jackson, 2006; Eisenberg, 2000; Singer & Leiberg, 2009; Singer & Lamm, 2009). Many researchers have investigated empathy as a multi-component concept which involves different subcomponents both in the cognitive domain – in this case, empathy is more related to the ability to understand the thoughts, beliefs and intentions - and in the bodily domain – that is related to humans capacity to understand motor intentions of others, strictly related to mirror neurons' discovery (see Rizzolatti & Sinigaglia, 2010, for a review). Within this concept, there are different facets of empathy-related phenomena. These aspects range from a more affective, automatic and primitive reaction through which we can feel what the other individual feels (for example, mimicry and emotional contagion) to a more cognitive response (such as perspective taking), which allows to identify and infer others' affective states.. The ability to feel others' emotions is a basic concept of emotional empathy, which is seen as a "hot route"; people get to know others' emotions by automatically reading their emotional reactions. To make it clearer, in the opening scene of Quentin Tarantino's Kill Bill volume 1 (2003), we do not know anything about the main character, played by Uma Thurman, or the circumstances, except what is shown on her face, which expresses fear, pain and anxiety. We can however "understand" her emotions by automatically sharing some of what we see being experienced on the character's face. Observers' facial mimicry and emotional contagion are two main mechanisms involved in this case, rather than a more cognitive and sophisticated process (Coplan, 2004). As I already mentioned in the previous section, mimicry can be described as an automatically elicited response that mirrors another person's emotional state through their facial, postural and vocal movements. The second “unmediated” process is termed emotional contagion, which represents a further step, which results in the convergence in the actual emotional experience (e.g. Hatfield, Cacioppo, & Rapson, 1992). This concept is consistent with Gallese’s *shared manifold hypothesis,* which has been considered at the basis of intersubjectivity and then empathy. The idea is that, within a mirror neuron framework, empathy should "accommodate and account for all different aspects of expressive behaviour... to unify under the same account the multiple aspects and possible levels of description of intersubjective relations" (Gallese, 2003, pp. 176-177). Similar to the mirror neuron account is the Perception-Action coupling Model (PAM) theorized by Preston and de Wall (Preston, 2007; Preston & de Waal, 2002), based on the common coding account (Prinz, 1997)[8]: we automatically share the target’s state by generating the associated “autonomic and somatic responses” (Preston & de Waal, 2002, p. 4). Further, there is also another empathy-related phenomenon that represents a more cognitive subcomponent of empathy, which is termed mentalizing. This subcomponent would allow humans to infer others’ mental states by using exquisitely cognitive resources devoted to reasoning. In the neuroimaging studies, to investigate this cognitive component of empathy it has been often asked participants to imagine what the observed target person was either thinking or feeling, other studies investigated how observers can take the target's perspective.

1.4.1.1 The model by Decety and Jackson (2004)

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[8] This theory proposed that perception and action share some underlying representation or process so perceptual information automatically prepares action without the need for any intervening cognitive process.

During the last two decades, different brain-based studies have been conducted with the aim to better understand neural underpinnings of empathy (Gerdes, Segal, Jackson, & Mullins, 2011). In 2004, Decety and Jackson, revising the several definitions about empathy and related concepts, proposed a model, which included three primary functional components that would contribute to a full-blown experience of empathy in humans (Decety & Jackson, 2004):

- The first component is the ability to automatically and unconsciously have an affective response, such as sharing other's people emotional states. This component endorses the affective sharing of empathy (Singer et al., 2004, 2006) but, in this first model, not the sensorimotor contagion[9] (Avenanti, Bueti, Galati, & Aglioti, 2005). Thus, this aspect is more related to the bottom-up processes of empathy;

- The second component is related to the self-other distinction, which represents a cognitive capacity to take the perspective of another individual, understanding other's pain and inferring other's mental state. Therefore, this component is more related to the conscious cognitive process of empathic response;

- The third component is the ability to regulate personal emotion engagement; which implies the capacity to disentangle the observer from the other in order to prevent a total overlapping between representations of the self and the other and so provoking distress or anxiety.

The novelty of this model was to consider the complexity, and the multi-sided characteristic of the empathy construct into account. Indeed, according to Decety and Jackson's functional model (2004), to produce the subjective experience of empathy is necessary the mutual interaction of all these three components, otherwise a mere

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[9] This index is often used to evaluate the automatic reaction of corticospinal excitability of onlookers who observe someone while is doing something. This index has been used in research involved in studying how sensorimotor cortex is active during observation of pain in others (e.g. Avenanti et al., 2005).

emotional contagion would occur, i.e. a full identification between the two individuals involved (observer and target) without the needed discrimination between them in order for a full-blown empathic experience to occur (de Waal, 1996).

1.4.1.2 The model by Zaki & Ochsner (2012)

Two levels are considered operating in empathy according to different rules and models of processing. Gallese and Goldman (1998; see also Goldman and Sripada, 2005) distinguished, for instance, low-level mindreading, characterized as an automatic, and mostly below the level of consciousness mechanism dedicated to the processing of social perceptual information, from high-level mindreading, allowing people to understand someone else's mental states by pretending his/her beliefs and desires. This functional distinction in the context of empathy for pain is also shaped at the neuroanatomical level as described by Zaki and Ochsner’s model (2012). They proposed a new model of empathy that involves the following subcomponents:

- Experience sharing: represents the ability to vicariously share the targets’ internal states on the basis of a neural resonance mechanism (i.e., affective/sensorimotor component);
- Mentalizing: it mainly consists in the ability to take others’ perspectives in order to understand their internal states (i.e., cognitive component);
- Prosocial concern: it concerns the motivation to improve targets’ experiences (for example, helping other people to reduce their suffering);

Although the literature related to this topic is broad, it is still unclear whether or how experience sharing and mentalizing are dissociated – at least partially - or somewhat interrelated. Neuroimaging studies investigating this aspect have demonstrated an anatomical dissociation of these three different systems. The experience sharing has its neural underpinnings in the mirror neuron system (i.e., IPL, inferior frontal gyrus, IFG, and dorsal premotor, dPMC), and in the limbic system (i.e., amygdala, ACC, AI and ventral striatum; e.g., Keysers, Kaas, & Gazzola, 2010; Lamm & Singer, 2010; Rizzolatti & Sinigaglia, 2010) and in other sensorimotor areas with mirror properties. When a person is observing someone who is touching the arm of another individual, it activates the primary and secondary somatosensory cortices (Bufalari, Aprile, Avenanti, Di Russo, & Aglioti, 2007; Keysers et al., 2004, for a review on this topic see Keysers et al., 2010) primarily involved in experiencing touch in first person. Likewise, sensory components of observed bodily pain (e.g., intensity, location) are mapped in primary and secondary somatosensory cortices (Bufalari et al., 2007; Canizales, Voisin, Michon, Roy, & Jackson, 2013; Cheng, Yang, Lin, Lee, & Decety, 2008). On the other side, mentalizing has its neural underpinnings in prefrontal cortical circuitries (Decety & Jackson, 2006; Decety & Lamm, 2006), specifically in the dorsomedial, dorsolateral, ventromedial and medial prefrontal cortices (dmPFC, dlPFC, vmPFC and mPFC, respectively), middle frontal gyrus (MFG), temporoparietal junction (TPJ) and precuneus (e.g. Amodio & Frith, 2006; Decety, 2011; Lamm, Decety, & Singer, 2011; Saxe & Kanwisher, 2003). Figure 16 depicts an anatomical schematic representation of the dissociation between experience sharing and mentalizing as presented by Zaki and Ochsner’s critical review (2012).

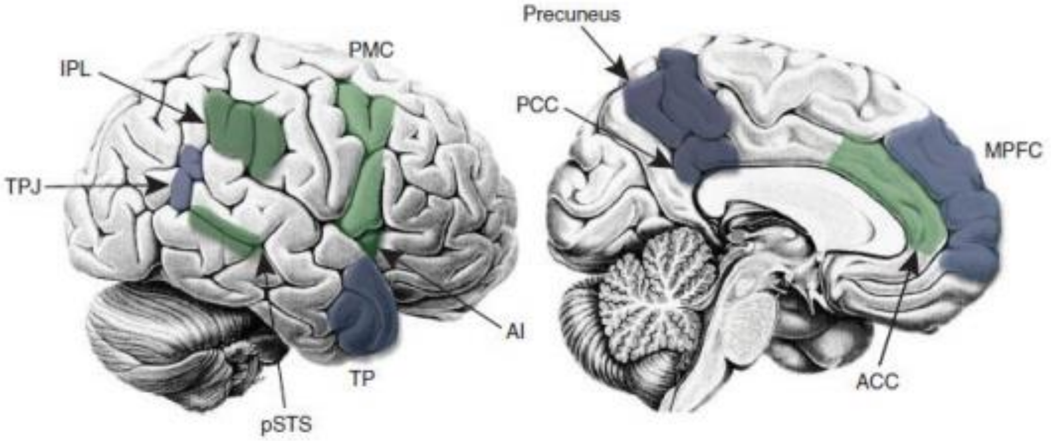

Figure 16 Schematic representation of the anatomical dissociation between experience sharing and mentalizing (Zaki & Ochsner, 2012).

To confirm this anatomical dissociation, precious empirical evidence has been provided by a lesional study by Shamay-Tsoory and colleagues (Shamay-Tsoory, Aharon-Peretz, & Perry, 2009). The authors individuated patients with lesions in either the IFG (i.e. a core region of the experience sharing) or the vmPFC (i.e. a core region of the mentalizing system) and administered them two empathy-related tasks, one engaging experience sharing and the other mentalizing abilities. Their results revealed that patients with lesions of the IFG showed a selective deficit in experience sharing whereas patients with lesions in the vmPFC showed a selective deficit in mentalizing.

5.2 Contextual variability in empathy

A notable aspect of the human ability to experience empathy toward other people's affective states and emotions is that a variety of factors that may shape it, including the characteristics of the observer and those of the individual experiencing a particular affective condition (Blair, 2005; Dapretto et al., 2006; Davis, 1983; Harris & Fiske, 2006; Hein, Silani, Preuschoff, Batson, & Singer, 2010; Philip et al., 2012; Wagner, Kelley, & Heatherton, 2011) or also the affective and social relationship existing between the observer and the other individual, such that at least part of the brain network underlying empathy (i.e., anterior cingulate cortex and anterior insula) is strongly activated in those cases when the partner, rather than a stranger, is experiencing a pain stimulation (Singer et al, 2004), or in instances where the other is an individual with whom the observer has established a relationship of trust rather than distrust (Singer et al., 2006), or when the individual experiencing pain belongs to the observer's ethnic group rather than a different ethnic group (Avenanti, Sirigu, & Aglioti, 2010; Contreras-Huerta, Baker, Reynolds, Batalha, & Cunnington, 2013; Contreras-Huerta, Hielscher, Sherwell, Rens, & Cunnington, 2014; Sessa, Meconi, Castelli, & Dell'Acqua, 2014; Xu, Zuo, Wang, & Han, 2009). In this specific context, observers are less likely to engage neural resonance when belonging to a different ethnic group than the one of the target experiencing pain (Hein et al., 2010). In brief, the chance that an empathic reaction will be triggered and its magnitude depend on the nature of the social and affective relationships that binds people. In everyday life situations, interindividual and contextual variance are involved in eliciting and modulating empathic reactions in individuals; individuals may be more or less empathic (Davis, 1983) and some situations are more likely to elicit or not empathy or one of its subcomponents. Furthermore, it is known that individual differences as measured by self-report questionnaires of empathy correlate with activity in brain areas associated with both experience sharing and mentalizing abilities (Singer et al., 2004).

5.3 A theoretical introduction to Experiment 3 and Experiment 4

As already mentioned before, in face-to-face interactions, communication has a multi-modal nature involving the processing of visual facial cues (such as the speaker's facial expression), the tone of the voice (i.e., affective prosody) and the choice of words (i.e., semantics; Borod et al., 2000; Pell, 2001; Schirmer, Kotz, & Friederici, 2002; Schwartz & Pell, 2012; Wurm, Vakoch, Strasser, Calin-Jageman, & Ross, 2001).

When witnessing others' physical pain, empathy is often triggered in the observer. In their influential review on empathy, Zaki and Ochsner (2012) suggested that "although neuroimaging can distinguish the spatial profiles of neural systems associated with experience sharing and mentalizing, electrophysiological techniques are more useful for elucidating the temporal dynamics of these processes". There is, indeed, evidence that this neuroanatomical distinction is revealed also at the functional level as shown by electrophysiological studies (Fan & Han, 2008; Sessa, Meconi, & Han, 2014). In this vein, Zaki and Ochsner cited an ERP study – now considered one of the earliest in the field – that elegantly revealed two successive temporal windows of neural activity reflecting experience sharing and mentalizing, respectively (Fan & Han, 2008). The authors administered participants with a classic version of the pain decision task and presented participants with one or two hands in neutral or in painful conditions. Participants were required to indicate whether the hands were depicted in either the painful or neutral conditions (i.e., pain decision task) or to note whether one or two hands were presented on the screen (i.e., counting task). The authors observed modulations in amplitude related to the processing of the painful condition of early (N1, P2, and N2–N3) and late components (P3) in the pain decision task manifested as a positive shift of the neural activity elicited by the painful condition when compared to the neutral condition. Crucially, when attentional resources were withdrawn from the painful information (i.e., in the counting task) the later P3 response was reduced to nil suggesting that the earlier and the later responses reflect more automatic versus controlled mechanisms of empathy, respectively.

In line with this evidence, experience-sharing and mentalizing can be selectively activated depending on the nature of the available cue, perceptual and non-perceptual, respectively (Waytz & Mitchell, 2011); see also (Lamm, Decety, & Singer, 2011). In a more recent ERP study, Sessa, Meconi, and Han (2014) supported the view that the nature of information available to the observers is crucial in order to selectively trigger experience-sharing (i.e., empathic reactions to painful facial expressions triggering P2 and N2–N3 ERP modulations) or rather mentalizing (i.e., empathic responses to verbal information of pain modulating the later P3 ERP component). Previous studies, both in the contexts of empathy (Sheng & Han, 2012) and recognition of emotional faces (Eimer & Holmes, 2007), have observed very similar ERP modulations elicited by facial expressions. Previous studies estimated the neural sources of the early and late ERP modulations (Sessa, Meconi, Castelli, et al., 2014; Sessa, Meconi, & Han, 2014) and found evidence compatible with previous work supporting two anatomically and functionally dissociable brain networks underlying experience sharing and mentalizing processes, respectively (Zaki & Ochsner, 2012). Moreover, the authors observed that these modulations correlated with measure of dispositional empathy (Sessa, Meconi, Castelli, et al., 2014; Sessa, Meconi, & Han, 2014). That is, the N2–N3 ERP reaction to pain was significantly correlated with one of the affective empathy subscales of the Interpersonal Reactivity Index (Sessa, Meconi, & Han, 2014) (IRI; Davis, 1983; i.e., the Empathic Concern), while the pain effects observed on the P3 component were significantly correlated with one of the cognitive empathy subscales of the IRI (Vaes, Meconi, & Sessa, 2016) (i.e., the Perspective Taking) and with the Empathy Quotient (Sessa & Meconi, 2015) (EQ; Baron-Cohen & Wheelwright, 2004).

Therefore, based on this broad convergence of evidence, researchers in the field interpret the modulations of the above-mentioned ERP components (i.e., positive shift of the ERPs elicited in the painful condition when compared to the neutral condition) as a correlate of empathic processes, as indicating experience sharing (P2, N2-N3) and mentalizing (P3) processes of empathy, respectively. The evidence reported above strongly supports the notion that the kind of available cue can then trigger these empathic processes. Within this body of research, empathic response to pain has been triggered either by the facial expression of pain or by body parts undergoing a painful stimulation (e.g., a needle pricking the skin). Other experimental manipulations included written sentences describing painful contexts. In real life, one common way to express pain is through verbal reports. Such reports include the characteristics of the speaker's voice expressing pain, such as prosody. The prosodic information clarifies the meaning, the intentions or the emotional content of the speech. The potential impact of prosody and its possible interactions with both facial expression and linguistic content within the two different systems and temporal windows associated with empathic processes is the focus of Experiment 3. In this study, by monitoring ERPs, it has been provided evidence that when empathizing with others' pain, affective prosody of the speech may interact with both the speaker’s facial expression and the expressed linguistic content (i.e., semantics) in two successive temporal windows. This characteristic can facilitate the understanding of the communication of potential urgencies, such as when the speaker expresses physical pain by their facial expression and/or tone of the voice, or when semantic content (i.e., the words of their verbal reports) is not accessible. Thus, the role of affective prosody in inducing an empathic response as an additional cue of others’ pain was investigated.

In Experiment 4, that included an ERPs and a behavioral study (respectively, Experiment 4a and Experiment 4b), it has been investigated another important variable which may shape empathic responses towards people in painful situations. In this study a new factor potentially able to affect empathy was studied, i.e. the physical distance between the observer and the target. It is known that the magnitude of an empathic reaction depends on the nature of the social and affective relationships that binds people. Interestingly, social and affective relationships are often designated in terms of "distance", and just as for the physical distance, the terms "close" and "distant" tend to be used in the context of relationships, for example, associating them with an intimate friend or with a relative almost unknown to us, respectively (George Lakoff & Johnson, 1980; George Lakoff & Mark, 1999). In this vein, it is possible to conceive social and affective relationships between individuals as if they were mapped onto a sort of virtual space. Support in favor of this proposal comes, for instance, from a fMRI study by Yamakawa, Kanai, Matsumura and Naito (2009) who asked their participants, in two different tasks, to evaluate social compatibility with presented individuals' faces and to evaluate physical distance of inanimate objects. The rationale for the implementation of these two tasks was that if evaluation of both psychological and physical distances has a common functional and neural substrate, one would expect to observe an overlapping activation in those brain regions involved in the representation of the egocentric physical space (Naito et al., 2008; Neggers, Van der Lubbe, Ramsey, & Postma, 2006; Rapcsak, Ochipa, Anderson, & Poizner, 1995; Roland, Larsen, Lassen, & Skinhoj, 1980; Sakata, Shibutani, & Kawano, 1980). In line with this hypothesis, Yamakawa and colleagues' (2009) findings provided evidence in favor of the existence of a common neural substrate in the parietal cortex for both mental representations of social relationships and physical space.

Further supporting the view that physical and psychological spaces are inextricably linked, is the observation, now dating back over fifty years, that the distance between individuals varies as a function of their intimacy (see, e.g., Hall, 1969; 1964). One of the most interesting and fundamental pillars of Proxemics − the study of personal space (Argyle & Dean, 1965; Hall et al., 1968; Hayduk, 1983) indicates that people unconsciously organize the space around them in concentric areas, so that the areas closest to one's body are the privileged space of action(s) for the most intimate interactions, and, conversely, the areas most distant from the body are mostly associated with the space of action(s) for interactions with individuals with whom they share a low degree of intimacy. These concentric "virtual" zones around the individual's body may vary according to different factors, such as the culture or the gender of the individuals, but the general principle according to which a relationship exists between the degree of intimacy between two individuals and the physical distance that tends to settle during their interaction is a constant element independent of other factors (Hall, 1964). Interesting and relatively recent studies in the social and affective neuroscience field have provided convergent evidence with Hall's pioneering ideas. For example, Kennedy and colleagues (Kennedy, Gläscher, Tyszka, & Adolphs, 2009) have shown that the amygdala activity is susceptible to interpersonal distance, and in particular, in line with the hypothesis that intimate and personal distances are associated with intimate relationships, the amygdalar activity increases when a stranger invades this space. Or also, in support of the relationship between the nature of the social/affective relationship and the physical distance, McCall and Singer (2015) have shown that following an economic task in which participants could play with fair or unfair players, participants tend to keep physically closer to decent players, while they can even turn their backs on unfair players. For all these considerations suggesting a direct relationship between physical and psychological distance it has been hypothesized that empathy toward others' pain could also be modulated on the basis of the physical distance between the observer and the individual subjected to a pain stimulation, just as happens for the social and affective distance (Avenanti et al., 2010; Singer et al, 2004; Xu et al., 2009).

Chapter 6

Part of the content presented in this chapter has been described in the following published article:

Meconi, F, Doro, M, Schiano Lomoriello, A, Mastrella, G, Sessa, P. Neural measures of the role of affective prosody in empathy for pain. *Scientific Reports*, 8 (1), pp. 291, 2018.

Experiment 3: Investigating the neural measures of the role of affective prosody in empathy for pain

The current study was specifically designed to unravel the role of affective prosody in inducing an empathic response as an additional cue of others' pain interacting with facial expressions and contextual information.

Specifically, by using ERP technique, I provided evidence that when empathizing with others' pain, affective prosody of the speech may interact with both the speaker's facial expression and the expressed linguistic content (i.e., semantics) in two successive temporal windows. This characteristic can facilitate the understanding of the communication of potential urgency, such as when the speaker expresses physical pain by their facial expression and/or tone of the voice, or when semantic content (i.e., the words of their verbal reports) is not accessible. Indeed, multi-modal communication can improve detection and comprehension of others' emotions and affective states.

When witnessing others' physical pain, empathy is often triggered in the observer. As I discussed at great length in Chapter 1, empathy is dissociable in two neuroanatomical components, "experience-sharing" engaging the mirror neurons and the limbic systems, and "mentalizing" engaging regions of the prefrontal and temporal cortices and precuneus (Amodio & Frith, 2006; Betti & Aglioti, 2016; Engen & Singer, 2013; Kanske, Böckler, Trautwein, & Singer, 2015; Shamay-Tsoory et al., 2009). There is, indeed, evidence that this neuroanatomical distinction is revealed also at the functional level as revealed by electrophysiological studies (Fan & Han, 2008; Paola Sessa, Meconi, & Han, 2014).

In line with previous evidence (Fan & Han, 2008; Sessa, Meconi, & Han, 2014), experience-sharing and mentalizing can be selectively activated depending on the nature of the available cue, perceptual and non-perceptual, respectively (Waytz &

Mitchell, 2011), see also (Lamm et al., 2011). Therefore, based on this broad convergence of evidence, researchers in the field interpret the modulations of the above-mentioned ERP components (i.e., positive shift of the ERPs elicited in the painful condition when compared to the neutral condition) as a correlate of empathic processes, underpinning experience sharing and mentalizing processes of empathy, respectively. The evidence reported above strongly supports the notion that these empathic processes can then be triggered by the kind of available cue.

Previous studies hold the view that prosody can interact with both facial expressions and verbal information. Cross-modal integration of audiovisual emotional signals appears to occur rapidly and automatically with (Paulmann, Titone, & Pell, 2012; Vroomen & de Gelder, 2000) and without conscious awareness (Doi & Shinohara, 2015).

Paulmann and colleagues (Paulmann, Titone, et al., 2012) used eye-tracker technique to study how prosodic information of instructions delivered trial by trial (e.g., “Click on the happy face”) influenced eye movements to emotional faces within a visual array. Importantly, affective prosody could be either congruent or incongruent with the emotional category of the face to be clicked on the basis of the instructions (e.g., “click on the happy face” pronounced with a congruent happy prosody or with an incongruent sad, angry or frightened prosody). Participants’ eye movements were monitored before and after the adjective included in the instructions was pronounced. The authors observed longer, frequent fixations to faces expressing congruent emotion than when expressing incongruent emotion with prosodic information. However, the influence of prosody on eye gaze decreased once the semantic emotional information (i.e., the adjective) was presented. In sum, these findings demonstrated that prosodic cues are extracted rapidly and automatically to guide eye gaze on facial features to process facial expressions of emotions. However, the effect of the prosodic cue weakens as the semantic information is unveiled supporting those results showing that even irrelevant semantics cannot be ignored when participants have to discriminate affective prosody of matching or mismatching utterances (Wittfoth et al., 2010).

Neuroimaging studies showed rightward lateralization of prosodic processing (Wittfoth et al., 2010), in line with brain lesions studies showing that dysprosody, but not aphasia, follows right brain injuries (Cancelliere & Kertesz, 1990; Ross & Monnot, 2008); but see also (Paulmann, 2015). The idea that semantic and prosodic processing are anatomically and functionally dissociable is not surprising since processing of affective prosodic information appears to be at least in part a pre-verbal ability that can be observed as early as in 7 months-old infants (Friederici, 2005; Grossmann, Oberecker, Koch, & Friederici, 2010) and it is also phylogenetically ancient, as it is present in macaque monkeys (Petkov et al., 2008).

A recent series of studies by Regenbogen and colleagues used skin conductance response and functional magnetic resonance imaging (fMRI) to investigate the integration of affective processing in multimodal emotion communication (Regenbogen et al., 2012). Regenbogen and colleagues (Regenbogen et al., 2012) exposed participants to video-clips showing actors expressing emotions through a full or partial combination of audio-visual cues such as prosody, facial expression and semantic content of the speech. Their findings showed that the empathic physiological response was limited in the partial (emotion was not expressed by one of the audio-visual cues) when compared to full combination of cues. Convergent evidence with these findings was provided by the authors in a similar neuroimaging study, that further revealed that the neural activation in the full and partial combination of audio-visual cues was very similar, involving brain areas of the mentalizing system (Regenbogen et al., 2012) (i.e., lateral and medial prefrontal cortices, orbitofrontal cortex and middle temporal lobe). However, this noteworthy study could not provide a full picture of which components of empathy are influenced by affective prosody nor could it trace the time-course of such influence. In the present study, by means of ERPs, we tried to draw such a picture, and we did so within the theoretical framework of empathy for others' pain (Sessa, Meconi, & Han, 2014; Zaki & Ochsner, 2012).

In the current study, I monitored neural empathic responses towards individuals expressing physical pain through verbal reports of painful experiences followed by facial expressions. ERP responses were time-locked to facial expressions. I orthogonally manipulated "facial expressions" (neutral vs. painful), the semantic accessibility of the verbal reports expressing pain (i.e., utterances in mother-tongue vs. utterances in a fictional language designed to sound natural; we named this manipulation "intelligibility": intelligible vs. unintelligible utterances) and the "prosody" of the verbal reports (neutral vs. painful). To note, the content of intelligible utterances was always of pain. The two sets of utterances (in mother-tongue and in fictional language) were declaimed by a professional actor so that the prosody of each utterance matched between languages. An independent sample of participants judged the intensity of pain conveyed by the prosody of each utterance confirming that the perception of the pain expressed by the tone of the voice did not differ between the two sets of utterances.

I also collected explicit measures of participants' dispositional empathy (i.e. Empathy Quotient (Baron-Cohen & Wheelwright, 2004) and Interpersonal Reactivity Index (Davis, 1983). In line with previous findings (Sessa, Meconi, & Han, 2014), I expected painful facial expressions and intelligible utterances (always with a content of pain) to trigger dissociable empathic reactions in two successive temporal windows. We time-locked ERP analysis to the presentation of facial stimuli as a function of preceding utterances and we anticipated that facial expressions would have selectively elicited empathic reactions on the P2 and N2–N3 ERP. Lastly, we expected intelligible utterances (i.e., utterances expressing a painful context in participants' mother-tongue) to trigger empathic reactions on the P3 ERP component when compared to unintelligible utterances (i.e., in a fictional language). On the basis of previous studies I expected these empathic reactions to manifest as positive shifts of ERPs time-locked to faces onset for painful facial expressions and intelligible utterances when compared to neutral conditions (Sessa, Meconi, & Han, 2014; Sheng & Han, 2012). The current study was specifically designed to unravel the role of affective prosody in inducing an empathic response as an additional cue of others' pain. I hypothesized and demonstrated that, by virtue of its dual-nature, affective prosody can be considered cross-domain information able to transversely influence processing of painful cues triggering experience-sharing (facial expressions; *pre-verbal*) and mentalizing responses (intelligible utterances with a content of pain; *verbal domain of processing*). More specifically, I anticipated that affective prosody would have affected the neural empathic response to painful facial expressions in the early temporal window linked to experience-sharing (i.e., P2, N2–N3 ERP reaction, time-locked to faces onset), and the empathic response to painful intelligible utterances in a dissociable and later temporal window associated with mentalizing (i.e., P3 reaction, always time-locked to the onset of faces).

6.1 Methods

Participants. Prior to data collection, we aimed to include 15-20 participants in the ERP analyses because it is suggested to be an appropriate sample in this field (Fan & Han, 2008; Sheng & Han, 2012). Data were collected from twenty-seven volunteers (10 males) from the University of Padova. Data from ten participants were discarded from analyses due to excessive electrophysiological artifacts, resulting in a final sample of seventeen participants (5 males; mean age: 24.29 years, SD = 3.72; three left-handed). By using G*Power 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) for a 3x2x2x2x2x2 repeated measures design, we calculated that for 95% of power given the smallest effect size we observed, 14 was an adequate sample size. Analyses were conducted only after data collection was complete. All participants reported normal or corrected-to-normal vision, normal hearing and no history of neurological disorders. Written informed consent was obtained from all participants. The experiment was performed in accordance with relevant guidelines and regulations and the protocol was approved by the Ethical Committee of University of Padova.

Stimuli

Stimuli were sixteen Caucasian male faces, with either a neutral or painful expression (Sheng & Han, 2012) as the perceptual cue (*pre-verbal domain*) and sixteen utterances, with either unintelligible or intelligible emotional content as the semantic cue (*verbal domain*). The face stimuli were scaled using an image-processing software to fit in 2.9° x 3.6° (width x height) rectangle from a viewing distance of approximately 70 cm.

The sentences were uttered by a professional Italian actor and presented by a central speaker at an average value of 52.5 dB. Eight utterances were in participants' mother-tongue (i.e., Italian) and each of them described a painful situation reported in first-person. Eight utterances were unintelligible (i.e., fictional language). Critically, each sentence was uttered with both neutral and painful prosody (i.e., prosodic cue). The Italian utterances were comparable for syntactic complexity, i.e., noun + verbal phrase (e.g., "I hurt myself with a knife" or "I got burned touching a muffler"). The utterances in a fictional language were paired to Italian utterances for length and prosody.

To confirm that intelligibility did not affect prosody and vice versa, we tested 20 subjects for a rating task. In two separate blocks, subjects were asked to report (within a 7 points Likert scale) the pain intensity and how much the utterances were conceptually understandable (counterbalanced). We found that there was no significant difference in the pain rating with regard to the prosody (i.e., the tone of the voice) between intelligible and unintelligible utterances (t = 1.59, p = .11). Further, there was no significant difference in the intelligibility of the sentences between painful and non-painful prosody (t = -1.01, p = .31). Finally, we tested whether the painful prosody was actually perceived more intense than the neutral one, finding a significant difference (t = -54.38, p < .001).

Participants were exposed to an orthogonal combination of the 16 faces, and the 16 sentences uttered with both neutral and painful prosody. Stimuli were presented using E-prime on a 17-in cathode ray tube monitor with 600 x 800 of resolution and 75 Hz of refreshing rate.

Experimental design

We implemented a variant of the pain decision task (Sheng, Han, & Han, 2016). Each trial began with a central fixation cross (600 ms), followed by the utterances (i.e., semantic and prosodic cues; 4000 ms). After a blank interval (800-1600 ms, jittered in steps of 100 ms), the face (i.e., perceptual cue) was displayed for 250 ms (Figure 17).

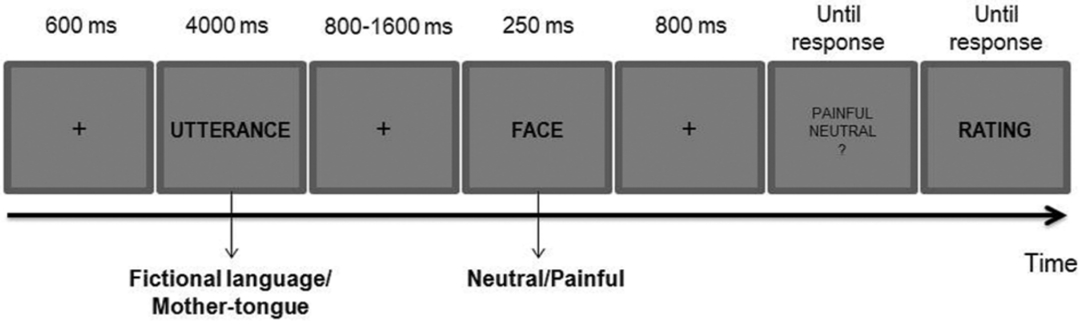

Figure 17 Grand-Averages of ERP time-locked to the onset of faces as a function of language and prosody of preceding utterances recorded at CP.

Participants were told that in each trial they would have heard a voice reporting potential important information to understand what the person displayed immediately after was feeling. Their task was to decide whether the face had a neutral or a painful expression by pressing one of two counterbalanced response keys. At the end of each trial, they were required to self-rate their empathy on a 7-points Likert scale for each face considering the preceding utterance. Following a brief session of practice, participants performed 320 trials in 5 blocks where all conditions were randomly intermixed. EEG was recorded while executing the pain decision task. At the end of the recording session, participants were administered with self-report questionnaires of dispositional empathy: The Italian version of the Empathy Quotient (EQ; Baron-Cohen & Wheelwright, 2004; Ruta, Mazzone, Mazzone, Wheelwright, & Baron-Cohen, 2012) and the Italian version of the Interpersonal Reactivity Index (IRI; Davis, 1983). The EQ has been mainly linked to cognitive aspects of empathy. The IRI is composed of four subscales measuring both affective and cognitive aspects of empathy: empathic concern, EC, and personal distress, PD; perspective taking, PT, and fantasy, FS, respectively).

Electrophysiological recording and analyses

The EEG was recorded from 64 active electrodes placed on an elastic Acti-Cap according to the 10/20 international system, referenced to the left earlobe. The EEG was re-referenced offline to the average of the left and right earlobes. Horizontal EOG was recorded bipolarly from two external electrodes positioned laterally to the external canthi. Vertical EOG was recorded from Fp1 and one external electrode placed below the left eye. The electrode impedance was kept less than 10 KΩ. EEG and EOG signals were amplified and digitized at a sampling rate of 250 Hz (pass band 0.01-80 Hz). The EEG was segmented into 1200-ms epochs starting 200 ms prior to the onset of the faces. The epochs were baseline-corrected based on the mean activity during the 200-ms pre-stimulus period. Trials associated with incorrect responses or contaminated by horizontal and vertical eye movements or other artifacts (exceeding ± 60μV and ± 80μV, respectively) were discarded from analysis. We kept participants who showed at least 20 trials in each condition. The final range of trials was 21-40 but only 3 participants showed less than 25 trials in at least one condition. Separate average waveforms for each condition were then generated time-locked to the presentation of the faces as a function of the preceding utterances. Statistical analyses of ERPs mean amplitudes focused on P2 (125−170 ms), N2−N3 (180−380 ms) and P3 (400−900 ms). The selection of a single temporal window including the N2 and N3 components was mainly based on our previous studies (Sessa, et al., 2014b; Sessa, et al., 2014) because it was critical for the purpose of the present investigation to replicate our previous findings on the dissociable nature of empathic responses triggered by facial expressions and other higher-level cues of pain. Mean ERP amplitude values were measured at four pooled sites from right fronto-central (rFC: F2, F4, F6, FC2, FC4, FC6) and centro-parietal (rCP: CP2, CP4, CP6, P2, P4, P6) regions, and from left fronto-central (lFC: F1, F3, F5, FC1, FC3, FC5) and centro-parietal (lCP: CP1, CP3, CP5, P1, P3, P5) regions.

Statistical analysis

Pain Decision Task. Reaction times (i.e., RTs) exceeding each individual mean RT in a given condition +/- 2.5 SD and associated with incorrect responses were excluded from analyses. RTs and mean proportions of correct responses were submitted to a repeated measure ANOVA including facial expression (neutral vs. painful), intelligibility (mother-tongue, i.e., Italian vs. fictional language) and prosody (neutral vs. painful) as within-subjects factors. ANOVAs carried out on mean amplitude values of each ERP component also included the within-subjects factor hemisphere (right vs. left) and were carried out separately for *FC* and *CP*.

The significant threshold for all statistical analyses was set to .05. Exact p values, mean squared errors (i.e., MS_e) and effect sizes (i.e., partial eta-squared, η_p^2) are reported. Confidence intervals (i.e., CIs, set at 95% in squared brackets) are defined only for paired t-tests and referred to difference of means (i.e., M_{diff}). Planned comparisons relevant to test the hypotheses of the present experiment are reported. Bonferroni correction was applied for multiple comparisons.

6.2 Results

*Questionnaires***.** The present sample of participants showed a mean EQ score in the middle empathy range according to the original study(Simon Baron-Cohen & Wheelwright, 2004), i.e. 46.83 (*SD* = 7.09). IRI scores were computed by averaging the scores of the items composing each subscale as reported in Table 1 IRI scores.Table 1.

IRI			
Cognitive		**Affective**	
Pt	3.69 (0.41)	*EC*	3.83 (0.53)
F	3.55 (0.66)	*PD*	2.66 (0.66)

Table 1 IRI scores.

Behavior

Participants were more accurate when prosody of the reports and the facial expression of the faces were congruent, as indexed by the interaction between the factors prosody and facial expression, $F(1,16) = 6.086$, $p = .025$, $MS_e = 0.000184$, $\eta_p^2 = .276$ – independently of the intelligibility of the semantic content – and post-hoc t-test ($t(16) = 2.467$, $p = .025$, $M_{diff} = .007$ [.002, .014]). No main effect or other interactions between factors reached significance level (max $F = 3.794$, min $p = .069$, max $\eta_p^2 = .192$). An ANOVA did not show any significant result for RTs (max $F = 3.570$, min $p = .077$, max $\eta_p^2 = .182$).

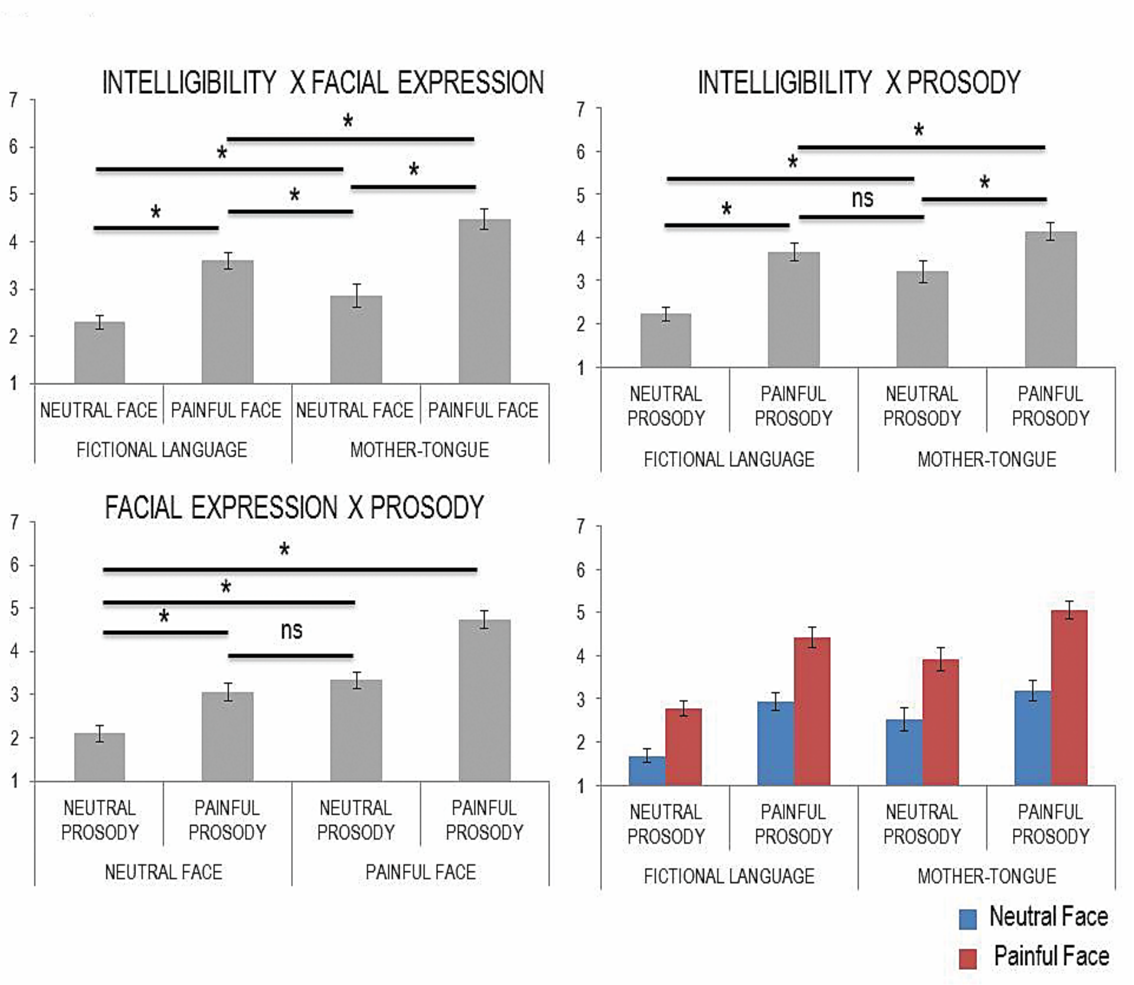

Figure 18 Rating results showing significant and non-significant comparisons for the interactions (upper panel and bottom left panel) and the whole pattern of results (bottom right panel). Error bars represent standard errors, asterisks represent significant comp comparisons; “n.s.” means “not-significant”.

An ANOVA on individual rating scores showed the main effects of facial expression, $F(1,16) = 126.405$, $p < .000001$, $MS_e = .575$, $\eta_p^2 = .888$, intelligibility, $F(1,16) = 25.063$, $p = .000129$, $MS_e = .714$, $\eta_p^2 = .610$, and prosody, $F(1,16) = 55.270$, $p = .000001$, $MS_e = .863$, $\eta_p^2 = .776$. All cues induced higher scores of self-rated empathy in painful conditions relative to neutral conditions. The two-way interaction between facial expression and prosody was significant, $F(1,16) = 10.219$, $p = .006$, $MS_e = .229$, $\eta_p^2 = .390$. Post-hoc t-tests revealed that participants rated their empathy as higher when both facial expression and prosody were painful compared to neutral, ($t(16) = 10.526$, $p <$

.000001). Both conditions in which only one of the cues was painful induced significantly higher scores than the condition in which both cues were neutral (min *t(16)* = 6.468, max *p* = .000008), but scores did not differ between these conditions when only one cue was painful (*t(16)* = 1.905, *p* = .075). The two-way interaction between intelligibility and prosody ($F(1,16) = 10.219$, $p = .006$, $MS_e = .229$, $\eta_p^2 = .390$) indicated that the difference in the rates assigned to painful and neutral prosody was higher when utterances were in a fictional language, when compared to those in participants' mother-tongue, (*t(16)* = 3.197, *p* = .006; $M_{diff} = .524$ [.177, .872]). Empathy for unintelligible utterances reported with both neutral and painful prosody were rated as lower than intelligible utterances pronounced with neutral and painful prosody (min *t(16)* = 3.252, max *p* = . 005). Rates to intelligible utterances with neutral prosody did not significantly differ from unintelligible utterances with painful prosody (*t(16)* = 1.945, *p* = .07). This pattern could be due to the explicit painful context expressed by intelligible utterances despite being pronounced with neutral prosody. Both unintelligible and intelligible utterances pronounced with painful prosody were rated as higher than those pronounced with neutral prosody (min *t(16)* = 6.320, max *p* = .00001). The two-way interaction between facial expression and intelligibility, ($F(1,16) = 5.135$, $p = .038$, $MS_e = .183$, $\eta_p^2 = .243$), revealed that painful, relative to neutral, faces induced higher self-rated empathy following utterances in participants' mother-tongue compared to those in a fictional language, (*t(16)* = -2.266, *p* = .038; $M_{diff} = -.332$ [-.643, -.021]), indexing an enhanced self-perceived empathy when both semantic and facial information conveyed pain. All the possible comparisons were significant (min *t(16)* = 3.493, max *p* = .003). The three-way interaction did not approach significance ($F < 1$). Figure 18 summarizes the whole pattern of results.

ERPs

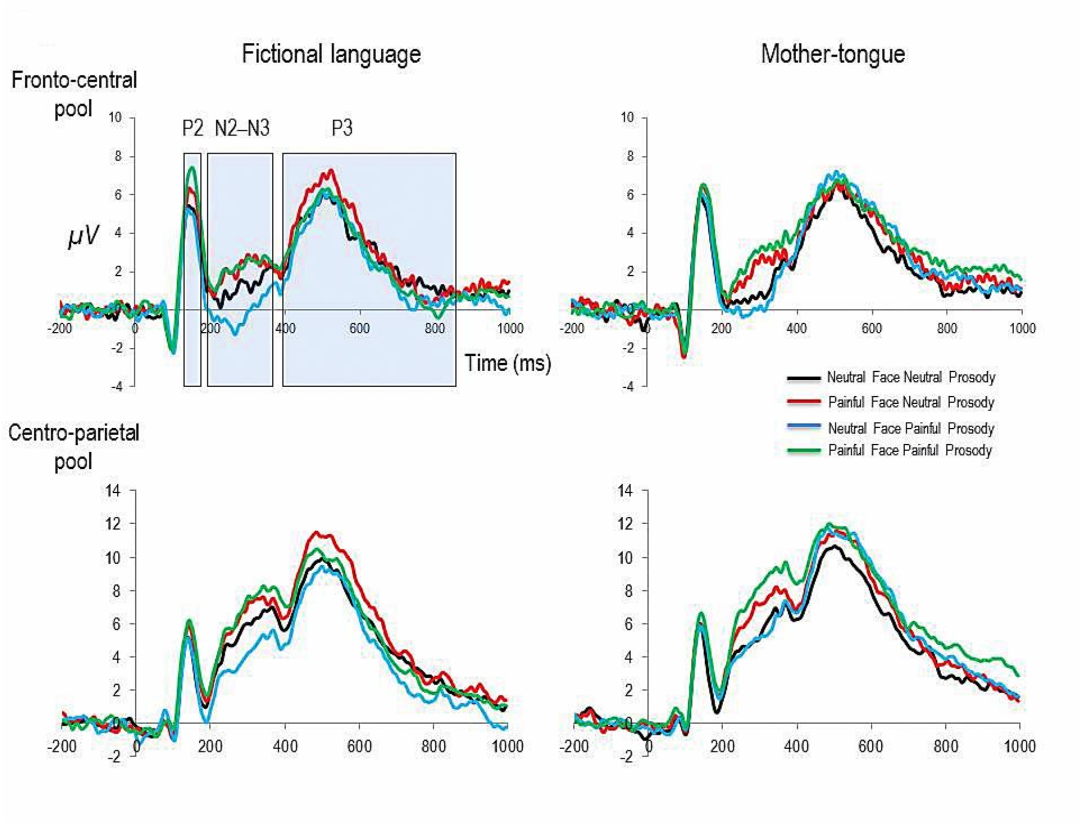

Figure 19 Grand averages of ERPs time-locked to the onset of faces recorded at FC (i.e., pooled rFC and lFC), and at CP (i.e., pooled rCP and lCP), as a function of preceding utterances superimposed with ERPs elicited in the neutral condition (i.e., neutral prosody/neutral facial expression) separately for participants' mother-tongue and fictional language.

Preliminary repeated measures ANOVA was carried out with the following factors within-subjects: component (P2 vs. N2–N3 vs. P3), area (fronto-central, *FC*, vs. centro-parietal, *CP*), hemisphere (left vs. right), facial expression (neutral vs. painful), intelligibility (intelligible vs. unintelligible utterance) and prosody (neutral vs. painful).

We observed a main effect of component, $F(1,16) = 4.036$, $p = .04$, $\eta_p^2 = .350$; of area, $F(1,16) = 13.068$, $p = .02$, $\eta_p^2 = .450$; a main effect of intelligibility, $F(1,16) = 20.765$, $p = .0003$, $\eta_p^2 = .565$; and of facial expression, $F(1,16) = 20.315$, $p = .0004$, $\eta_p^2 = .559$. Importantly, we observed significant interaction between component and area, *F*(2,15) = 16.839, *p* = .0001, η_p^2 = .692; the interaction between component and facial expression, *F*(2,15) = 7.098, *p* = .007, η_p^2 = .486, and between component and intelligibility, *F*(2,15) = 8.298, *p* = .004, η_p^2 = .525. Lastly, we observed a significant interaction between component, facial expression and prosody *F*(2,15) = 8.130, *p* = .004, η_p^2 = .520. Based on these preliminary interactions with the factors component and area, we carried out a second repeated measures ANOVAs separately for each component, again including area as a within-subjects factor. We observed a significant interaction between the area of the scalp and intelligibility on the P2 component (*F*(1,16) = 6.015, *p* = .026, η_p^2 = .273). The factor area significantly interacted with intelligibility and prosody (*F*(1,16) = 5.069, *p* = .039, η_p^2 = .241) and with facial expression (*F*(1,16) = 4.482, *p* = .05, η_p^2 = .219) on the P3 component. We then conducted separated repeated measures ANOVAs for each area of the scalp on the P2 and on the P3 but not on the N2–N3components (Figure 19).

P2. With this component, we expected to observe a main effect of the facial expression. The ANOVA revealed a significant main effect of facial expression irrespective of the hemisphere at both pools, *F*(1,16) = 12.711, *p* = .003, MS_e = 3.271, η_p^2 = .443 at *FC*, *F*(1,16) = 7.908, *p* = .013, MS_e = 5.445, η_p^2 = .331 at *CP*: painful facial expressions elicited larger P2 (*FC*: 5.630 μV, *SE* = .635; *CP*: 5.260 μV, *SE* = .568) than neutral facial expressions (*FC*: 4.848 μV, *SE* = .495, *CP*: 4.464 μV, *SE* = .690).

The effect of prosody. The three-way interaction between facial expression, prosody and intelligibility reached significance threshold at *FC*, *F*(1,16) = 4.606, *p* = .048, MS_e = 1.680, η_p^2 = .224). To highlight the effect of prosody, we conducted separate ANOVAs for neutral and painful prosody with facial expression and intelligibility as within-subject factors. ANOVA conducted for neutral prosody did not reveal any significant effect (max *F*(1,16) = 2.384, min *p* =.142, max η_p^2 = .130). By contrast, ANOVA conducted for painful prosody revealed a main effect of facial expression,

$F(1,16) = 10.183$, $p = .006$, $MS_e = 1.797$, $\eta_p^2 = .389$ and the interaction between facial expression and intelligibility, $F(1,16) = 8.066$, $p = .012$, $MS_e = 1.120$, $\eta_p^2 = .335$. Bonferroni corrected post-hoc comparisons revealed that painful faces elicited larger P2 than neutral faces when preceded by utterances in a fictional language, ($t(16) = 4.033$, $p = .001$; $M_{diff} = 1.766$ [.84, 2.7]) but not when preceded by intelligible utterances, ($t < 1$).

At CP, we observed a main effect of intelligibility, $F(1,16) = 7.028$, $p = .017$, $MS_e = 3.110$, $\eta_p^2 = .305$, i.e. larger P2 for utterances in mother-tongue than those in a fictional language, that was further qualified by a three-way interaction between intelligibility, prosody and hemisphere $F(1,16) = 5.224$, $p = .036$, $MS_e = .202$, $\eta_p^2 = .246$. Again, to highlight the effect of prosody, we conducted separate ANOVAs for neutral and painful prosody with hemisphere and intelligibility as within-subject factors. ANOVA conducted for neutral prosody, revealed a significant interaction between hemisphere and language, $F(1,16) = 5.704$, $p = .030$, $MS_e = .107$, $\eta_p^2 = .263$. Bonferroni corrected post-hoc comparisons did not reveal any significant effect (max $t(16) = 1.78$, min $p = .094$). The ANOVA conducted for painful prosody revealed a main effect of language, $F(1,16) = 6.232$, $p = .024$, $MS_e = 1.204$, $\eta_p^2 = .280$, showing that intelligible utterances elicited larger P2 than unintelligible utterances.

The main effects of prosody and of hemisphere were not significant, neither were remaining interactions (max $F(1,16) = 2.688$, min $p =.121$, max $\eta_p^2 = .144$).

N2−N3. Based on previous findings, we mainly we expected to observe a main effect of the facial expression manifest as a positive shift of painful when compared to neutral facial expression.

The ANOVA conducted with the factor area as within-subjects factor revealed a main effect of the area $F(1,16) = 18.862$, $p = .001$, $MS_e = 103.73$, $\eta_p^2 = .541$ and of facial expression $F(1,16) = 36.588$, $p = .000017$, $MS_e = 9.313$, $\eta_p^2 = .696$. N2–N3 was significantly more negative at FC when compared to that distributed at CP; more importantly, painful facial expression elicited more positive N2–N3 than neutral expression, i.e. an empathic reaction towards painful faces. This effect was more prominent in the right hemisphere as indexed by the interaction between facial expression and hemisphere $F(1,16) = 6.842$, $p = .019$, $MS_e = .421$, $\eta_p^2 = .300$.

The effect of prosody. The interaction between facial expression and prosody was significant, $F(1,16) = 7.574$, $p = .014$, $MS_e = 7.516$, $\eta_p^2 = .321$. Planned comparisons revealed that neutral facial expressions preceded by incongruent painful prosody decreased N2−N3 empathic reaction when compared to neutral condition, i.e. neutral faces preceded by congruent neutral prosody, $t(16) = -3.207$, $p = .008$; $M_{diff} = -.821$ [-1.39 -.246]. This indexed larger negativity for neutral faces preceded by painful relative to neutral prosody. By contrast, painful facial expression preceded by congruent painful prosody increased N2–N3 empathic reaction when compared to the neutral condition, $t(16) = 3.608$, $p = .002$; $M_{diff} = 1.41$ [-3.608 -.582]. This empathic reaction was not enhanced when compared to the empathic reaction to painful facial expression preceded by neutral prosody, $t(16) = 1.383$, $p = .186$; $M_{diff} = .473$ [-.252 1.198]. Remarkably, painful facial expressions preceded by neutral prosody did elicit an N2−N3 empathic reaction relative to the neutral condition, $t(16) = 2.655$, $p = .017$; $M_{diff} = .936$ [.188 1.683].

No main effect of intelligibility $F(1,16) = 3.567$, $p = .077$, $MS_e = 4.405$, $\eta_p^2 = .182$ nor of prosody or hemisphere were observed (both $Fs < 1$). None of the other two-way, three-way and four-way interactions were significant (max $F(1,16) = 4.076$, min $p = .061$, max $\eta_p^2 = .203$).

See

Figure 20 (panel a) for bar graphs representing the main effects of facial expression on the P2 and on the N2–N3 (left and middle panel).

P3. Replicating previous findings, on this component we expected to observe a main effect of the context. In the current study, that was given by the contrast between utterances in mother-tongue, i.e. the context was always painful, and those in a fictional language, where there was no semantic access to the context (Figure 21).

The ANOVAs revealed a main effect of intelligibility at both sites ($F(1,16) = 9.143$, $p = .008$, $MS_e = 6.941$, $\eta_p^2 = .364$, at *FC*; $F(1,16) = 27.477$, $p = .000081$, $MS_e = 5.577$, $\eta_p^2 = .632$, at *CP*) replicating our previous results (Sessa, Meconi, & Han, 2014). P3 time-locked on the onset of the face was larger when faces were preceded by intelligible utterances, i.e. utterances in participants' mother-tongue, when compared to unintelligible utterances, i.e. in a fictional language.

The effect of prosody. The interaction between intelligibility and prosody was significant at *CP*, $F(1,16) = 10.517$, $p = .005$, $MS_e = 4.444$, $\eta_p^2 = .397$ (the same effect was only marginally significant at *FC*, $F(1,16) = 4.025$, $p = .062$, $MS_e = 4.889$, $\eta_p^2 = .201$). Planned comparisons at *CP* revealed that when content was intelligible, P3 time-locked to the onset of faces did show an empathic reaction to painful prosody, i.e. larger for intelligible utterances pronounced with painful than neutral prosody, $t(16) = 2.193$ $p = .043$ ($M_{diff} = .89$ [.03 1.74]). When content was unintelligible, such a pattern was not observed: P3 for unintelligible utterances pronounced with painful prosody decreased relative to neutral prosody, $t(16) = -2.570$, $p = .021$ ($M_{diff} = -.77$ [-1.40 -.13]).

I also observed an unexpected modulation of the P3 component due to the facial expression at *CP*, $F(1,16) = 5.409$, $p = .034$, $MS_e = 6.881$, $\eta_p^2 = .253$ and at rFC as revealed by the significant interaction between hemisphere and facial expression at *FC*,

F(1,16) = 6.087, p = .025, MS_e = 1.543, η_p^2 = .276 and post-hoc comparisons ($t(16)$ = 2.328 p = .033, M_{diff} = .66 [.06 1.27] at rFC but not at lFC, t < 1): painful facial expressions elicited larger P3 than neutral facial expressions.

Finally, I observed a new significant interaction between hemisphere, facial expression and prosody at *CP*, F(1, 16) = 5.613, p = .031, MS_e = .215, η_p^2 = .260. To highlight the effect of prosody, we conducted separate ANOVAs for neutral and painful prosody with hemisphere and facial expression as within-subject factors. None of them revealed any significant result, (max F(1,16) = 4.045, min p =.061, max η_p^2 = .202.

The main effect of prosody and the other interactions did not reach significance level (max F(1,16) = 3.319, min p = .087, max η_p^2 = .172).

See Figure 20 (panel a) for bar graph representing the effect of intelligibility on the P3 (right panel). See Panel b for bar graphs representing the effect of prosody on empathic reactions for each time-window.

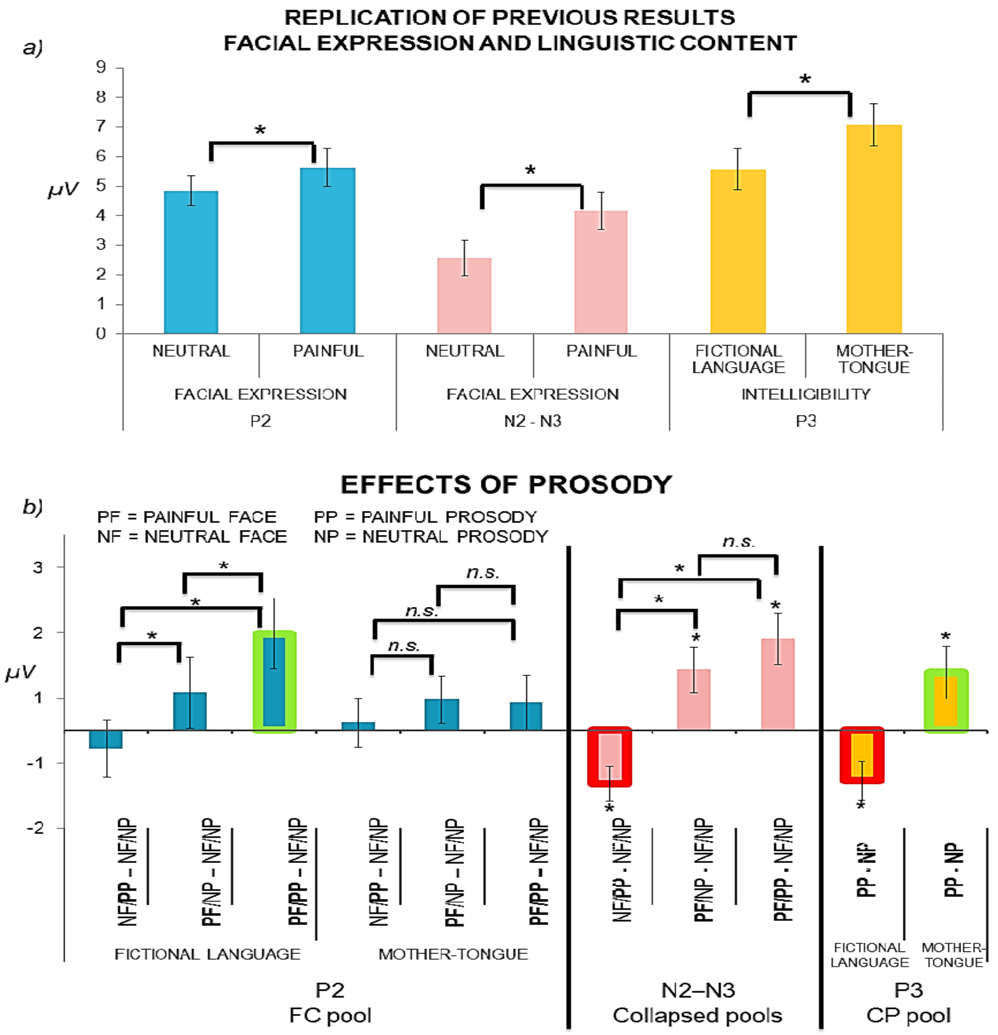

Figure 20 Panel a) Bar graphs showing main effects of facial expression on the P2 and on the N2–N3 components and of the intelligibility on the P3 component. Panel b) Bar graphs showing the effect of prosody on empathic reactions for each ERP component. Empathic reactions are shown as the difference between painful and neutral conditions. Error bars represent standard errors, asterisks significant comparisons, “n.s.” means “not-significant”.

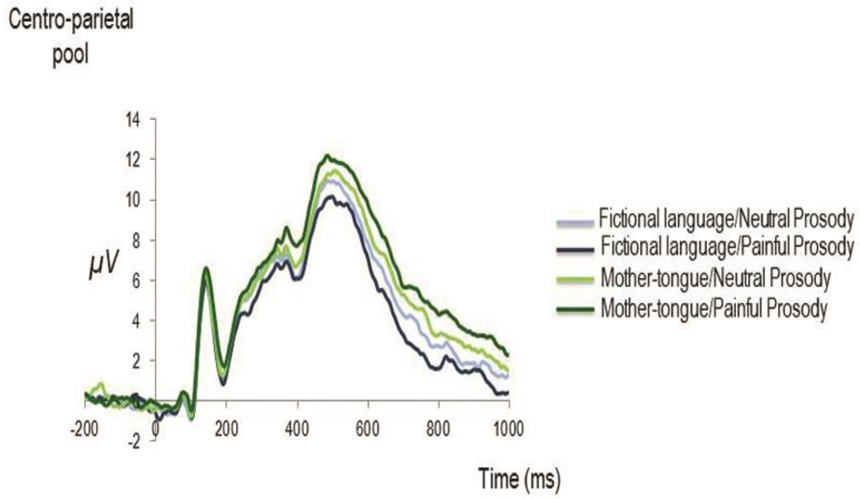

Figure 21 Grand-Averages of ERP time-locked to the onset of faces as a function of language and prosody of preceding utterances recorded at CP.

Correlational analysis. With the aim of further qualifying neural responses as experience-sharing or mentalizing responses we correlated ERP empathic reactions (i.e., painful minus neutral conditions) with participants' dispositional empathy as measured by the IRI and the EQ. More specifically, the painful-minus-neutral score was computed for both the pre-verbal and verbal domains of processing. A *perceptual cue reaction* was computed for the pre-verbal domain by subtracting ERP to neutral faces preceded by utterances with neutral prosody from ERP to painful faces preceded by utterances with neutral prosody regardless of the intelligibility and of the hemisphere. A *semantic cue reaction* was computed for the verbal domain by subtracting ERP to faces as a function of utterances in a fictional language from ERP to faces as a function of Italian utterances regardless of facial expression, prosody and hemisphere. For both reactions, positive values indexed an empathic reaction.

Correlational analysis results

The *perceptual cue reaction* on the P2 component was qualified as an empathic reaction associated with affective empathy, i.e. experience-sharing, as it significantly correlated with the affective subscale of the IRI, the empathic concern (EC) at *CP*, *r* = .516, *p* = .017 (the correlation was not significant at *FC*, *r* = .326, *p* = .101) but not with EQ, max *r* = -.116, min *p* = .328. The same reaction marginally correlated with EC on the N2–N3 at *CP*, *r* = .390, *p* = .061 (at *FC*, *r* = .315, *p* = .109), but did not correlate with the EQ, max *r* = .099, min *p* = .352.

The *semantic cue reaction* on the P3 component, positively correlated with the EQ (*r* = .517 – .751, max *p* = .017), but not with the EC, max *r* = .290, min *p* = .129, associating this empathic reaction with cognitive empathy, i.e. mentalizing, see Figure 22.

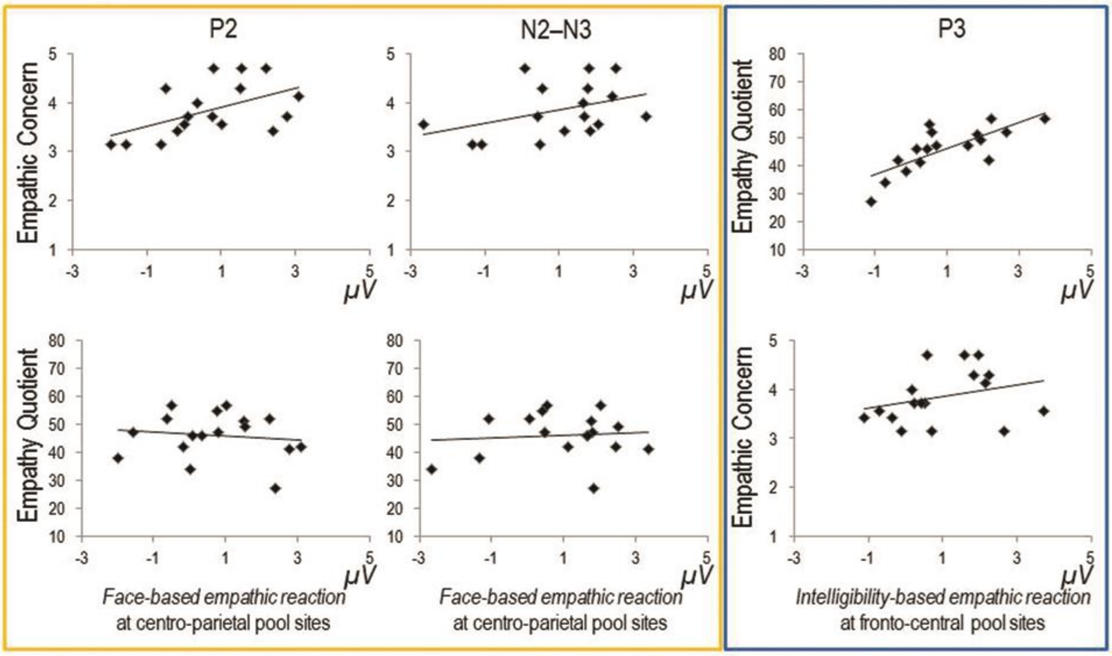

Figure 22 Scatter plots of the correlations between ERP empathic reactions and self-report measures of dispositional empathy.

6.3 Discussion

In the current study, I investigated the role of affective prosody in neural empathic responses to physical pain expressed by pre-verbal and verbal cues of pain, (i.e.

facial expressions and utterances). I orthogonally manipulated facial expressions (neutral vs. painful), intelligibility of the utterances (intelligible vs. unintelligible, i.e. utterances in mother-tongue vs. utterances in fictional language) and affective prosody (neutral vs. painful). On each trial of the experimental design a face stimulus was presented at the centre of the computer screen, either with a neutral or a painful expression; it was preceded at variable intervals by an utterance, either intelligible or unintelligible, pronounced with either a neutral prosody or an affective prosody expressing the speaker’s pain. All ERPs waveforms were time-locked to the presentation of the face stimuli. Importantly, intelligible utterances (i.e., utterances in mother-tongue) always considered a painful content. Our purpose was to monitor ERP empathic responses to others’ pain time-locked to the onset of faces (manifested as a positive shift of ERPs reflecting painful when compared to neutral conditions) as a function of all the combinations of cues of pain. I was interested in replicating our previous findings (Sessa, Meconi, & Han, 2014), in which we demonstrated that when time-locked to faces onset, P2 and N2–N3 empathic responses to others’ pain were driven by facial expressions, whereas P3 empathic responses were driven by higher level cues of pain such as the painful content (i.e., choice of words) of a verbal expression. These two different temporal-windows are functionally dissociable and very likely reflections of experience-sharing and mentalizing components of empathy as supported also by source analysis (Sessa, Meconi, Castelli, et al., 2014; Sessa, Meconi, & Han, 2014; Zaki & Ochsner, 2012). Most important, the main aim of the present investigation was to elucidate how affective prosody influenced early and late empathic responses to pain. I hypothesised that because of its dual-nature − pre-verbal but also accompanying the semantic content of the speech − prosody could interact with facial expression within an early temporal window of processing and with semantic content within a later temporal window of processing.

Replicating previous study (Sessa, Meconi, & Han, 2014), the authors time-locked ERP analysis to the onset of faces and observed that painful facial expressions modulated P2 and N2–N3 components associated with the experience-sharing response. Painful contexts maximally triggered the P3 response linked to mentalizing, as further corroborated by participants' self-rated empathy and by the pattern of correlational analysis.

Crucially, I observed that painful prosody acted on a pre-verbal domain enhancing ERP empathic reaction to painful faces when preceded by unintelligible utterances, i.e. in the fictional language, within the time-window associated with experience-sharing, including the P2 component. Painful prosody acted on a verbal domain enhancing P3 empathic reaction to painful semantic content, linked to mentalizing mechanisms. This effect of empathic reaction enhancement to painful facial expressions due to painful prosodic information was absent within the N2–N3 temporal window. N2–N3 amplitude to neutral facial expressions preceded by utterances with painful prosody was significantly less positive than that elicited by neutral facial expression preceded by utterances with neutral prosody. This pattern was opposite to what is usually observed in ERP studies on empathy. This may suggest that the incongruence between prosody and facial expression interfered with the elicitation of an empathic response. Nevertheless, this further observation strongly corroborates the view that prosody and facial expression information may interact within this earlier temporal window, including the P2 and N2–N3. Notably, a similar interference in the elicitation of neural empathic response was observed on the P3 component under conditions in which unintelligible utterances where pronounced with a painful prosody. This finding is particularly interesting when contrasted with the empathic response enhancement that we observed for intelligible utterances pronounced with a painful prosody. This pattern seems to suggest that prosodic information may magnify a higher-level empathic response linked to language (and to mentalizing) only when it is associated with a semantic content.

This pattern of neural responses translated into higher scores of self-rated empathy for utterances pronounced with painful prosody compared to neutral ones, as well for conditions where facial expressions and prosody were painful and for intelligible utterances pronounced with painful prosody when compared to other combinations.

Taken together, these findings are consistent with those studies on on-line processing of prosodic information showing that vocal emotion recognition, i.e. prosody, can occur pre-attentively and automatically in the time-range including the Mismatch Negativity (MMN; Schirmer, Striano, & Friederici, 2005) and the P2 (Iredale, Rushby, McDonald, Dimoska-Di Marco, & Swift, 2013; Schirmer & Kotz, 2006). The MMN has been shown to peak at about 200 ms in an oddball task where standard and deviant stimuli were emotionally and neutrally spoken syllables. The differential MMN response to such comparison, larger for emotional than neutral stimuli, could therefore be taken as an index of the human ability to automatically derive emotional significance from auditory information even when irrelevant to the task. The modulations of the P2 have been related to the salience of the stimulus that conveys emotional content (Iredale et al., 2013). Importantly, the modulations of the centro-parietal P2 can also reflect the processing of the information important in a specific context: P2 is also modulated by individual characteristics of participants and experimentally-induced knowledge about categories of visual stimuli that are physically equivalent in the context of empathy for pain (Vaes, Meconi, Sessa, & Olechowski, 2016). In line with Schirmer and Kotz (Schirmer & Kotz, 2006), evaluation of prosody encompasses a later verbal stage of processing that is related to the context evaluation and semantic integration with earlier pre-verbal bottom-up prosodic cues. When participants are required to detect an emotional change from vocal cues that can convey either prosodic and semantic information, ERP studies showed that such emotional change detection is reflected on larger P3 (Chen et al., 2016; Paulmann, Jessen, & Kotz, 2012) when compared to non-violations conditions. Findings in the context of emotional change detection with high ecological validity (Chen et al., 2016) can also help explain late modulations of the P3 as a function of bottom-up processes such as processing of facial expression observed in the present study. Although the present investigation considered neural responses time-locked to faces onset as a function of facial expression, accessibility to semantic content of pain (i.e., intelligibility) and prosody, we propose that on-line processing of prosodic information (as in the studies described above) and off-line processing of prosodic information (as in our study) could induce very similar ERP modulations encompassing temporal-windows linked to pre-verbal and verbal domains.

Interestingly, affective prosody also showed interactive effects with intelligibility of the utterances in a very early time-window, i.e. on the P2 (i.e., neutral faces preceded by utterances in mother-tongue with painful prosody induced a larger P2 reaction when compared to neutral faces preceded by utterances in a fictional language with painful prosody), and with the facial expression in the latest time-window, i.e. on the P3, confined to the right hemisphere at the centro-parietal sites (i.e., painful facial expressions elicited larger P3 than neutral facial expressions when preceded by utterances with painful prosody independently of their intelligibility). Within this framework, affective prosody of pain has a distinct role in enhancing neural empathic reactions by favouring the processing of congruent facial expressions of pain beyond the time-window linked to experience-sharing and favouring mentalizing processes on those faces; and, on the other side, by favouring earlier empathic reactions linked to experience-sharing to those neutral facial expressions that were preceded by utterances with a content of pain (i.e., intelligible utterances).

Importantly, similar to previous work (Sessa, Meconi, & Han, 2014), facial expression and intelligibility never interacted within the earlier and the later time-windows. Remarkably, despite the higher ecological validity of the present stimuli when compared to our previous work where facial expressions were preceded by written sentences in third person (e.g., “This person got their finger hammered”), facial expression and intelligibility never interacted within both the earlier and the later time-windows, indexing that pre-verbal and verbal domains of processing distinctively contribute to the occurrence of the empathic response.

This whole pattern of results dovetails nicely with the ascertained view that affective prosody processing is a phylogenetically and ontogenetically ancient pre-verbal ability that develops along with intelligibility abilities. Similarly, it has been suggested that affective and cognitive components of empathy, i.e. experience-sharing and mentalizing, might have evolved along two different evolutionary trajectories attributing phylogenetically older age to experience-sharing than to mentalizing (Bischof-Köhler, 2012; Gonzalez-Liencres, Shamay-Tsoory, & Brüne, 2013; Smith, 2010). Explicit inference on others’ inner states is believed to be a higher-order cognitive ability that is shared only by apes and humans (de Waal, 2008; Edgar, Paul, Harris, Penturn, & Nicol, 2012) and its selection might be associated with increasing of social interactions complexity due to groups exchanges (Trivers, 1971).

Chapter 7

Part of the content presented in this chapter has been described in the following published article:

Schiano Lomoriello, A., Meconi, F., Rinaldi, I., Sessa, P. (2018). Out of sight out of mind: Perceived physical distance between the observer and someone in pain shapes observer's neural empathic reactions. *Frontiers in Psychology*. DOI: 10.3389/fpsyg.2018.01824

Experiment 4: Exploring the role of physical distance in empathy for pain

The present investigation aimed at exploring whether the physical distance between an observer and an individual in a particular affective state (induced by a painful stimulation) is a critical factor in modulating the magnitude of an empathic neural reaction in the observer.

As I have already discussed at great length, empathy is comprised of at least two components, widely independent and dissociable, both functionally and anatomically (Decety & Lamm, 2007; Sessa, Meconi, Castelli, & Dell'Acqua, 2014; Zaki & Ochsner, 2012). One of the components is termed affective empathy or experience sharing − mainly based on neural resonance mechanisms − and the other component is termed cognitive empathy − mainly based on mental state attribution ability (Decety & Lamm, 2007; Zaki, 2013; Zaki & Ochsner, 2012).

Empathy reaction may be shaped by a variety of factors, including the characteristics of the observer and those of the individual experiencing a particular affective condition (Blair, 2005; Dapretto et al., 2006; Davis, 1983; Harris & Fiske, 2006; Hein, Silani, Preuschoff, Batson, & Singer, 2010; Philip et al., 2012; Wagner, Kelley, & Heatherton, 2011) or also the affective and social relationship existing between the observer and the other individual, such that at least part of the brain network underlying empathy (i.e., anterior cingulate cortex and anterior insula) is strongly activated in those cases when the partner, rather than a stranger, is experiencing a pain stimulation (Singer et al., 2004), or in cases when the other is an individual with whom the observer has established a relationship of trust rather than distrust (Singer et al., 2006), or when the individual experiencing pain belongs to the observer's ethnic group rather than a different ethnic group (Avenanti, Sirigu, & Aglioti, 2010; Contreras-Huerta, Baker, Reynolds, Batalha, & Cunnington, 2013; Contreras-Huerta, Hielscher, Sherwell, Rens, & Cunnington, 2014; Sessa, Meconi, Castelli, et al., 2014; Xu, Zuo, Wang, & Han, 2009). In brief, the chance that an empathic reaction will be triggered and its magnitude depend on the nature of the social and affective relationships that binds people.

Notably, social and affective relationships are often designated in terms of "distance", and just as for the physical distance, the terms "close" and "distant" tend to be used in the context of relationships, for example, associating them with an intimate friend or with a relative almost unknown to us, respectively (Lakoff & Johnson, 1980; Lakoff & Mark, 1999). There is evidence supporting that both psychological and physical distances has a common functional and neural substrate, one would expect to observe an overlapping activation in those brain regions involved in the representation of the egocentric physical space (Naito et al., 2008; Neggers, Van der Lubbe, Ramsey, & Postma, 2006; Rapcsak et al., 1995; Roland et al., 1980; Sakata, Shibutani, & Kawano, 1980). Yamakawa and colleagues' (2009), in an fMRI study, found a neural overlapping in the parietal cortex for both mental representations of social relationship and physical space. This inextricable link between physical and psychological spaces is also supported by previous theories about *Proxemics* (Argyle & Dean, 1965; Hall et al., 1968; Hayduk, 1983), indicating that people unconsciously organize the space around them in concentric areas, so that the areas closest to one's body are the privileged space of action(s) for the most intimate interactions, and, conversely, the areas most distant from the body are mostly associated with the space of action(s) for interactions with individuals with whom they share a low degree of intimacy.

In this Experiment 4 (4a and 4b), I wanted to investigate whether the observer's emphatic reaction toward a target subjected to a pain stimulation could be modulated on the basis of their physical distance, just as happens for the social and affective distance (Avenanti et al., 2010; Singer et al., 2004, 2006; Xu et al., 2009).

In order to test this hypothesis, in Experiment 4a two groups of participants were administered a pain decision task (Sessa, Meconi, Castelli, et al., 2014; Sessa, Meconi, & Han, 2014; Xu et al., 2009; Meconi, Doro, Schiano Lomoriello, Mastrella, & Sessa, 2018; Vaes, Meconi, Sessa, & Olechowski, 2016) in which faces (either upright or inverted) were presented in two different experimental conditions, i.e. pricked by a syringe (pain condition) or touched by a Q-tip (neutral condition), while participants' electroencephalogram (EEG) was recorded. Participants' task was to decide whether each face was painfully or neutrally stimulated. Importantly, the two groups of participants were presented with face stimuli of one of two possible sizes in order to manipulate the retinal size and therefore the perceived physical distance (see, e.g., Gogel, 1998), which approximately corresponded to close (6.56 feet, approximately 2 meters/close social distance) and far (9.84 feet, approximately 3 meters/far social distance) portions of the social distance (Hall, 1964). The choice to select these two specific perceived distances was based on the organization of the concentric "virtual" zones identified by the Proxemics. In particular, I choose distances that were attributable to the "zone" ascribed to the "social distance" as identified by Hall (1963). This zone is located beyond the personal space that is reserved for more or less intimately known people, and is instead reserved for strangers, people one has just met and acquaintances. Since the faces that participants observed in this study were all of strangers, I considered it more appropriate from an ecological point of view that they were presented within the social distance zone. Furthermore, we have avoided presenting faces at a perceived distance corresponding to the personal space since it is known that, when this space is invaded, affective states that are in contrast with a possible empathic reaction may occur in the observer, such as anxiety, distress or anger (Hall, 1969). The social distance, on the other hand, permits interaction with others, but allows at the same time the individual to feel safe. It is important to add that this social distance zone can be in turn divided into two different portions or *phases* affecting the (potential) interaction with others, one corresponding to the close social space (within 7 feet or 2.1 meters) and one corresponding to the far social space (over 7 feet, and up to about 12 feet or 3.7 meters). Therefore, in line with this body of knowledge, we decided to use two sizes of face stimuli corresponding to perceived distances within the close social zone and within the distant social zone.

The usually observed ERPs modulations observed in the pain decision task involve a shift towards more positive values for the pain condition than the neutral condition of a subset of ERPs components ranging from the P2 to the P3/LPP components recorded at both frontal and parietal electrode sites (Sessa & Meconi, 2015; Sheng et al., 2016; see also, e.g., Donchin, 1981; Donchin & Coles, 1988; Sessa, Luria, Verleger, & Dell'Acqua, 2007; Verleger, 1988). An ERP empathic reaction is defined by the difference between ERP(s) elicited in the pain and in the neutral conditions (Decety, Yang, & Cheng, 2010; Fan & Han, 2008; Li & Han, 2010; Meconi, Doro, Schiano Lomoriello, Mastrella, & Sessa, 2018; Sessa, Meconi, & Han, 2014; Sheng & Han, 2012; Vaes et al., 2016). Behavioral responses have been collected to ensure that participants were actively focusing on the information driven by the stimulating object, i.e. painful or neutral, that in turn triggers the ERP empathic reactions (Fan & Han, 2008). In Experiment 1, I expected to observe a moderating effect on empathic ERP reactions as a function of the perceived physical distance of the faces, such that the group of participants exposed to faces perceived as more distant would have manifested a lower magnitude of these neural empathic reactions when compared to the group of participants exposed to faces perceived as closer. I hypothesized that inverted faces would not have induced an empathic reaction because of the disruption of the configural/holistic processing (Leder

& Bruce, 2000) in either groups of participants. For this reason I expected reduced if null empathic reactions for inverted faces for both groups of participants. In this vein, I considered the inverted face condition that served as a control for other possible intervening factors in modulating ERPs. However, to our knowledge this is the first study investigating whether inverted faces painfully or neutrally stimulated may induce or not empathic reactions, therefore this aspect of the present study was purely exploratory.

A second experiment (Experiment 4b) was further designed in order to test whether possible modulations of the neural empathic reactions in Experiment 1 could be ascribable to differences in the ability to identify faces of the two different sizes. In order to investigate this possibility, in Experiment 4b, a new group of participants was engaged in a behavioural match-to-sample task involving the two-size upright face stimuli of Experiment 4a.

7.1 Experiment 4a

7.1.1 Method

Participants

Before starting data collection, we established to enter into ERP analyses data from 15-20 participants for each of the two experimental groups because of existing literature in this field that suggests it is an appropriate sample (Fan & Han, 2008; Sheng & Han, 2012). Analyses were conducted only after data collection was complete. Data were then collected from 40 volunteer healthy students (11 males) from the University of Padova. Data from 7 participants were excluded from the analyses due to excessive electrophysiological artifacts (more than 25% of the trials), of which 17 for one group and 16 for the other group. For this reason an additional participant was tested such that the two groups had the same number of participants. All participants reported normal or corrected-to-normal vision and normal audition and no history of neurological disorders.

They were randomly assigned to the two different groups, as a function of the two different physical sizes of face stimuli. Each group included 17 participants (for far physical distance: 5 males; mean age: 23.8 years, SD =; 4.28, 4 left-handed; for close physical distance: 6 males, mean age: 23.2 years, SD =; 3.62, 4 left-handed). All participants signed a consent form according to the ethical principles approved by the University of Padova.

Stimuli

The stimuli were 12 digital photographs of White faces with a neutral facial expression from the Eberhardt Lab Face Database (Mind, Culture, & Society Laboratory at Stanford University, http://www.stanford.edu/group/mcslab/cgi-bin/wordpress/examine-the-research/). Each face was digitally manipulated in order to obtain stimuli for two different stimulation conditions, one in which faces received a painful stimulation (needle of a syringe penetration), and one in which faces received a neutral (Q-tip touch) stimulation (applied either to the left or to the right cheek)[10].

All faces were presented in the upright and inverted orientation and in two different physical sizes, in order to manipulate retinal size and perceived physical distance, both beyond the intimate and personal distances, and roughly corresponding to the close and far portions of social distance (Hall, 1964). Face stimuli appearing to be in the far portion of social distance fit in 1.6° x 2.5° (width x height), whereas face stimuli appearing in the close portion of social distance fit in 2.5° x 3.3° (width x height). One group was exposed to faces appearing to be distant from participants 6.56 feet (approximately 2 meters; close social distance) and the other group was exposed to faces appearing to be distant from participants 9.84 feet (approximately 3 meters; far social

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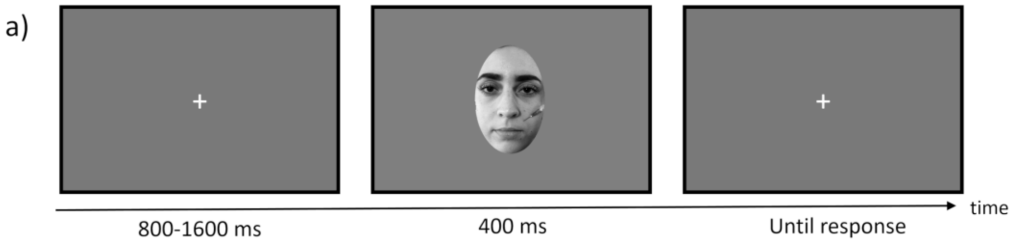
[10] The use of faces with a neutral facial expression receiving painful or non-painful stimulation has been used also in previous studied (see for example, Xu et al., 2009).

distance). Stimuli were presented on a 17-in cathode ray tube monitor controlled by a computer running E-prime software.

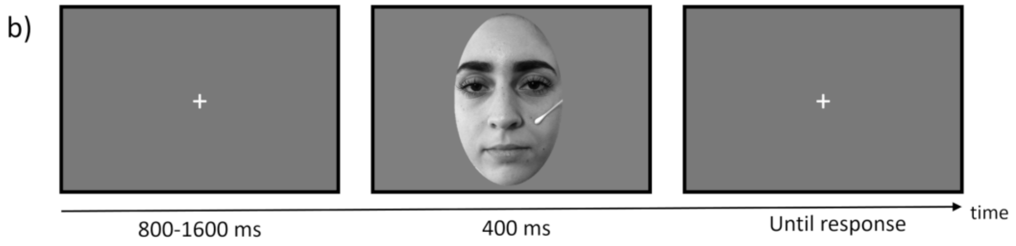
Experimental design

I implemented a variant of the pain decision task. Each trial began with the presentation of a fixation cross at the centre of the screen (800–1600 ms, jittered in steps of 100 ms), followed by a face displayed for 400 ms. The sequence of events of each trial is depicted in Figure 23. Please note that the original face stimuli have been replaced in Figure 23 other face stimuli not belonging to the Eberhardt Lab Face Database according to the terms of use of the Database.

Participants were instructed to decide whether each face was painfully or neutrally stimulated by pressing one of two appropriately labelled keys of the computer keyboard as quickly and accurately as possible. Following a brief session of practice in order to familiarize with the task, participants performed 576 trials divided in 4 blocks (144 trials for each block including all the possible experimental combinations, intermixed within each block). Participants could manage a break session between a block and the next block of trials and decided when to continue by pressing the space bar. The experiment lasted for approximately 30-40 minutes. The entire experimental session, including the preparation of the participant for the EEG data collection, lasted about 60-75 minutes.



Representation of a painfully stimulated face in the "far social distance" condition



Representation of a neutrally stimulated face in the "close social distance" condition

Figure 23 Timeline of each trial for Experiment 1 (pain decision task): a) example of a trial for the far social distance condition with a painfully stimulated face; b) example of a trial for the close social distance condition with a neutrally stimulated face. Original face stimuli have been replaced with actors according to the terms of use of the Eberhardt Lab Face Database.

Electrophysiological recording and analyses

The EEG was recorded from 64 active electrodes distributed over the scalp in accordance with the international 10/20 system placed on an elastic Acti-Cap, referenced to the left earlobe. The EEG was re-referenced offline to the average of the left and right earlobes. Horizontal EOG (i.e., HEOG) was recorded bipolarly from two external electrodes positioned laterally to the left and right external canthi. Vertical EOG (i.e., VEOG) was recorded from Fp1 and one external electrode placed below the left eye. The electrode impedance was kept less than 10 KΩ because of the highly viscous electro-gel and the properties of active electrodes. Offline EEG processing and analyses were conducted using Brain Vision Analyzer software (Brain Products; www.brainproducts.com).

EEG, HEOG and VEOG signals were amplified (pass band 0.01–80 Hz) and digitized at a sampling rate of 250 Hz. The EEG was segmented into 1200 ms epochs starting 200 ms prior to the onset of the faces. The epochs were baseline-corrected based on the mean activity during the 200 ms pre-stimulus period, for each electrode site. Trials associated with incorrect responses or contaminated by large horizontal eye movements, eye blinks or other artifacts (exceeding ± 30 μV, ± 60 μV and ± 80 μV, respectively) were automatically discarded from analysis, which accounted for the exclusion of an average of 6% of trials (with an average of 5.8 for the "close social distance" group ranging from 1% to 15% and an average of 6.4 for the "far social distance” group ranging from 1% to 14%). Separate average waveforms for each condition were then generated time-locked to the presentation of the face stimuli for each experimental condition. Statistical analyses of ERPs mean amplitudes focused on a time window ranging from 300 and 600 ms, corresponding to the P3 ERP component. Mean P3 amplitude values were measured at pooled electrode sites selected from fronto-central (Fz, F1, F2, F3, F4, F5, F6, FCz, FC1, FC2, FC3, FC4, FC5, FC6) and centro-parietal (CPz, CP1, CP2, CP3, CP4, CP5, CP6, Pz, P1, P2, P3, P4, P5, P6) electrodes according to visual inspection and previous work (Fan & Han, 2008; Meconi, Vaes, & Sessa, 2015; Sessa & Meconi, 2015; Sessa, Meconi, & Han, 2014).

7.1.2 Results

The significant threshold for all statistical analyses was set to .05. Exact *p* values and effect sizes (i.e., partial eta-squared, ηp^2) are reported. Planned comparisons relevant to test the hypotheses of the present experiment are reported.

Behavioral results

Individual mean proportion of correct responses was submitted to a mixed analysis of variance (ANOVA), considering stimulation of face stimuli (painfully vs.

neutrally stimulated) and orientation (upright vs. inverted) as within-subjects factors and physical distance (far social distance vs. close social distance) as a between-subjects factor. The main effect of neither face stimuli or orientation were significant (respectively: $F < 1$, $p = .970$, $\eta p^2 = .000$; $F(1,32) = 3.679$, $p = .064$, $\eta p^2 = .103$); the mean proportion of correct responses for face stimuli neutrally stimulated in the upright orientation was .984; *SD* = .17, and in the inverted orientation condition was .985; *SD* = .14; the mean proportion of correct responses for face stimuli painfully stimulated in the upright orientation was .985; *SD* = .17, and in the inverted orientation was .9.88; *SD* = .14). The interactions between face stimuli and physical distance and between orientation and physical distance were not significant: $F < 1$, $p = .986$, $\eta p^2 = .000$; $F < 1$, $p = .341$, $\eta p^2 = .028$, respectively.

Reaction times (RTs) exceeding each individual mean RT in a given condition ± 2.5 *SD* and RTs associated with incorrect responses were excluded from the RTs analysis. Individual mean proportion of correct responses and RTs were submitted to a mixed ANOVA, including face stimuli (painfully vs. neutrally stimulated) and orientation (upright vs. inverted) as within-subjects factors and physical distance (far social distance vs. close social distance) as a between-subjects factor. None of the effects were statistically significant ($F < 1$; min $p = 0.98$).

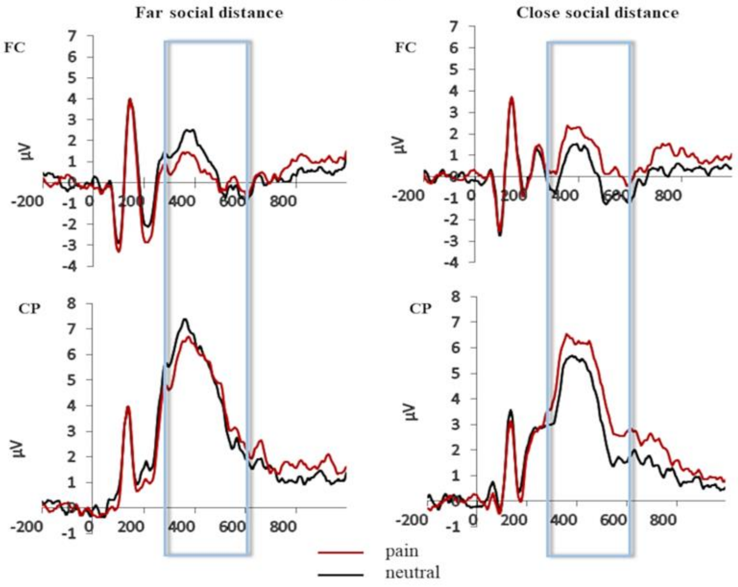
ERPs

Grand averages of the face-locked ERP waveforms elicited in the pain and neutral stimulation conditions separately for pooled fronto-central (FC) and centro-parietal (CP) electrode site and for close and far social distance are shown in Figure 24 (upright face stimuli and inverted face stimuli).

A mixed analyses of variance (ANOVA) of P3 amplitude values including stimulation of face stimuli (painfully vs. neutrally stimulated) and orientation (upright vs.

inverted) as within-subjects factors and physical distance (far vs. close) as a between-subjects factor was carried out for each ERP electrodes pool.

The ANOVA revealed a significant main effect of orientation at FC pooled electrode sites, $F(1,32) = 18.610$, $p < .001$, $\eta p^2 = .368$, and at CP pooled electrode sites, $F(1,32) =16.908$, $p = .001$, $\eta p^2 = .514$). The main effect of stimulation of face stimuli reached significance level only for CP pooled sites, $F(1,32) = 7.950$, $p = .012$, $\eta p^2 = .332$, (at FC pooled sites: $F <1$). The interaction between these two factors did not reach significance level for neither of the two pooled electrode sites (FC pooled sites: F (1, 32) = 1.735, $p = .206$, $\eta p^2 = .98$; CP pooled sites $F < 1$). Notably, the interaction between stimulation of face stimuli and physical distance reached significance both at FC pooled electrode sites, $F(1,32) = 8.697$, $p = .001$, $\eta p^2 = .020$, and at CP pooled electrode sites, $F(1,32) = 4.589$, $p = .040$, $\eta p^2 = .125$. Planned comparisons revealed that for face stimuli perceived at a closer physical distance the painful condition elicited more positive P3 amplitude than the neutral condition (at FC pooled sites: $t = - 3.044$, $p = .008$; *Mdiff* = -1.050 [-1.78, -3.18]; at CP pooled sites: $t = - 2.626$, $p = .018$; *Mdiff* = -.915 [.-1,65, -.176]). This effect was manifest as a positive shift of the ERP activity for face stimuli painfully stimulated (at FC pooled sites .964 μV, *SD* = 2.34; at CP pooled sites 4.98 μV, *SD* = 3.48) relative to face stimuli neutrally stimulated (at FC pooled sites - .0862 μV, *SD* = 2.25; at CP pooled sites 5.05 μV, *SD* = 3.09). Importantly, this positive shift indexing an empathic reaction was not observed for face stimuli appearing at far physical distance (at FC pooled sites: $t = 1.056$, $p = .307$; *Mdiff* = .408 [- .411, 1.22]; at CP pooled sites: $t = .188$, $p = .853$, *Mdiff* = .069 [.712, .8516]. The interaction between orientation and physical distance and the triple interaction between stimulation of face stimuli, physical distance and orientation were not significant (at FC: both *Fs* > 1; at CP: $F(1,32) = 1.444$, $p = .238$, $\eta p^2 = .043$ and $F < 1$, respectively).


a) Upright face stimuli

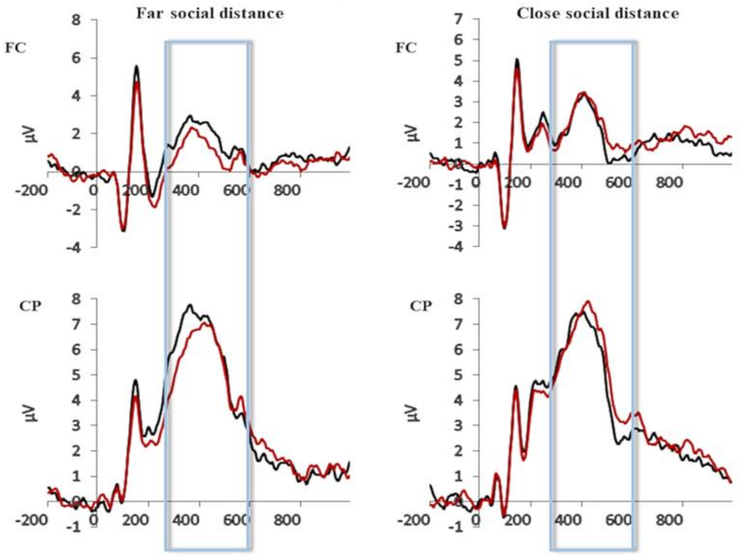

b) Inverted face stimuli

Figure 24 a) Upright face stimuli: Grand averages of the face-locked ERP waveforms for the upright face stimuli elicited in the pain and neutral stimulation conditions separately for pooled fronto-central (FC) and centro-parietal (CP) electrode site and for close and far social distance.
b) Inverted face stimuli: Grand averages of the face-locked ERP waveforms for the inverted face stimuli elicited in the pain and neutral stimulation conditions separately for pooled fronto-central (FC) and centro-parietal (CP) electrode site and for close and far social distance.

7.2 Experiment 4b

The experimental hypothesis on the modulating role of physical distance on empathy was corroborated, i.e. I observed greater empathic ERP reactions for the group of participants exposed to faces perceived as closer compared to the group of participants exposed to faces perceived as more distant, independently of faces orientation. As this first experiment left open the possibility that the differences observed between the two groups could depend on a different degree of discriminability of the faces perceived as closer and those perceived as more distant, we designed a second experiment (Experiment 4b) to test whether the modulation of neural empathic reaction observed in Experiment 4a could be ascribable to differences in the ability to identify faces of the two different sizes. In order to investigate this possibility, in Experiment 4b, a new group of participants was engaged in a behavioural match-to-sample task involving the two-size upright face stimuli of Experiment 4a.

7.2.1 Method

Participants

Data were collected from 22 volunteer healthy students (3 males) from the University of Padova. All reported normal or corrected-to-normal vision and no history of neurological disorders. All 22 participants (3 males; mean age: 23.40 years, SD =1.79; 3 left-handed) were included in the final sample. All participants signed a consent form according to the ethical principles approved by the University of Padova. Analyses were conducted only after data collection was complete.

Stimuli

The stimuli were the same 12 digital photographs of White neutral faces from the Eberhardt Lab Face Database (Mind, Culture, & Society Laboratory at Stanford

University, https://web.stanford.edu/group/mcslab/cgi-bin/wordpress/examine-the-research/) used in Experiment 1 (including the painful/neutral stimulation).

All faces were presented in the two different physical sizes used in Experiment 1. Stimuli were presented on a 17-in cathode ray tube monitor controlled by a computer running E-prime software.

Procedure

Experimental design

I implemented a variant of the discrimination task based on an XAB match-to-sample task used by Newell and Bülthoff (2002; see also Young et al., 1997). On each trial a face stimulus (stimulus X) was presented and then followed by two face stimuli (stimuli A and B) presented simultaneously, one on the left and one the right of the fixation.

Each trial began with a fixation cross presented for 500 ms. Then the first face stimulus (X) of one of the two possible sizes was shown for 750 ms in the center of the screen. The next pair of face stimuli (A and B), of the same size of the first face (stimulus X), remained on the screen until the participant pressed a response button. Each of the A and B face stimuli were displayed 3 cm to the left and to the right relative to the center of the screen.

Participants were instructed to respond as fast and as accurately as possible, indicating which face stimulus of the AB pair was identical to the preceding face stimulus X. Participants were instructed to press a key on the left (or on the right) of the keyboard to indicate that the face stimulus presented on the left (or on the right) was identical to the previously presented face stimulus (stimulus X). Following a brief session of practice in order to familiarize with the task, participants performed 528 trials, divided in 4 blocks (i.e., each block consisting of 132 trials). Faces of different sizes were presented in separate block of trials, whose order was counterbalanced between participants. Participants could manage a break session between the blocks trials and decided when to continue by pressing the space bar. The experiment lasted about 35 minutes.

Figure 25 shows two examples of trials, one (a) for the far social distance condition, and the other (b) for the close social distance condition. Original face stimuli have been replaced in the Figure 25 (a and b) with other face stimuli not belonging to the original database according to the terms of use of the Eberhardt Lab Face Database.

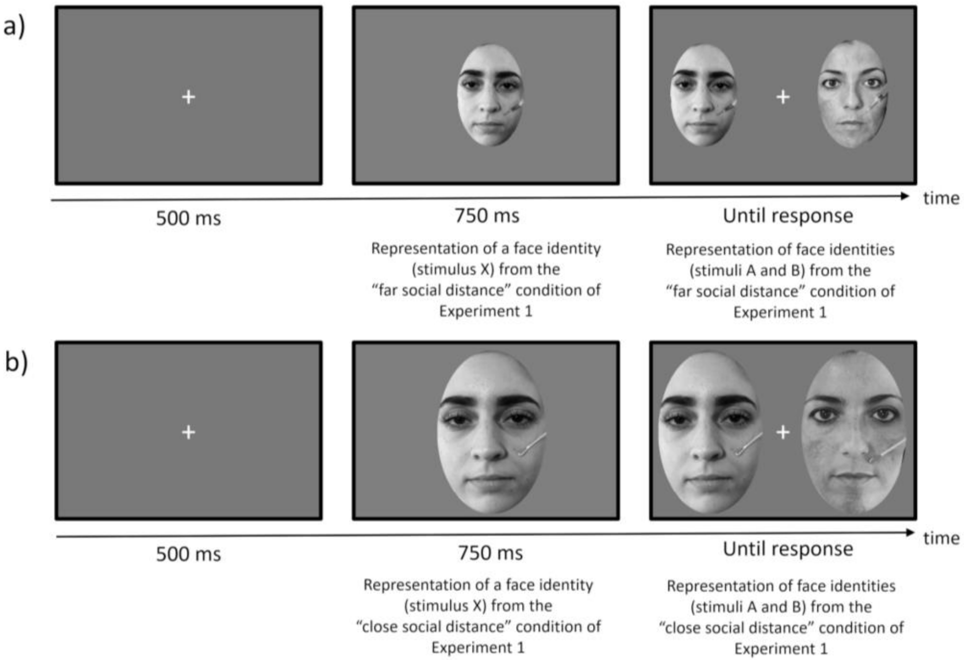


Figure 25 Timeline of each trial for Experiment 2 (match-to-sample task): a) example of a trial with faces used for the "far social distance" condition of Experiment 1; b) example of a trial with faces used for the "close social distance" condition of Experiment 1. Original face stimuli have been replaced with actors according to the terms of use of the Eberhardt Lab Face Database.

7.2.2 Results

The significant threshold for all statistical analyses was set to .05. Exact *p* values and effect sizes (i.e., partial eta-squared, ηp^2) are reported. Planned comparisons relevant to test the hypotheses of the present experiment are reported.

Behavioral results

Individual mean proportions of correct responses were submitted to a one-way analysis of variance (ANOVA), considering physical distance (far vs. close) as a within-subjects factor. The main effect of physical distance did not approach significance level: $F(1,21) = .236$, $p = .632$, $\eta p^2 = .11$ (see Figure 26).

RTs exceeding each individual mean RTs in a given condition ± 2.5 *SD* and RTs associated with incorrect responses were excluded from the RTs analysis. RTs were submitted to a one-way analysis of variance (ANOVA), considering physical distance (far vs. close) as a within-subjects factor. The effect of physical distance did not approach significant level: $F(1,21) = .648$, $p = .430$, $\eta p^2 = .030$.

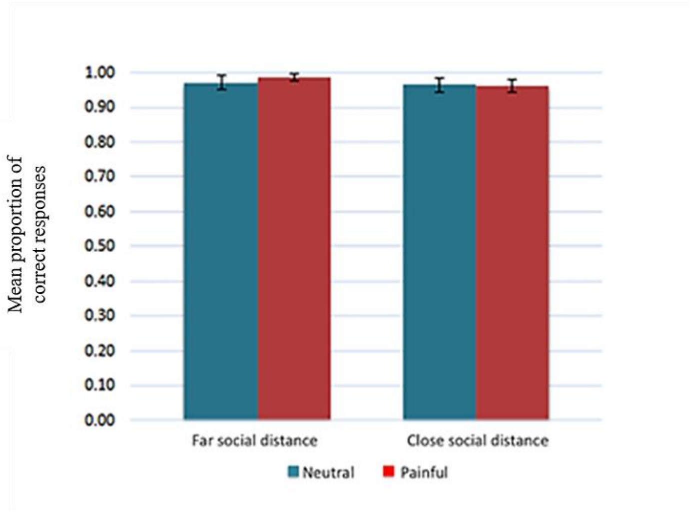


Figure 26 Bar chart displaying mean rating scores for each condition for Experiment 2. Error bars represent standard errors.

7.3 Discussion

A significant body of research has undoubtedly shown that the magnitude of an observer's empathic reaction depends on the social and affective bond existing with the individual experiencing an affective state in first-person indirect (Avenanti et al., 2010; Contreras-Huerta et al., 2013, 2014; Lockwood, 2016; Rameson & Lieberman, 2009; Sessa, Meconi, & Han, 2014; Singer et al, 2004; Xu et al., 2009). Based on robust experimental evidence suggesting the existence of an inextricable link between the processing of physical distance and that of psychological distance (Hall, 1964, 1969), the present study aimed at investigating whether physical distance, like the psychological distance, could be a modulator of the magnitude of the observer's empathic reaction for an individual in a state of physical pain. In order to test this hypothesis, between-subjects experimental design (Experiment 4a) was implemented. In this Experiment, I manipulated the perceived physical distance (close social distance: 6.56 feet, approximately 2 meters vs. far social distance: 9.84 feet, approximately 3 meters) of upright and inverted faces pricked by a syringe (i.e., pain condition) or touched by a Q-tip (i.e., neutral condition). I therefore expected to observe a reduced empathic reaction in the group of participants exposed to faces perceived as more distant when compared to the empathic reaction in the group of participants exposed to faces perceived as closer. Whether this reaction could be selectively observed for upright faces was an open question. In line with this hypothesis, the results indicated that in a time window between 300 and 600 ms following the presentation of the face stimuli, a clear ERP pattern previously linked with an empathic reaction (e.g., Meconi et al., 2015; Sessa et al., 2007; Sheng and Han, 2012) was observed at both fronto-central and centro-parietal regions in the group of participants exposed to the face stimuli perceived as closer, while this reaction was absent in the group of participants exposed to face stimuli perceived as more distant. This effect did not interact with the orientation of the faces, suggesting that also inverted faces could elicit an empathic reaction. Importantly, no differences were observed in terms of accuracy in discriminating between the painful and the neutral stimulation conditions indicating that the differences in empathic reactions between the two groups of participants did not depend on differences in the ability to discriminate between the two stimulation categories (i.e., painful vs. neutral stimuli) in the two different sizes conditions, further suggesting that the observed differences in the empathic reaction depended indeed on the manipulation of perceived distance of face stimuli.

Experiment 4a did not allow clarifying whether the modulation of the empathic reaction in the two groups depended on differences in discriminability of the faces of the two sizes. This possibility could be particularly relevant in light of the consolidated knowledge in the context of the social psychology of two possible putative cognitive operations that people use during the perception of others, i.e. individuation and categorization (see Brewer, 1988; Fiske & Neuberg, 1990). While individuation is that mechanism by which the other individual is perceived as a unique entity, the mechanism of categorization leads to others' perception based on their categorization as belonging to a specific social group. Notably, evidence in the context of empathy toward others' pain suggests that these mechanisms may be critical modulators of the empathic reaction, so that individuation favors an empathic reaction while categorization tends to be associated with its suppression (Sheng & Han, 2012). These considerations could therefore suggest that under conditions, in which faces are more easily discriminable, an individuation mechanism can be favored and this in turn could promote an empathic reaction. I then implemented a second experiment (Experiment 4b) that involved one further group of participants engaged in a behavioural match-to-sample task involving the same two-size upright face stimuli of Experiment 4a to test the hypothesis that the two categories of faces (perceived as closer and perceived as more distant) could be more or less easily identifiable. Results of Experiment 4b revealed that face stimuli of the two sizes could be equally identifiable both in terms of accuracy and reaction times, supporting the view that the critical factor triggering differential empathic reactions in the two groups of participants in Experiment 4a was not related to the likelihood of identifying the faces of the two sizes. We have to admit that this conclusion should be taken with caution because of the ceiling effect observed with regard to the accuracy level; however, we believe that the observation that also reaction times, that are characterized by a more meaningful variation, did not differ between the two sizes conditions provide additional support in favour of our interpretation. It is important to stress that this whole pattern of findings does not imply that an individuation mechanism may not be preferred for faces perceived as closer relative to those perceived as more distant, but rather that the implementation of this mechanism, rather than that of categorization, does not seem to be a direct consequence of the ease/difficulty of identifying faces.

We confess that we cannot rule out the possibility that the size of the faces *per se* (rather than distance perception) have produced those observed modulations in neural empathic reactions. Nevertheless, we believe this is unlikely since each face was neutrally or painfully stimulated by a tool that was proportional in size to the stimulated face, so the tool provided a contextual cue that participants could use to estimate distance. The findings that the two groups of participants were equally accurate and fast in deciding whether the faces were painfully or neutrally stimulated (Experiment 4a) and in discriminating faces of the two sizes (Experiment 4b) strongly support the idea that it was not the size per se the key modulator factor of the empathic reactions but rather the perceived distance of the faces. Moreover, for stimuli whose size is known and familiar to an observer, their size and the retinal image size are sufficient indications to induce an estimate of physical distance (see, e.g. Gogel, 1998).

This research wants to provide an initial suggestion regarding the relationship between neural activity previously linked to empathy and perceived distance. P3 modulation, within this types of experimental paradigms, can constitute an important "observation windows" of a part of the full-blown empathic experience, and, at the moment at least, these modulations seem to be those reliably linked to the observation of vicarious pain (Coll, 2018). The idea at the basis of this experiment was not to dissect empathy as a function of perceived distance but to propose that the effects of perceived distance on empathy may depend on different possible mechanisms. Although the perception of distance has been proved a fundamental modulator of interpersonal processes, including empathy for pain as demonstrated in the present work, the underlying mechanism is not well understood. At least two classes of theories – that are not mutually exclusive – could account for this modulatory effect, i.e. the *Construal Level Theory* (CLT; Trope, Liberman, & Wakslak, 2007) and the *Embodied Cognition Theory* (see, e.g., Caruana & Borghi, 2013; Dijkstra, Kaschak, & Zwaan, 2007; Gallese, 2005; Goldman & de Vignemont, 2009; Niedenthal, 2007). The first theoretical approach suggests that as the physical, temporal, social and psychological distance between an individual and an event, an object, or even a person or a group of people increases, not only the salience and perceived relevance diminish (e.g., Latané, Liu, Nowak, Bonevento, & Zheng, 1995; Latané, 1981; Williams & Bargh, 2008), but also mental representations of events, objects and other people profoundly change so that as the distance increases, the degree of abstraction of mental representations also increases (e.g., Henderson, Wakslak, Fujita, & Rohrbach, 2011). Notably, Williams et al. (2008) observed that among all of these different types of distances, physical distance is a sort of ontogenetic precursor of all of other types, "the foundation for the later-developed concept of psychological distance" (Williams & Bargh, 2008). Interestingly, this idea dovetails nicely with the evidence provided by the fMRI study by Yamakawa and colleagues (2009) presented in a previous paragraph suggesting a common neural underpinning for both psychological and physical distance representations in the parietal cortex. Moreover, in line with both the CLT and the experimental evidence provided by the present study, the previous work by Williams and Bargh (2008) had shown, through the implementation of 4 experiments, that when people are exposed to cues of physical distance these can have a moderating effect on their emotional experience, for instance by modulating the degree of emotional attachment to family members or by reducing the level of emotional distress to the vision of violent media. These results converge with the finding that physical distance can therefore also play an important role in moderating an observer's empathic reaction toward others’ pain.

According to the theories of Embodied Cognition, most of the cognitive processes depend, reflect, or are influenced by the body control systems (e.g., Caruana & Borghi, 2013). Cognition would therefore be inextricably linked to the body and to its relation with the environment, and it would not be based on abstract and amodal representations. At least three different interpretations of how embodiment might influence cognition have been proposed (see Goldman & de Vignemont, 2009). According to a first interpretation, the body anatomy itself would play a role in cognition, precisely because of the anatomical characteristics of the different body parts. A second interpretation considers how the actions produced by the body can have a deep influence on cognitive processes (e.g., Dijkstra et al., 2007; Niedenthal, 2007); for example, posture and facial expressions could influence the way people remember, discriminate between different categories of stimuli, and could even influence their emotional state. A third interpretation of embodiment, proposed and termed by Gallese (2005) *Embodied Simulation*, refers to the role that mental representations involving the body can have on cognition. This last interpretation of embodiment is strongly associated with the construct of empathy, and several authors, more or less explicitly, have suggested that embodied simulation/mirroring mechanisms are at the basis of the most automatic component of empathy (Csibra, 2008; Gallese, Migone, & Eagle, 2006; Gallese, 2003, 2008; Gallese & Goldman, 1998; Hickok, 2009; Lamm & Singer, 2010; Singer & Lamm, 2009; Uithol, van Rooij, Bekkering, & Haselager, 2011; but see also Lamm & Majdandžić, 2015). Caggiano et al., (2009) have shown the existence of a subpopulation of mirror neurons in the premotor cortex of rhesus monkeys whose activity is modulated on the basis of the spatial position in which the observed action occurs; in particular, half of these neurons are activated preferentially for the monkey’s peripersonal space while the other half is more responsive for the extrapersonal space. The authors interpreted these fascinating results by suggesting that mirror neurons (and likely, more generally, mirror mechanisms) not only constitute the neural substrate of the “understanding of *what others are doing*, but also may contribute toward selecting *how I might interact with them*” (Caggiano et al., 2009). This result could suggest that the neurally instantiated *we-centric space* (Gallese, 2003) underlying the embodied simulation − conceived as the mechanism that mediates our ability to share the meaning of actions, emotions, emotional states with others − might be sensitive to the physical distance that separates the observer and the other individual and to the space of potential interaction between the two, the so-called *interaction space*, that is the shared reaching space of the two individuals (Nguyen & Wachsmuth, 2011). These findings and observations could allow to predict that even the empathic reactions of an observer could be influenced by the distance that separates her/him from the individual experiencing a particular affective state and that these reactions might be different when the two individuals are within the space of potential interaction or not. We acknowledge that at the moment this second interpretation regarding the mechanism underlying the effect of physical distance in the modulation of empathy is certainly speculative (although intriguing) and will require further research.

Finally, I want to mention that our findings are in line with the evidence reported by Yang and colleagues (Yang, Shafai, & Oruc, 2014) that the efficiency of faces recognition, for both upright and inverted faces, varies as a function of faces size. The authors manipulated faces size between 1° and 10° of visual angle and demonstrated that only faces larger than 6° of visual angle are associated with the recruitment of specialized face processes. Additionally, while for faces smaller than 6° of visual angle (corresponding to a perceived distance of 2 m), only a quantitative difference between upright and inverted faces was observed in the recruitment of these processes, for faces larger than 6° of visual angle the difference was qualitative. The authors note that the distance of 2 m corresponds to the typical interpersonal distance in the context of conversations and social interactions. In brief, their findings support the notion that faces can be processed either through generic recognition processes or involve specialized face-sensitive processes depending on their perceived distance. Interestingly, the perceived distance of the larger faces used in our study corresponds to the upper limit indicated by Yang and colleagues. Finally, the evidence reported by Yang and colleagues also dovetails nicely with the mechanisms underlying CLT and embodied simulation as discussed in the previous paragraphs.

In conclusion, I am aware that this experiment does not create a vivid scenario in which participants perceive themselves to be close or distant from a hypothetical suffering other individual, thus a possible way to create a more ecologic situation could require implementing the same paradigm in Virtual Reality (VR) to investigate the separate and combined contribution of physical and social distance on empathic neural responses.

Chapter 8 – General Discussion

The central aim of this Thesis was to answer some central questions about how humans understand others' affective states. In particular, in this Thesis I have presented investigations that focused on the processing of facial expressions by assigning them a meaning and on how some variables are central in modulating empathic neural responses when an individual observes another individual experiencing a condition of physical pain, i.e. affective prosody and physical distance.

In order to achieve these goals, I have conducted 5 experiments. In the Experiment 1 and 2, I wanted to focus on the role of facial mimicry in facial emotion recognition by using ERPs approach. In particular, the Experiment 1 aimed at exploring the potential connection between facial mimicry and the early stage of the construction of visual percept involved in face and facial expressions processes; in the Experiment 2 I wanted to investigate whether and how facial mimicry could interact with later stages of visual processing focusing on the construction of visual working memory (VWM) representations of facial expressions of emotions, by also monitoring whether this process can depend on the degree of observers' empathy. Experiment 1 and 2 are then strongly related since they aimed both testing a functional link between the visual system and facial mimicry/sensorimotor simulation during the processing of facial expressions of emotions. These studies were based on previous behavioral evidence (Wood et al., 2016), which supported the conclusion that blocking/altering facial mimicry (through the application of facial gel) had a selective negative impact on discrimination of facial expressions. On this basis, and coherently with these results, the authors proposed a simulation model to explain how facial emotion recognition process occurs. They suggested for recognition/discrimination of others' emotions a parallel activation of the visual system (for the construction of a percept) and the simulation system (for the construction of sensorimotor and somatovisceral representation(s)) that, according to the authors, may or may not include the observer's facial mimicry, which is conceived as spillover of the sensorimotor simulation. The authors theorized that the simulation process would recursively modulate the clarity of the visual percept and would contribute to the recognition of facial expressions and the attribution of an affective state to the observed individual. However, this previous evidence is indirect and does not allow to reach these interesting conclusions with certainty. In Experiment 1, using the same experimental paradigm as Wood et al. (2016), I demonstrated that the alteration due to the presence of the gel affects the early stage of the visual percept construction. In fact, results showed a modulation of the N170 ERP component amplitude as a function of the mimicry condition. In particular, the N170 amplitude was larger for the face stimuli when participants wore the facial gel compared to when their mimicry was not blocked/altered, likely suggesting that larger visual resources have to be recruited for a correct construction of visual percepts of facial expressions when mimicry/simulation is compromised. Alternatively, the modulation of the N170 might indicate an impairment of configural processing of faces when mimicry/simulation is compromised. In both scenarios, the present work demonstrates a direct connection between the sensorimotor and the visual systems. Moreover, in the Experiment 2, I investigated whether the impact of an impairment of mimicry could be observed also on later stages of visual processing, in particular at the level of the VWM representations of facial expressions. Demonstrating an impact of the mimicry/simulation on this stage of processing is particularly relevant given the centrality of this stage in the cognitive architecture. According to the model by Wood and colleagues (2016), mimicry/simulation might act by enhancing the clarity of these representations. I then expected that under conditions of blocked/altered mimicry, VWM representations of faces would have been compromised, resulting in smaller amplitudes of the SPCN ERP component. This is exactly what I have observed, in particularly for highly empathic individuals, further supporting Wood et al.'s model (2016). The findings of Experiment 2, then, demonstrate that the specific stage of VWM is involved in this feedback processing from simulation to visual analysis. Moreover, these findings represent a progress also with regard to the studies on VWM as they provide further knowledge on how this memory system operates and on what can be the sources of input information able to modulate its functioning. Specifically, these results suggest that VWM receives the feedback of sensorimotor regions during the processing of faces and facial expressions, including also emotional information. The present results can represent a valuable progress for the definition of a simulation model for the recognition and understanding of others' emotions.

Taken together this evidence constitutes an upgrade of the previous simulation model (Wood et al. 2016). Figure 27 depicts a model aiming at clarifying the distinct stages of visual representation of facial expressions that simulation is able to influence. In brief and summarizing, I have used the ERPs technique because by virtue of its high temporal resolution was an optimal tool in order to track the hypothesized influence of mimicry/simulation on the stages of visual analysis of facial expressions. In two experiments (Experiment 1 and Experiment 2) I then demonstrated that mimicry/simulation might influence early stages of facial expressions processing, including structural encoding of faces (modulation of the N170 observed in Experiment 1), and also later stages of visual representations of those faces (modulation of the SPCN observed in Experiment 2).

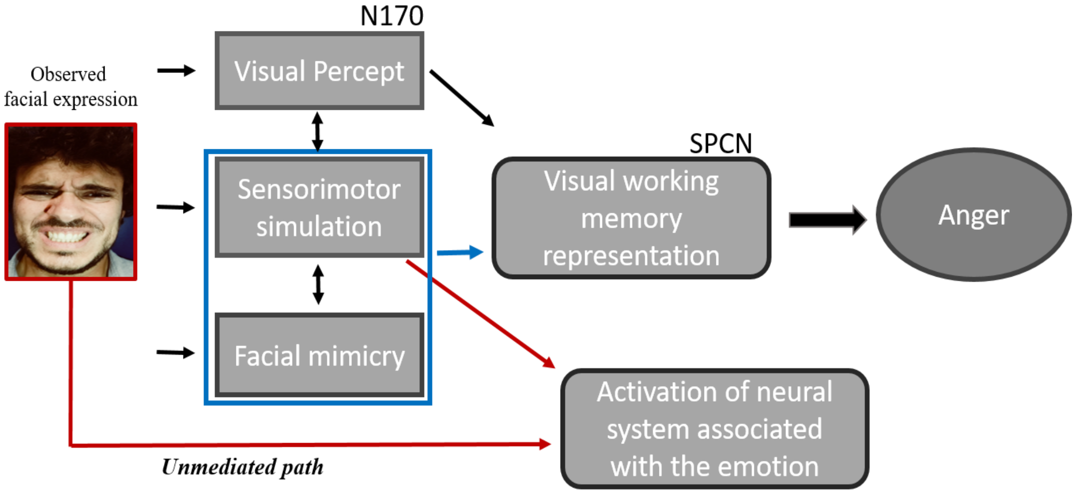


Figure 27 Simulation and recognition model of facial expression based on ERP evidence in the experiments 1 and 2 of this thesis.

In Figure 27, I propose a model, which describes how we recognize emotions by looking at another person’s facial expression according to the findings of the Experiments 1 and 2. Sensorimotor processes involved in producing a particular facial expression can trigger other components of the emotion system. This connection implies that simulating another's facial expression can fully or partially activate the associated emotion system in the brain of the perceiver. When a perceiver observes an angry face of a male expresser, this percept enables in parallel the activation of two different systems, one for the visual analysis of faces and facial expressions, and a second one for sensorimotor simulation of facial expressions and other motor control areas, which may result in facial mimicry. This latter system would trigger the activation of the emotion system that is the whole of those additional brain regions involved in the emotional processing (including the limbic areas). The combination of these processing steps, in continuous iterative interaction with each other, would allow us to understand the emotion expressed by others’ faces, assigning an affective state to the others, and possibly producing appropriate behavioural responses. According to the results of Experiment 1’ it is possible to claim in favor of a functional connection between simulation mechanisms and the visual system. Indeed, when something is disturbing the possibility to use freely facial muscles, the visual system may help by increasing its activity, as indexed by the increase of the N170 amplitude when participant wore the gel mask altering their facial mimicry.

Further, due to the Experiment 2, it was possible also to investigate a possible link between the simulation mechanism and the construction of VWM representations of facial expressions of emotions, by also monitoring whether this process can depend on the degree of empathy of the observer. Since it has been demonstrated in Experiment 2 that interfering with the simulation mechanism also affects the quality of the representation of facial expressions, it can be possible to speculate on the existence of a functional path between sensorimotor activity and visual working memory representation (although it is still possible that sensorimotor activity influences VWM *via* the visual system). Following Wood and colleague's model (2016), I supposed the existence of an unmediated path that allows to directly activate the "emotion system".

Future research could involve clinical populations with a complete or near complete, facial paralysis in order to better test the role of facial mimicry in a more ecological situation. In this regard, subjects with congenital facial paralysis constitute a particularly interesting population. Among these, the subjects with Moebius Syndrome have a congenital facial paralysis due to the underdevelopment of the seventh cranial nerve which occurs early in prenatal life (Briegel, 2006).

In the literature, studies regarding the recognition/discrimination skills of facial expressions in patients with the syndrome are few and inconsistent. In some cases it was not observed impairment compared to subjects with typical development (Bogart & Matsumoto, 2010), while in other cases a partial deficit was observed and not for all the tested patients involved (Bate, Cook, Mole, & Cole; J, 2013; Calder, Keane, Cole, Campbell, & Young, 2000; Giannini et al., 1984). However, given the rarity of the condition, it is possible that these contradictory results may depend on the small sample size, but it is also possible that the tasks used in these previous studies were not sufficiently sensitive. Or, given the fact that the syndrome is congenital, it is also possible, in a neuroconstructivist perspective, that patients with the syndrome have developed a different mechanism, neurally implemented, for the recognition/discrimination of other people's facial expressions, for example based on the Theory of Mind (see Goldaman & Sripada, 2005; Theory-Theory) or on a more sophisticated and in-depth visual analysis. The subjects with the syndrome, together with subjects who have instead acquired a facial paralysis, are certainly populations of great importance to understand more deeply the mechanisms underlying the recognition of facial expressions and the possible alternative pathways that, when mimicry is compromised, the cognitive system could follow to compensate it.

A potential future goal within this framework might be to explore whether the effect of a paralysis in congenital syndromes could cause a deficit in the ability to quantify the intensity of a specific emotion category. Indeed, it could be possible that people with congenital paralysis show the same accuracy level as a control group. In this case, another possibility is that facial mimicry may help in decoding the emotion intensity, but extremely sensitive experimental tasks are needed to be able to observe this possible small advantage. This aspect is particularly important in our daily life since it helps people to better understand other’s emotions and quantify the room of maneuver during real online interaction. Another perspective could involve people with paralysis as a consequence of a stroke or nerve damage due to injuries or diseases to study patients that did not have time to develop or enhance other compensatory mechanisms to achieve the recognition/discrimination of subtle emotions. Future studies with the goal to investigate facial mimicry should take into account the EMG recordings over corrugator supercilii and zygomaticus major (depending on emotion and muscle of interest).. Indeed, a significant limitation of these two studies (i.e. Experiment 1 and 2), which aimed at investigating the effect of facial mimicry alteration on different processing stages, is that it is not possible an estimation of the different muscle activity when participants wore the hardening gel and when they could move their facial muscles freely.

The second part of my Thesis mostly focuses on empathy as another important human skill that helps us to create interactions and connections with others that are around us. Empathy reactions may be shaped by a variety of factors already investigated in several studies, such as characteristics of the observer (Blair, 2005; Dapretto et al., 2006; Davis, 1983; Harris & Fiske, 2006; Hein, Silani, Preuschoff, Batson, & Singer, 2010; Philip et al., 2012; Wagner, Kelley, & Heatherton, 2011) or also the affective and social relationships existing between the observer and the target. Experiment 3 aimed at investigating the role of the rhythmic and intonational aspect of language in neural responses of empathy of pain. In the present study, I provided evidence that affective prosody is a powerful communication signal of others' pain by virtue of its dual-nature that conserved its evolutionary value along with human cognitive development. It enhances human ability to share others' pain by acting transversely on the two main empathy systems in two successive temporal windows. From a broader perspective, these findings may explain how harmonic interactions may survive partial or degraded information (i.e., when the speaker's words are not understandable or their facial expression is not visible) and allow powerful communication in contexts of immediate necessity, for instance, as in case of others' physical injuries.

The last Experiment (4a and 4b) aimed at studying whether the physical distance between an observer and an individual in a painful stimulation is a critical factor in modulating the magnitude of an empathic neural reaction in the observer. In this, I provided evidence that also the physical distance between an observer and another individual in a particular affective state − such that induced by physical pain − is a decisive factor for the modulation of an empathic reaction in the observer. This evidence provides an important insight into the framework of knowledge on factors capable of shaping empathy, and it is certainly important also in relation to the evidence suggesting a strong link between representations, also in neural terms, of physical and psychological distance. Further, it is important to underline that empathy and its neural underpinnings could also be modulated by the characteristics of the person who is empathizing, and his/her experience with pain (for instance it would be important to consider his/her profession). Another significant factor modulating empathy is the gender – both of the person who is empathizing and of the suffering individual. There is evidence showing (Simon, Craig, Miltner, & Rainville, 2006) an higher level of activity in the amygdala, the ACC, and in the somatosensory cortex when participants observed pain expressed on the faces of men rather than on those of women. Stronger activation was observed in the amygdala of both men and women. In our daily life, physical distance plays a fundamental role influencing our choices. An interesting study demonstrated that physical distance could influence the choice to donate; real and perceived spatial distance impact the likelihood of charitable action (Touré-Tillery & Fishbach, 2016). Although it is obvious that in everyday life situations it is not possible to establish in advance the physical distance between an observer and someone subjected to physical pain (given the unpredictability of such situations), the evidence on the importance of physical distance in modulating an empathic reaction could be fundamental for psychotherapy, clinical and medical contexts, in which psychotherapists, doctors and health professionals could use this knowledge to favor or not, as appropriate, an empathic reaction in themselves and in their patients.

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