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The role of bodily signals in facial expression recognition

A thesis submitted for the Degree of Ph.D. in the Faculty of Social Sciences at the University of Kent

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Al mio faro

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Abstract

This thesis examines the role of facial mimicry during tasks of facial emotional expression recognition. The first study examines whether facial proprioception modulates the ability to recognise facial expressions, and/or facial mimicry. Results showed that, although mimicry was detected, participants' recognition ability was not modulated by their facial proprioceptive ability. Study 2 examines whether and how the presence of contextual information that are either congruent or incongruent with emotional facial expressions modulates the accuracy of the recognition of the expression and/or facial mimicry. Study 3 has a similar method and design to the second and includes both clear-cut and low-intensity emotional facial expressions. Taken together, Studies 2 and 3 show that the ambiguity of facial expressions and/or the affective incongruence of linguistic context decreased the recognition ability of happy and angry faces.

In the fourth chapter we report two EEG-EMG studies (Study 4 and 5) aimed at examining the relationship between facial mimicry and ERPs associated with emotional processing (EPN and N400). The two studies compare the time-course of these ERPs with that of facial mimicry during a fast valence detection task (Study 4) and an explicit emotional recognition task (Study 5), to examine the interplay between cognitive processes and facial mimicry. The facial expressions used in both studies cover four levels of intensity per emotion. Study 4 involves a valence detection task of rapidly exposed emotional facial expressions. The task of Study 5 measured instead the participant's ability to recognise discrete emotional expressions. Findings from both studies are in line with the hypothesis that N400 is sensitive to the augmented demand of an emotion recognition task. The studies' findings suggest that internal simulation occurs especially in case of increased task demand and develops through a

complementary cognitive-peripheral process where mimicry responds selectively in respect to central activity.

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Chapter 1

Theories of facial expression recognition

1.1 Facial expressions

Emotions allow us to be informed about how the person we are interacting with evaluates the situation and our own behaviour, and about their future intentions (Hess & Fischer, 2014). Emotional signals motivate the others' behaviour and are aimed at the modification of the surrounding social environment (e.g. prompting approach or avoiding attitudes in the observer; Fridlund et al., 1991).

An emotional facial expression is the result of the activation of various facial muscles to create a different morphology of the visible muscular configuration of the face, which is assumed to be associated with a change of the cognitive, emotional and physiological state of the subject (such as feelings, needs, motives and intentions) in spontaneous conditions. These morphological changes of physical features of the face can involve muscles around the eyes (e.g. the frowning muscles), of the lips and mouth (e.g. pulling up or backwards the mouth corners, stretching or tightening the lips) etc. (Frank et al., 1993). Due to the strong relationship between the change of the facial expression and the inner state, it is generally believed that facial expressions are part of an adaptive function of communication of inner feelings and mental states, meant to be perceived and decoded by the observer (Adolphs, 2006; Barresi & Moore, 1996). In light of this, the other main assumption is that the information that can be extracted from a facial expression tells something reliable about the subject's internal feelings which can be used as a source of social interaction (Calvo & Nummenmaa, 2015). The cognitive process in which the perception and processing of a specific discrete arrangement of facial muscles results in the (expressed or unexpressed) assignment of a universally shared affective label is called recognition of facial expressions (Calvo & Nummenmaa, 2015).

Our visual attention tends to be drawn by the faces of other people and seeing changes in the facial muscular features has considerable attentional priority (Bindemann et al., 2005; Mack et al., 2002; Ro et al., 2001; Shelley-tremblay & Mack, 1999). A fast processing of the other's facial expressions, especially those informing of a potential danger in the environment, such as fearful faces, has a great adaptive value and is important for quick and effective social interactions. We are able to effortlessly recognise facial expressions in less than one second, even when the face is perceived without conscious awareness (i.e. under the threshold of conscious perception; Bijlstra et al., 2010). However, despite the meaningful production and recognition of emotional facial expressions is important for smoother and effective social interactions, individuals seem to differ considerably in their performance at emotion recognition tasks, especially when dealing with complex emotions (Kaminska et al., 2020). It has been showed that the perception of faces is dissociated from the capacity to understand facial expressions (e.g. Künecke et al., 2014). Therefore it seems that faces and facial expressions represent different types of visual objects and that the latter have significant priority as compared to the former because, under the same conditions of movement extent, the perception of features' movement is better and quicker perceived and retained (Wood, Rychlowska, et al., 2016).

1.2 Brief historical overview of theories of facial expression recognition

1.2.1 The first discoveries

Darwin made one of the first attempts to operationalize the link between a particular state of mind and a physical appearance of the face (e.g. after a grief 'the eyelids droop […]

the lips, cheeks, and lower jaw all sink downwards'; Darwin, 2013, page 178). Early psychologists soon became able to quantifiably appreciate the crucial communicative role of facial expressions, the informative function of which can overtake that of language (Mehrabian, 1968). Emotional recognition has been traditionally referred to as emotional *mindreading*, which is the function and ability to infer others' mental states through the observation of their behaviour. It usually allows the reader to acquire information about the expresser's feelings, beliefs, intentions, and every mental state that is considered important for that specific social interaction.

In the early '90s Simon Baron-Cohen observed that by the age of 7-9 months, humans show the ability to understand whether another person is attentive or not by observing a 'watching behaviour'. The author argued that looking consistently at an object suggests a state of attention towards that object (Baron-Cohen, 1991). These and other similar discoveries led to the formulation of the Theory of Mind (ToM) hypothesis, according to which each individual assumes the existence of a mind in other people. This assumption lays at the basis of our existence as conscious humans and constitutes the main condition of social interaction. Due to the ToM, everyone is able to consider the others as owners of unobservable mental states such as beliefs, intentions, emotions, desires etc. In other words, the ToM allows one to assume that others have a similar mind to their own and therefore similar mental contents (Leslie, 1987).

As mentioned earlier, it is believed that the ToM is critical for the development of proper social interactions as it represents the psychological basis of *mindreading* (Premack & Wooclryff, 1978). The ToM allows us to interpret and observe behaviour, ensuring the constant possibility of understanding the world surrounding us, which is primarily represented by the intentions and purposes of others. A second function that the ToM ensures, is the possibility to formulate prediction of others' behaviour (Churchland, 1991). Most of the research on this topic has been about the ToM development in childhood. The majority of works on this field has been focused on children's false beliefs (Asakura & Inui, 2016). A great number of studies have shown that children begin to understand other's false beliefs at around 4-5 years old. The development of this line of research has highlighted the progressive nature of this cognitive change (Wellman et al., 2006).

In the attempt of trying to explain how exactly the ToM develops, two main theories investigated its application on developmental and cognitive psychology: the Theory-theory (Gopnik & Wellman, 1992) and the ST (Gallese & Goldman, 1998).

1.2.2 The Theory-theories

The predominant view regarding how *mindreading* exactly operates until little more than two decades ago was the Theory-theory. This theory posits that individuals base their understanding of the outside world on folk psychology, which allows them to rely on an array of notions 'roughly adequate to the demands of everyday life' (Churchland, 1991, p. 51). In the traditional, as well as most popular, model of this theory, accounts regarding the others' behaviour result from a series of laws that associate the observed behaviour with a conceptual explanation of it (Gopnik & Wellman, 1992; Wellman, 1990). Though there is little consensus about the nature of these rules, it seems that Theory-theorists agree regarding the existence of tacit or implicit laws. According to such authors, there is a body of implicit knowledge constituted by general rule-like notions that support each assumption made (Churchland, 1991). The word 'Theory' refers to the fact that these laws are abstract and generally applicable. Examples of general Theory-theory principles are 'people seek things they desire; people act according to their beliefs, not objective reality; people are unhappy when their desires are not fulfilled' (Apperly, 2008, page 269). According to the Theory-theory, to understand someone else's inner state one cannot simply generalise relying on their previous experiences (e.g. associating a certain manifest behaviour with a situation, if these have been experienced together most of the times, such as being annoyed during a long queue). Indeed, we also have to operate a process of translation from a level of communication to another. Thus, during a *mindreading* attempt, the observation (e.g. the facial muscular configuration of complaint) becomes a concept (e.g. an expression of complaint). In light of this, according to this theory, our understanding of others inner states relates to interpretations based on common sense or 'folk psychology'. The explanation as well as prediction of our and others' behaviour is gained through a process of attribution of intentions resulting from an inference based on a series of information about the target (Goldman & Sripada, 2005; Ratcliffe, 2006). According to Ratcliffe and colleagues, such attribution of intentions operates when 'self' and 'other' form a unique-coupled system. Therefore, they suggest that, no matter how close or detached is the perspective-taking, *mindreading* is an interactive process (Ratcliffe, 2006).

This theory posits that there is a complete detachment from the behaviour observed, as the understanding process leads to a pure linguistic explicative and predictive concept (e.g. the hypothesis of an emotion, need, desire, belief etc.). It follows that each derived representational construct can be misleading or incorrect, in which case the behaviour must be reinterpreted. Importantly, this process is applied to others as well as oneself.

According to some authors, the capacity to rely on this folk psychology is innate (e.g. Gordon, 1986); according to others, such as Gopnik and Wellman (1992), the capacity of *mindreading* develops until it reaches a proper 'representational understanding' capacity.

Specifically, early on the child would be capable only of 'non-representational understanding of mind' regarding 'desire-perception states'; later he/she would develop a broader and more comprehensive understanding of many aspects of perception and desire (Gopnik & Wellman, 1992). According to Gopnik, children become more and more aware of abstract and logical causal rules that represent actual theories that allow them to interpret and make prediction of new evidence from the other's behaviour. Thus, children continuously explore their environment examining and testing their facts in light of their theory.

1.2.3 The simulation theories

The discovery of single cells in the macaque's region F5 (the correspondent of the premotor cortex in humans) firing both during the performance and observation of certain kind of actions (di Pellegrino et al., 1992), led researchers to investigate the possible interconnection between perception and inner experience of same states of mind. Between the late '80s and the early '90s, philosophers of the mind and developmental scientists such as Gordon, Gallese and Goldman (Gallese & Goldman, 1998; Gordon, 1986) introduced the Simulation Theory (ST) as an explanation and prediction model of the human ability of *mindreading*. The ST was presented as a general wide-spectrum model suggesting that Mirror Neurons (MNs) would support a mirror system that sustains the understanding not only of others' actions and intentions, but also of others' states of mind. This mirror system would perform a simulation of another's intentions or state of mind sustaining certain aspects of social interaction (Enticott et al., 2008). In other words, ST takes into account the physiological and biological events occurring while people understand other people's behaviour and emotions. The nature in between perception and action of the MNs, and the evidence of the involvement of the premotor areas during *mindreading* (Carr et al., 2003;

Winkielman et al., 2009), led these authors to propose the existence of a mechanism in which both MNs and folk psychology are activated. More specifically. MNs activate both when an action is observed and when the same action is performed and typically respond during a goal-directed action (e.g. grasping). Similar discoveries have also been found in humans. Importantly, a study by Fadiga and colleagues (Fadiga et al., 1995) demonstrated that the neuronal activity in the observer increases only in brain areas controlling those muscles that would be involved in the same movement. Therefore, in light of these findings, imitation seems to be crucial to endorse social information processing. Since the activation of MNs aims at imitating someone else's goal-directed movements, it has been suggested that it also enables the observer to anticipate and, therefore, understand the others' intentions (Gallese & Goldman, 1998). Similar hypotheses have been suggested in the domain of emotional facial expressions (e.g. happy or sad faces). Specifically, it has been proposed that there is a correspondence between the activations of facial muscles and neural areas in the expresser and the observer (Carr et al., 2003; Wicker et al., 2003). These findings led to the suggestion that the perception of others displaying a feeling or an emotion, triggers an affective as well as sensorial *echo* in the observer that is aimed at understanding that emotion (Avenanti et al., 2006; Singer et al., 2004). It has been proposed that MNs are responsible for the correct development of social cognition and social interaction abilities such as empathy, and for the processing of one's own and other's emotions (Gallese, 2001; Gallese & Goldman, 1998; Pelphrey & Morris, 2006; Uddin et al., 2007).

A consistent amount of studies conducted on clinical and neuropsychological patients with social cognition deficits (e.g. autism) shows a reduction of MNs activation (Hadjikhani et al., 2006; Oberman et al., 2005), and a correlation between the severity of the symptoms and MNs reduced activation (Dapretto et al., 2006). It has also been showed that the processing of emotionally salient faces was associated with MNs activation (Enticott et al., 2008). The ST hypothesis represents a great step away from folk psychology as, according to this point of view, understanding others' emotions does not only stem from a cognitive inference, but also from a sensorimotor involvement in the body of the observer.

The ST was soon consolidated and there was a growth in the number of studies trying to investigate and corroborate its assumptions. Philosophers of the mind differentiated ST from the *mindreading*-based Theory-Theory (Apperly, 2008; Harris, 1992) on the basis of the intrinsic substantial dissimilarity of their main assumptions. Specifically, the Theory-theory, as a semantical information-based approach, argues that the *mindreading* process takes place through the attribution of psychological concepts acquired a priori (e.g. desire) and organizing principles of these concepts (e.g. people's actions are usually driven by their desires); on the other hand, the SM proposes that there is a sensorimotor function that helps an ongoing interpretation of others' mental states. Indeed, the SM is based on the assumption that, in some or most of the cases, there is a part in the process of *mindreading* that relies on the emotional and sensorial similarities of the reader and the mind being read. Therefore, some of the work performed in the attempt to achieve the reading must be done using one's own mind as a reference point, assuming that the same feelings have the same emotional-sensorimotor groundings (Apperly, 2008). According to the simulationists, relying on simulation using your own mind as a model would spare effort as well as time to the whole process. Moreover, ST's theorists consider dubious, from a phylogenetic and ontogenetic point of view, that our ability to understand others' behaviour only depends on a comprehensive philosophy of causes of inner conditions (Apperly, 2008).

The basic hypothesis of simulationist theorists is that MNs activity during emotional *mindreading* provides the observer with an internal re-enactment of the emotion perceived. This would hint at the experience of that emotion and would deliver a bodily (peripheral) feedback that helps and interacts with high-level cognitive operation (Gallese & Goldman, 1998).

1.2.4 Models of the Simulation Theory of emotion recognition

STs of emotion recognition arise among embodied cognition theories and suggest that one of the functions that sustain the process of the recognition of other’s emotions is conveyed by an internal automatic and unintentional simulation of the emotional state observed. Such simulation leads to a subsequent attribution of an emotional label to the target emotion (Heberlein & Atkinson, 2009). Embodied cognition theories generally posit that ongoing bodily sensorial and motor activations during a high-level cognitive task play a decisive role for the correct development of that task (Borghi & Cimatti, 2010). Similar to other embodiment theories, ST highlights the critical role of the ongoing body reaction to the perceived emotional stimuli, which is treated as a source of information as well as the mnemonic and semantic elements associated to the stimuli themselves (Niedenthal et al., 2005). All the STs base their assumption on the existence of shared or, at least, highly overlapping neural substrates supporting both the emotion’s perception and experience (Grèzes & Decety, 2001). A consistent amount of studies seem to corroborate this assumption showing how the activity of the amygdala changes according to the facial expression presented (Hasselmo et al., 1989). It has also been demonstrated that disruptions to the amygdala weakens the perception and understanding of facial expressions (Adolphs et al., 1994).

The basic hypothesis of STs is that the observer attributes a mental state after having tried to re-enact internally the same state (Rizzolatti et al., 2001). A way to implement this is with the attributor directly assigning a mental state after having replicated it or the presumed process that leads to that mental state. Another way is with the attributor selecting the mental state that matches the most the internal psycho-physiological outcome after a series of re-enactments (Goldman & Sripada, 2005). This second process would be characterized by a potential series of simulation attempts the upshot of which is likely to be similar to that observed. The one which is considered most alike to the observed behaviour is then designated and ascribed.

Importantly, some simulationist theorists, such as Gordon, argue that the simulation process still entails some semantic information, represented by the attribution of a semantic label at the end of the recognition process (Gordon, 1996). But whilst in the Theory-theory the only source of information is what is perceived externally, in the ST the observer has two sources of information: the other and one's own cognitive-body state. Goldman and Sripada (Goldman & Sripada, 2005) highlight the importance of making clear that the simulated state of mind does not account to a real state of mind but 'something like a token or facsimile of a mental state in [the observers'] own mind' (p. 198). The authors traced a summary of the various models that explore the functional mechanism of simulation. Basing their review on the literature on paired deficits (which will be discussed in more detail below, in Section 1.3), the authors proposed and discussed possible operative mechanism models of ST able to account for the findings (Goldman & Sripada, 2005). These models are more focused on emotional facial expression recognition and they will be addressed here as they have been conceived and proposed. ST models mainly account for the facilitating role of ongoing reactions of the whole body during the emotion *mindreading* process. Goldman and Sripada describe four different models which will be briefly considered below: the generate-and-test model, the reverse simulation model, the reverse simulation with 'as if' loop and the unmediated resonance model.

1.2.4.1 Generate-and-test model

The Generate-And-Test Model arises from the attempt to interpret the paired deficit findings on neuropsychological subjects. It considers the sequential display of two main stages during the process of face-based emotional understanding: the generation of a potential target emotion and the matching check with the observed emotion. After the visual acquisition of the facial expression, the observer hypothesises a target emotion that could match the one perceived. This hypothesis becomes an internal and covert re-enactment at a central and (potentially) peripheral level. '[The observer] lets this facsimile (or pretend) emotion run its typical course, which includes the production of its natural facial expression, or at least a neural instruction to the facial musculature to construct the relevant expression' (Goldman & Sripada, 2005, page 202). The object of this simulation (and of the observer's proprioception if a facial expression is generated at a peripheral level) is then compared with the object of visual perception. If the system recognizes a match between simulation and perception, that emotion is then considered the target emotion and attributed to the observed individual. Importantly, the observer compares a mere visual perception (with no semantic information associated to it whatsoever) with a mere bodily and facial proprioceptive state that replicates what the observer would feel if the hypothesised emotion was real. That said, the exact mechanism that rules such comparison is not clearly exposed. Regarding the generation stage, it could either be a trial-and-error method with a series of emotions covertly re-enacted before the selection of a target emotion, or it is a higher level cognition-guided process in which the emotion tested is suggested by a theoretical filter (presumably powered by information already stored about the expresser and the situation). This last proposal has led the authors to consider this model as not fully simulationist and closer to hybrid theories (discussed in 1.2.5 below).

1.2.4.2 Reverse Simulation model

The Reverse Simulation Model considers the facial physiological reactions occurring during the *mindreading* process as a crucial factor. Specifically, while in the Generate-and-Test model the peripheral activation was only the outcome of a cognitive mediated hypothesis, this model focuses on the spontaneous and rapid reflex-like reproduction in the observer's face of the facial expression perceived (facial *mimicry*; (U. Dimberg, 1982; L. Lundqvist, 1995). Such mimicry occurs without any high-level cognitive mediation. This model claims that the nature of the simulation process is intrinsic and purely embodied, and conceives facial mimicry of the target emotion as essential for the correct functioning of the recognition process before any high-level cognitive assistance. If the emotion visualized and the emotion felt through facial mimicry seem to match, the target emotion is assigned. This latest aspect is similar to what happens according to the Generate-and-Test model. Importantly, facial mimicry tends to be very subtle and reduced in intensity compared to the original facial expression. Therefore, according to this model, the observer experiences the emotion mimicked and then judges whether the perceived face muscles configuration belongs to the same category of their own facial muscles' configuration. Consequently, the mediation of the observer's facial proprioception has a critical role as it ensures a proper simulation. In this way, not only the peripheral facial activation is crucial, but also the activation of the facial proprioceptive centres (i.e. parietal somatosensory regions). This model therefore hypothesises that not only the activation of facial mimicry, but also one's levels of proprioception, predict facial expressions recognition abilities. This hypothesis will be discussed further and investigated in Chapter 2.

1.2.4.3 Reverse Simulation with ‘As If’ Loop model

The Reverse Simulation With ‘As If’ Loop postulated by Adolphs, Damasio, Tranel and Cooper (Adolphs et al., 2000; Damasio, 1994) posits that the ‘as if’ loop theorised in the reverse simulation model does not occur with the mediation of facial mimicry, but with a central cognitive somatosensory representation of a plausibly similar emotion to the one observed. For this model, as soon as the visual perception of the facial expression is acquired, a somatosensory simulation is triggered. Such internal simulation allows the mind-reader to have a sensorial concept-free suggestion of the bodily experience that the observed person might have, which is then linked to a semantic classification. Similar to what is theorised in all ST models, if the semantic emotion label is approved as the target emotion, it is then attributed to the expresser.

1.2.4.4 Unmediated Resonance model

The fourth model described by Goldman and Sripada is the Unmediated Resonance Model. This model is explicitly influenced by the discoveries of the mirror neurons during the observation of someone else’s motor behaviour (Gallese et al., 1996; Rizzolatti et al., 2001). According to this model, the understanding of face-based emotions occurs through the activation of the same neural substrate supporting the emotion observed and through an actual emotional contagion (Preston & Waal, 2017). The visual perception of the expression would instantly elicit the neural circuits associated to the emotion suggested by that given expression, without any mediation of peripheral muscular activations and without a reproduction of a facsimile that hints at the target emotion. Thus, in this model there is no simulation, but simply a somatosensorial echo of the original observed emotion. The resonance is then semantically categorized, as in the case of the mediated models. Goldman and Sripada (2005) highlight that it is questionable that this model can be classified as a genuine simulation model, in light of the fact that there is no simulation occurring during the recognition process. However, they suggest that as long as the model sees the target emotion as the ‘result of the attributor’s instantiating, undergoing, or experiencing, that very state’, it could be treated as a simulation theorization.

1.2.5 Mixed theories: a compromise between the Theory-theory and the Simulation Theory models

Until now, both high-level cognitive-based and simulation-based emotion recognition theories have received support from research evidence. This has led some authors to postulate the action of mechanisms involving both simulation and theory processing. Goldman*,* for example, highlights that *mindreading* refers to the act of inferring the mental state of someone else rather than a behaviour, and therefore the object of the simulation is merely conceptual (i.e. the observer thinks about a concept that describes someone else’s mental and\or emotional state; Goldman, 2009). The author also distinguishes between ‘low-level simulation’ which is, supposedly, the sensorimotor mirroring and ‘high-level simulation’ involving the imagination of semantic attributes.

1.2.6 Section summary

Emotional recognition (or *mindreading*) is the function and ability to infer others’ affective mental states through the observation of their behaviour. It usually allows the reader to acquire information about the expresser’s feelings, beliefs, intentions and every affective mental state that is considered important for that specific social interaction.

The ToM hypothesis postulates that *mindreading* is based on the innate assumption that each individual relies on the existence of a mind in other people which is similar to their own. This belief allows individuals to put themselves into another's shoes, to interpret and observe behaviour, to understand intentions and purposes of others (Baron-Cohen, 1991; Churchland, 1991; Leslie, 1987). In the attempt to explain how exactly the ToM develops, two main theories investigated its application on developmental and cognitive psychology: the Theory-theory (Gopnik & Wellman, 1992) and the ST (Gallese & Goldman, 1998).

The Theory-theory posits that individuals base their understanding of the outside world on folk psychology which allows them to count on a body of implicit knowledge constituted by general rule-like notions that support each assumption made (Churchland, 1991).

Led by the discovery of mirror neurons scientists such as Gordon, Gallese and Goldman (Gallese & Goldman, 1998; Gordon, 1986), introduced the ST which suggests that Mirror Neurons (MNs) support a mirror system that sustains the understanding of other people's behaviour and emotions. The basic hypothesis of simulationists is that MNs activity during emotional *mindreading* provides the observer with an internal reproduction of the emotion perceived. This would hint at the experience of that emotion and would deliver a bodily (peripheral) feedback that helps and interacts with high-level cognitive operation (Gallese & Goldman, 1998).

The following section will discuss the evidence that critically shaped the theoretical discourse on STs. More specifically, I will discuss findings on facial mirroring and how its effect might be crucial for the simulation process.

1.3 An evaluation of the simulation theories of emotional facial expression recognition. Is facial mimicry crucial for the simulation process?

It has been suggested that the recognition of emotional facial expressions might have a specific adaptive value, presumably more important than other kinds of social cognition: '[…] it is conceivable that specialized programs have evolved for the recognition of emotions, and these specialized programs may not operate in other *mindreading* tasks' (Goldman & Sripada, 2005, page 195). The processes linked to face-based emotion recognition have been so far investigated as a *mindreading* function *per se* and represent one of the most examined branch of emotion recognition.

As illustrated above, in the Theory-theory argumentation it is presumed that in front of a facial expression, one assigns an emotion label among a series of representations of particular facial configurations (Goldman & Sripada, 2005). Regardless of the specific model, a Theory-theory-conceived procedure is presumed to develop from an initial visual acquisition of the facial muscle configuration, which in turn induces the activation of the semantic association between that facial configuration and a related emotion label, ending with the activation of the semantic knowledge associated with the emotion.

On the other hand, according to an ST argumentation, the understanding of the facial expression would be attained through an ongoing attempt to produce the very same state in the observer's sensorimotor and/or emotional systems. Both central and peripheral mechanisms are considered to be involved in simulation processes; these will be reviewed below.

1.3.1 Central mechanisms

A consistent corpus of evidence in favour or ST models comes from the observation of ‘paired-deficits’ in neuropsychological patients: patients with damage to emotion-related areas (e.g. bilateral amygdala disruption) who show impaired experience of emotions in response to stimuli that trigger autonomic-reaction also show abnormal recognition of the same emotions, especially fear, disgust and anger (Adolphs et al., 1994, 1999; Adolphs, 2002; Goldman & Sripada, 2005; Lawrence et al., 2007; Phillips et al., 1997, 1998). There is also evidence of an overlap between the experience and the recognition of emotions in healthy individuals: fMRI studies showed that during the perception of faces displaying specific emotional states, the neural areas known to be active during the experience of those state show increased activation (Phillips et al., 1997, 1998; Wicker et al., 2003). In line with ST models, there is also the anatomical evidence of the somatosensory cortex that directly projects into the motor cortex and has secondary projections to the promotor cortex (Borich et al., 2015). Studies showed that during perception of facial expressions, neural activation patterns in the somatosensory cortex of the observer allow to predict the category the observed emotion belongs to (Kragel & LaBar, 2016). This suggests that, as predicted by the ST, the neural substrates of emotion perception and experience overlap to a great extent (see Goldman & Sripada, 2005 for a review). Accordingly, a study by Adolphs and colleagues (2000) has shown that patients with right parietal lesions (i.e. somatosensory areas supporting body and facial proprioception) displayed weakened face-based emotion recognition (Adolphs et al., 2000).

1.3.2 Peripheral mechanisms

Beside the paired-deficits data, which provide evidence for the role of central simulation mechanisms in the recognition of emotions from facial expressions, studies over the last 30 years have also consistently reported the observation of *facial mimicry* in reaction to the perception of emotional facial expressions (U. Dimberg, 1982). Through the use of electromyography, studies have reported that during the observation of facial expressions there are clear activations in the observer's face of the same muscles involved in the production of the perceived emotional facial expression (e.g., Dimberg, 1982, 1990). Thus, for example, the exposure to happy faces increases the activation of the *zygomaticus major* muscle, and the exposure to angry faces increases the activation of the *corrugator supercilii* muscle, as 'the zygomaticus muscle elevates the lips to form a smile, whereas the corrugator muscle knits the eyebrows during a frown' (Dimberg et al., 2000, page 86). These reactions have been detected by EMG recordings on the observer's face as soon as 300 ms after the picture onset (Dimberg et al., 2000; Künecke et al., 2014). Therefore, facial muscles' activation in response to observed facial emotional expressions occurs covertly without any voluntary attentive demand or consciousness (Korb et al., 2010; Krumhuber et al., 2014; Schneider & Shiffrin, 1977). The mimicry not only occurs after the explicit exposure to emotional faces, but also during implicit presentations, namely when the picture appears too fast (e.g. 30 ms) to be consciously perceived (Dimberg et al., 2000). Specifically, it has been demonstrated that people react to happy and angry faces by mimicking those expressions as unconscious and spontaneous reactions to a priming-like timing exposure to pictures. It has also been shown that such spontaneous reaction cannot be inhibited, as it is manifested even when subjects were instructed to suppress it (Dimberg et al., 2002; Korb et al., 2010). Moreover, mimicry occurs even when the facial expression is not relevant to the task (Lee et al., 2008), and it is present even in new-borns (Field et al., 1982; Meltzoff & Moore, 1989). These findings suggest that facial mimicry is an automatic reflex-like reaction.

There is a considerable corpus of research showing that increased facial mimicry during the exposure to a specific facial expression is associated with better recognition of that expression's meaning, intensity, valence and intention (Hyniewska & Sato, 2015; Korb et al., 2014; Ku¨ necke et al., 2014; Lobmaier & Fischer, 2015; Rychlowska et al., 2014). The link between the movement as well as, presumably, the perception of one's own facial muscles (proprioception) and the perception of one's own emotions and feelings has been widely demonstrated. Studies on women that undergo the botulinum procedure for cosmetic purposes have also provided supporting evidence. Botulinum injections paralyze muscles, particularly those involved in the production of facial expressions (e.g. the *corrugator supercilii* or the *orbicularis orii*). After botulinum injection, participants in these studies experienced less depressive symptoms and reacted less to emotionally negative stimuli (Davis et al., 2010; Finzi & Rosenthal, 2014; Wollmer et al., 2012), and showed weakened amygdala activity during the voluntary production of a facial expressions (Hennenlotter et al., 2009). Moreover, and more relevant to the simulationist hypotheses, participants undergoing botulinum treatment show impaired emotion recognition ability (Lewis, 2018; Shafiee, Sedighi & Sherafat, 2018; Paracampo et al., 2016) and an decreased ability to detect gradual changes in facial emotion (Bulnes, Marien, Vandekerckhove & Cleeremans, 2019). In line with this evidence, research on patients with bilateral or unilateral facial paralysis showed a correspondence between depressive symptoms and the blockage of smiling muscles (i.e. *zygomaticus*) (VanSwearingen et al., 1999) and abnormal perception of dynamic asymmetrical facial expression (Wood et al., 2016).

All these findings have mostly been interpreted in light of the observations of MNs (Gallese & Goldman, 1998) and considered as supporting the idea of overlapping neural substrates of action and perception. It has been proposed that the perception-behaviour link is due to shared schemas (Chartrand & Bargh, 1999; Preston & Waal, 2017), or shared representations (Barresi & Moore, 1996), or 'spreading activation' (Hess & Fischer, 2014; Prinz, 1997) between the observer and the expresser.

It has also been shown that manipulations interfering with mimicry are associated with the disruption of recognition of facial expressions (Oberman et al., 2007; Ponari et al., 2012). Hess and Fischer defined such perception-behaviour link that has been found in the literature on facial mimicry, as the Matched Motor Hypothesis (MMH). The MMH describes the process whereby 'merely perceiving a specific non-verbal display automatically entrains the same expression in the perceiver' (Hess & Fischer, 2014, page 48).

Importantly, facial expression recognition seems to be affected, not only by the blockage of the 'motor output' from facial muscles, but also by the disruption to the subject's proprioception and/or interoception. For instance, Adolphs and collaborators (2000) found that the region of largest overlap in a sample of brain-damaged patients who were impaired at recognising facial expressions comprised the primary and secondary somatosensory cortices (S1 and S2); similarly, studies on healthy volunteers showed that transcranial magnetic stimulation (TMS) to S1 lengthen facial expression recognition reaction times (Pourtois et al., 2004) and disrupted the ability to match faces based on their emotional facial expression (Pitcher et al., 2008). Interestingly, similar results were found for recognition of emotional non-verbal vocal expressions (Banissy et al., 2010). Moreover, it has been shown that patients with damage to the insula, a cortical structure considered to be the processing centre of somato-visceral sensations, show impaired recognition rates of a variety of emotional facial expressions (Terasawa et al., 2015).

However, and conversely, some studies show a lack of correspondence between mimicry and better recognition of facial expressions (e.g., Blairy et al., 1999; Hessa & Blairy, 2001). Moreover, a study by Calder and colleagues showed that three people with Möbius syndrome, a congenital disorder that causes facial paralysis, were able to consistently identify the six basic emotions (e.g. happiness, sadness, anger, fear, disgust, and surprise) and many morphed facial expressions (Calder et al., 2000). Similar findings have been reported by Keillor and colleagues whose study shows that a patient with bilateral facial paralysis has a normal experience of emotions and a normal ability to detect and recognize facial expressions (Keillor et al., 2002). These studies show that the detection and identification of emotions is possible without the help of a sensorimotor simulation, and indeed even in correspondence of disrupted production of the same emotions in the observer.

Hess and Fischer (2014) have pointed to weaknesses in most of the research carried out on mimicry and they propose two main functions of mimicry: affiliative and subtle emotion decoding. Regarding the first point, the authors have argued that research on mimicry conducted so far exhibits a series of intrinsic weaknesses or untheorized assumptions. Specifically, according to the authors, pictures of smiling, angry, sad or fearful faces cannot provide us with a measure for the mimicry of discrete emotions, but only of their general valence. This assumption is consistent with findings showing that increased activation of the zygomaticus muscle is associated with positive valence ratings, while increased activation of the corrugator is associated with negative valence ratings (Hess & Fischer, 2014; Hess & Fischer, 2013; Larsen et al., 2003). Therefore, researchers cannot conclude that the observation of mimicry indicates the occurrence of a simulation process. Mimicry is instead, in their view, likely to represent a mere emotional contagion.

Secondly, they argue that the occurrence of mimicry and the changes in its intensity serve affiliative purposes. Thus, emotions conveying negative feelings, such as anger, fear, sadness or contempt, are less likely to be mimicked, whereas emotions conveying feelings of affiliation are more likely to be mimicked. In this view, the authors argue that the mimicry consistently observed in response to angry faces is instead a report of emotional contagion. Thirdly, in line with the previous assumption that mimicry facilitates affiliation feelings, they argue that individuals are more likely to mimic the emotions displayed by their in-group members. Fourthly, according to the authors, mimicry is not an automatic simulation, but is rather determined by a mentalization causing the motor reaction. Thus, sensorimotor simulation is not automatic and supporting the mentalization, but on the contrary, it is the mentalization that leads to a motor reaction (Hess & Fischer, 2014).

Hess and Fischer (2014) have therefore proposed a new model for the function of mimicry. These authors define facial mimicry as the event in which two non-verbal time-locked and co-occurring emotional expressions match each other, with one display being dependent on the other and with the dependent display being ‘a sharing of the original emotional display, rather than a reaction to the original display’ (Hess & Fischer, 2014, page 46). They also highlight the difference between emotional facial mimicry, emotional contagion and affective empathy (Hess & Fischer, 2014). In their view, facial mimicry can only occur when the observer is affectively affiliate to the expresser, and thus only when the observer already knows the reasons that caused the expresser’s emotion. Under this model, mimicry reflects the observer’s understanding and sharing of the expresser’s emotional state. This means that, in Hess and Fischer’s view, the picture-paradigms in which the observer’s mimicry is measured during exposure to pictures of facial expressions, are incapable of determining whether the EMG activation is the product of an affective sharing or simply of an individual’s reaction to positive or negative stimuli. Indeed, the authors propose that this phenomenon is more likely to be an emotional contagion rather than mimicry. On the other hand, the authors define affective empathy as the process in which the observer engages or tries to engage with the expresser's emotional state in the attempt to recreate the same state, or a mild facsimile, that allows them to feel together with the expresser. Therefore, the main difference between mimicry and empathy is that the former involves a congruent reproduction of the observed emotion while empathy does not. Hess and Fischer's statements imply that every time there is mimicry, there already is an underlying understanding of the emotion observed. If, however, mimicry occurs during a process of affective empathy, the emotion internally recalled is congruent with the one observed. Consequently, an empathic engagement is required during every simulation process, but measurable facial mimicry only occurs when there is an explicit and intentional emotional understanding. As a consequence, according to the authors, mimicry never reflects an implicit emotional understanding even if - as most of the STs mentioned above postulate - it occurs automatically as a results of a visually triggered sensorimotor activation (Goldman & Sripada, 2005).

The significance of the observer's facial reaction, whether reflecting motor mimicry or valence-based emotional contagion, is however still widely debated. For example, a recent study by Wingenbach and colleagues (2020) reported that participants observing both basic emotion and complex emotion, produced very distinct patterns of facial muscle activation in response to a variety of basic and complex emotions, suggesting that mimicry does not only mirror emotions' valence, as it was postulated by Hess and Fisher (2014), but it is rather emotion-specific. In particular, congruent emotion-specific mimicry was measured during exposure to happiness, fear, sadness, disgust and surprise, and also in response to pride and embarrassment. Such result is in contrast with Hess and Fisher's theorization as mimicry has proved to be a simulation of discrete emotions and therefore sensible to single affective displays.

Wood and colleagues (2016) proposed a further model that accounts for the mechanism of sensorimotor simulation during facial expression recognition. The authors argue that the simulation process cannot commit the same amount of attentive and sensorimotor resources to all the cases of emotion mindreading. According to this model, face-based emotion recognition tends to follow the principle of cognitive energy saving, that is the emotion appraisal is an attentional limited cognitive process and therefore if the simulation arises, it cannot allocate the same amount of sensorimotor resources to all attempts of emotion reading. Embracing this assumption, easily primes to deduct that facial mimicry reactions are not always essential.

In this way, facial mimicry is not always crucial during the recognition process. The likelihood of its occurrence and its intensity are proportional to the reader's motivation to read that emotion as well as to the ambiguity of the emotion and the context. Their assumptions have been prompted by evidence of mimicry occurring more often when the reader looked the expresser in the eye (Rychlowska et al., 2012). In this model, facial mimicry is not a core factor or step of sensorimotor simulation, but simply a supplementary aide that enhances the effectiveness of the simulation process only when the understanding process is not straightforward (e.g. with ambiguous expressions, when the context does not provide enough information). Even without the occurrence of facial mimicry, simulation still occurs centrally in sensorimotor and emotional areas, and therefore measuring the intensity of the zygomaticus and corrugator muscles activity during facial expression recognition tasks does not provide a measure of the extent of the simulation. Specifically, in this model the visual perception of the emotion triggers the sensorimotor areas of the face (which may or may not result in measurable facial mimicry) which in turn activate areas involved in the experience of the emotion perceived, producing a partial activation of that emotion. This partial activation allows the explicit or implicit (i.e. without conscious awareness) recognition of the emotion. Once the emotion is inferred, semantic knowledge associated to that emotion may be involved to complete the emotion recognition. In this system, the visual, motor, premotor, somatosensory and limbic areas' may be recursively engaged, until the simulation allows for the inference of an emotion.

In light of these recent theories and findings, mimicry seems therefore to support a partial simulation, whereby both sensory and motor aspects are involved in an embodied representation of emotions.

1.3.3 Section summary

The processes linked to emotional facial expression recognition have been traditionally investigated as a *mindreading* function *per se* and represent one of the most examined branch of emotion recognition. Theory-theory-conceived models assume that recognition of facial expressions develop from an initial visual acquisition of the facial muscle configuration, which in turn induces the activation of a semantic representation of the emotion and an emotional label. STs adopt the hypothesis of a sensorimotor reproduction of the very same state in the observer's sensorimotor and/or emotional systems.

Many studies have reported that during the observation of facial expressions, the same muscles involved in the production of that expression, activate automatically in the observer's face (e.g., Dimberg, 1982, 1990). Such facial mimicry has been often associated with better facial expression recognition (Hyniewska & Sato, 2015; Korb et al., 2010, 2014; Ku¨ necke et al., 2014; Lobmaier & Fischer, 2015; Rychlowska et al., 2014) and the blockage of mimicry is associated with the disruption of recognition of facial expressions (Ponari et al., 2012; Oberman et al., 2007).

However, the occurrence of mimicry and its role in the recognition process is still debated. Hess and Fischer (2014) propose that mimicry does not represent a sensorimotor simulation of discrete emotions, but it is, rather, valence-specific; they also argue that mimicry is activated by affiliative feelings only, so mimicry observed in response to angry faces probably reflects emotional contagion. Finally, they suggest that the mentalization causes mimicry, and not *vice versa* (Hess, & Fischer, 2014). Similarly, Wood and colleagues (Wood et al., 2016) proposed that facial mimicry is not crucial for the recognition process and it occurs only with the reader's motivation or when the expression is difficult to understand, for instance when the context or the facial percept don't provide enough information on their own. In the following chapters, I will try to address some of these issues, for example by looking at the role of contextual information in Chapter 3, and at the interplay between semantic processing and facial mimicry in a variety of tasks and with faces varying in intensity, in Chapter 4.

1.4 Conclusions

ST models account for the facilitating role of sensorimotor simulations during emotion *mindreading* process. Until now, both purely semantic-based and simulation-based emotion recognition theories have received support from research evidence. This has led some authors to postulate the action of mechanisms involving both sensorimotor simulation and theory-theory processing.

A substantial amount of research has shown a link between production and recognition of emotional facial expressions(e.g., Adolphs, 2002; Adolphs et al., 1994, 1999; Goldman & Sripada, 2005; Lawrence et al., 2007; Phillips et al., 1997, 1998). Moreover, impaired functioning of the autonomic nervous system has been shown on patients with emotion-related damaged areas and patients with lesions on the somatosensory areas displayed weakened face-based emotion recognition (Adolphs et al., 2000; Wicker et al., 2003).

Despite the amount of studies reporting facial mimicry during facial expression recognition tasks, the literature on mimicry remains inconsistent as many studies show a lack of correspondence between mimicry and better recognition of facial expressions (Blairy et al., 1999; Hessa & Blairy, 2001). Recent theories and findings suggest that, although not always crucial, mimicry seems to play an important role in the sensorimotor simulation.

1.5 Structure of the present thesis

This thesis examines the role of facial mimicry – measured with facial EMG – during emotional facial expression recognition tasks.

The second chapter investigates the STs' prediction that bodily feedback during the recognition process facilitates the understanding of the perceived emotion. In order to do this, in the first study, we examined whether and how the ability to perceive one's own facial movements (facial proprioception) modulates the ability to recognise facial expressions, and/or the occurrence and intensity of facial mimicry. Results showed that, although mimicry was detected, participants' recognition ability was not modulated by their facial proprioceptive ability. The ceiling effect found on the accuracy scores, also suggests that the task was too little demanding and therefore presumably not able to produce conditions that can account for the utility of a potential simulation process.

The third chapter investigates the claim that facial mimicry is modulated by contextual information, a theory originally proposed by Hess and Fisher and later reformulated by Wood and colleagues. This claim was investigated through two studies (Study 2 and Study 3).

Firstly, in Study 2, we examined whether and how the presence of contextual information that are either congruent or incongruent with emotional facial expressions modulates the accuracy of the expression's recognition and/or the occurrence and intensity of facial mimicry. To avoid the previous study ceiling effects on accuracy scores, and in order to observe any modulation effects of context, Study 2 featured low-intensity emotional facial expressions. To further disentangle the relationship between contextual information and the recognition of emotional facial expressions, we ran a third study with a similar method and design to the second, which adopted a database of faces that was standardised through pilot studies and which included both clear-cut and low-intensity emotional facial expressions. Taken together, Studies 2 and 3 showed that the ambiguity of facial expressions and/or the affective incongruency of linguistic context decreased the recognition ability of happy and angry faces. Findings suggest that sensorimotor simulation supported by mimicry occurs especially during laborious recognition.

In the fourth chapter we report two EEG-EMG studies (Study 4 and 5) aimed to examine the relationship between facial mimicry and ERPs associated with emotional processing. The two studies compare the time-course of these ERPs (central cognitive emotional processing) with that of facial mimicry (peripheral feedback) during a fast valence detection task (Study 4) and an explicit emotional recognition task (Study 5), to examine the interplay between cognitive processes and facial mimicry. Both studies measured EPN and N400 ERPs, together with facial EMG. In light of the findings in the previous chapter, the facial expressions used in both studies covered four levels of intensity per emotion. The two studies measured the relationship between these ERPs and facial mimicry during two different tasks: Study 4 involved a valence detection task of rapidly exposed emotional facial expressions. The task of the Study 5 measured instead the participant's ability to recognise and classify discrete emotional expressions. Findings from both studies are in line with the hypothesis that N400 is sensitive to the augmented demand of an emotion recognition task. N400 has been found more negative for more demanding semantic retrieval conditions, namely with low and medium intensity facial expressions presented among a few alternatives. Findings suggest that internal simulation occurs especially in case of increased task demand and it develops through a complementary cognitive-peripheral process where mimicry responds selectively in respect to central activity. In both studies behavioural results revealed that participants were more able and faster at recognizing high intensity facial expressions than medium and low intensity facial expressions suggesting that the recognition task became more demanding as the face intensity lessened.

Chapter 2

The influence of facial proprioception on mimicry and facial expression recognition abilities

2.1 Introduction

Often people spontaneously and rapidly react to an observed facial expression with a subtle facial mimicry (undetectable with a naked eye) which can be measured with facial electromyography (EMG). Previous studies have consistently detected distinct facial EMG activity of the same muscles involved in the production of the observed expression (Dimberg et al., 2000), and some have suggested that facial mimicry is necessary for accurate and fast recognition of facial expressions (Oberman et al., 2007; Pistoia et al., 2010; Ponari et al., 2012). According to the STs, mimicry would facilitate facial expression recognition because it allows for a more direct interpretation of the emotional state that is then attributed to the expresses (see Wood et al., 2016 for a review). As discussed in Chapter 1, STs suggest a crucial role of the observer's facial proprioception during the simulation process. The main claim is that the perceiver unconsciously mimics the observed expression, and the proprioceptive feedback from their own facial muscles' activation is used as an additional source of information that is then compared with the observed expression (Goldman & Sripada, 2005). This implies that, in order to interpret someone else's emotion, we might need to be able to perceive our own mimicry. Crucially, the extent by which people mimic and perceive their own face movements (proprioception) is highly variable between individuals (Wood, Lupyan, et al., 2016); this might explain, at least in part, why people differ in their ability to recognise facial expressions.

2.1.1 Proprioception

Proprioception is defined as the ability to perceive and cognitively process the musculoskeletal feedback coming from one’s own body. Therefore, proprioception informs the central nervous system about both static and dynamic positions of joints and muscles (Cobo et al., 2017). Proprioception is the central processing of muscles and tendons activity input coming from distal nerves and it allows to identify where body segments are in space at rest (position sense) and during movement (kinaesthetic sense; Frayne et al., 2016b). Each segment of the body involved in motor activity is also innervated from sensory nerves that provide the central nervous system with the information about the ongoing motor activity or inactivity. The muscles spindles receive motor information while the tendon receptors receive information of the tendons’ status. These sensory organs inform the central nervous system about the occurrence of muscles tensions and joint positions (Cattaneo & Pavesi, 2014).

All facial expressions are controlled by the facial nerve (cranial nerve VII: CNVII), but proprioceptive receptors are only present in the trigeminal nerve (cranial nerve V: CNV) which transmit the proprioceptive information to the mesencephalic nucleus (see Figure 2.1). Because of the lack of spindles from most of the facial muscles (Happak et al., 1994), “facial movements lack a conventional proprioceptive feedback system, which is only in part vicariate by cutaneous afferents” (Cobo et al., 2017, page 15). Cattaneo and Pavesi (2014) proposed that the facial motor system is a “partly deafferented system” and propose the presence of cutaneous mechanoceptors that act as proprioception receptors of the ongoing facial movements. According to their view, facial mechanoceptors provide the motor system with information about the phasic components of movement. However, they do to seem to provide the motor system with information about the tonic/postural positions. Baumel (1974) proposed that receptors of the trigeminal nerve innervate evenly the skin of the face and may therefore be able to receive information from the facial muscles innervated by the facial nerve. In this way, the communication between the trigeminal and facial nerve allows individuals to produce facial expressions and to regulate them.

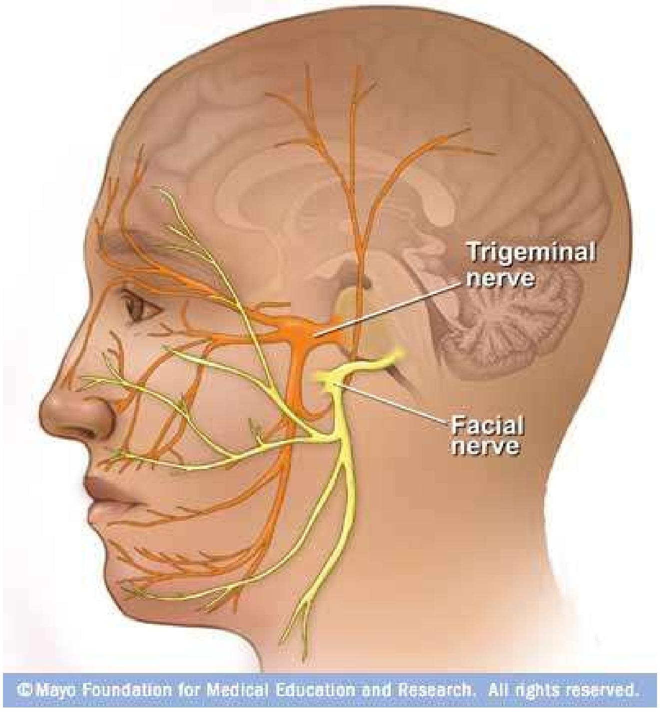


Figure 2.1. The trigeminal nerve is responsible for sensation on the face. The facial nerve supports muscles of facial expression.

2.2 Study 1

Theories of embodied cognition suggest a determining role of proprioceptive-visual integration during the detection of facial expressions. In fact, proprioceptive signal coming from facial mimicry supports the recognition ability representing a peripheral sensorimotor feedback during simulation (Baumeister et al., 2016; Korb et al., 2017; Niedenthal et al., 2005, 2010; Wood, Rychlowska, et al., 2016). As discussed in Chapter 1, crucial evidence for the role of simulation processes in emotion recognition comes from studies that demonstrated the involvement of brain regions whose primary function is to represent changes in one's own bodily states (proprioception and interoception), namely the somatosensory cortices and the insula (Adolphs et al., 2000; Pitcher et al., 2008; Pourtois et al., 2004; Terasawa et al., 2015; also see Ross & Atkinson, 2020). At a peripheral level, a number of studies have demonstrated that altering the proprioceptive response from the face impairs emotion detection (Baumeister et al., 2016; Neal & Chartrand, 2011; Rychlowska et al., 2014; Stel & Van Knippenberg, 2014; Wood, Lupyan, et al., 2016). For example, Neal and Chartrand (2011) demonstrated that dampening facial proprioceptive signals via the use of Botulinum impaired facial expression recognition, while amplifying proprioceptive signals using a restrictive gel enhanced facial expression recognition abilities. The latter finding is particularly interesting because it is the first time proprioception was manipulated without blocking mimicry (Neal and Chartrand, 2011). However, although these studies manipulated proprioception (either indirectly, constraining facial mimicry, or directly impairing the afferent signal from the muscles), they did not inform of whether proprioception ability interacts with recognition ability. Moreover, to our knowledge, no study has before investigated the relationship between mimicry and individual differences in proprioception.

With the present study we seek to investigate whether facial expression recognition abilities correlate with individuals' facial mimicry and with facial proprioception. We also seek to investigate whether facial proprioception modulates mimicry intensity during observation of facial expressions, such as whether individuals with better proprioception display any different mimicry behaviour compared to individuals with lower proprioception. Finally, we seek to investigate whether there is an interaction between proprioceptive ability, mimicry intensity and recognition ability.

We measured facial proprioception using the Active Movement Extent Discrimination Apparatus (AMEDA) ideated by Frayne and colleagues (Frayne et al., 2016a). AMEDA provides with a quantitative measure of buccal-lips proprioception, which, is assumed, is representative of the proprioception of all craniofacial movements. If, as postulated by Cobo and colleagues (2017), the facial nerve transmits its information to the trigeminal nerve, we assume that the communication between the buccal branches and the CNV operates similarly for the other branches (see Figure 2.2 for an illustration of the innervation of the facial muscles).

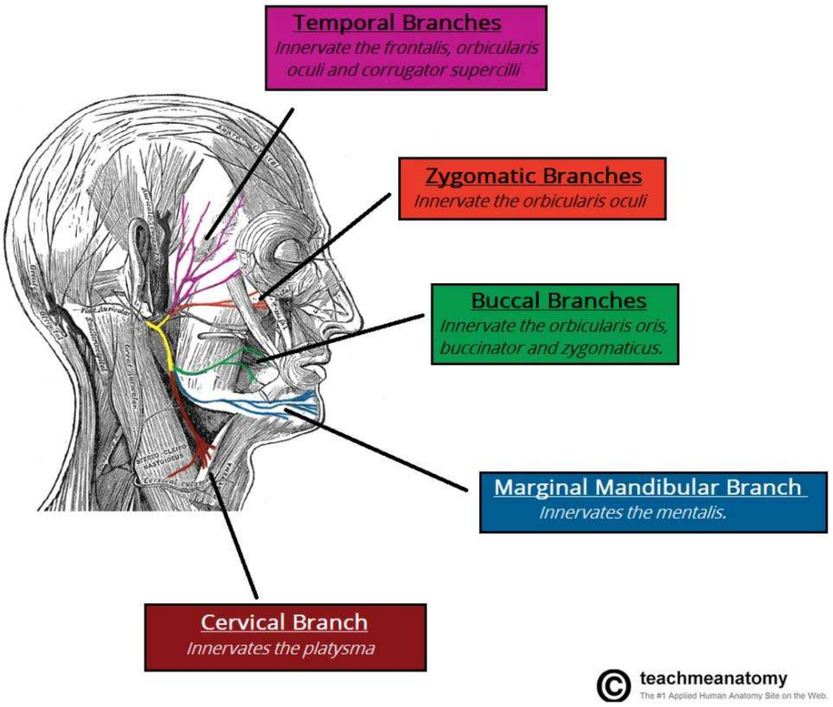


Figure 2.2. Branches of the facial nerve

2.2.1 Design and hypothesis

The study is a within-subjects design. Our independent variables are subjects' facial proprioception (FPA) and subjects' facial mimicry. Our dependent variables are recognition reaction times and accuracy.

We expect to replicate the finding that facial muscles are activated during observation of facial expressions. We also hypothesise that highest levels of facial proprioception will positively correlate with facial expression recognition accuracy and RTs.

2.2.2 Methods

2.2.2.1 Participants

Thirty-four healthy adults (females = 22) participated to this study (mean age = 23.11, SD = 8.90, range = 18-57 years). Participants were recruited through the University of Kent Research Participation Scheme and were all students at the University of Kent. All the participants declared to be right-handed and with normal or corrected-to-normal-vision. Participants in this study had no history of conditions which have been found to affect facial proprioception (facial, TMJ or dental injuries and disorders, facial nerve damage, significant lower facial deformities (e.g. cleft palate), significant recent dental work, multiple sclerosis, Parkinson’s disease, chronic fatigue syndrome, type 1 or 2 diabetes, vestibular disturbances such as benign paroxysmal positional vertigo, or rheumatoid arthritis; Frayne et al., 2016a). All the participants gave an informed consent to participate to the present study. 22 of them received 6£, 12 received university credits as reward for the participation. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

2.2.2.2 Materials and methods

2.2.2.2.1 Stimuli

Facial expressions featured three emotions (anger, fear, happiness) and a neutral condition; images have been selected from the Radboud Faces Database (RaFD; Langner et al., 2010), which is a database of images of static posed emotional and neutral facial expressions. We used only two actors (i.e. actor 01 and 30) and only frontal displays. The pictures were cropped in order to remove the hair and leave visible only the facial features. We chose one female and one male actor whose physiognomy was the most broadly Caucasian. We used different actors for the training session in order to avoid any practical effect caused by the familiarity of the face.

2.2.2.2.2 AMEDA

AMEDA is a well-established psychophysiological method to assess facial proprioceptive ability (Frayne et al., 2016a). It serves to detect subjects' discrimination ability of specific active movement of their lips. Our apparatus consisted of three cylindrical plastic plugs and one cylindrical plastic baseline of 33 mm diameter. The task consisted in 30 movement-detection trials. Participants were asked to respond with one of three number options reflecting their judgement on the lip closure movement around plugs of different sizes (5 mm = 1, 6 mm = 2, 7 mm = 3). The plugs were administered manually by the experimenter and all the items have been attached to some rods to facilitate the administration. The plugs and the baseline were sterilized in a solution of Milton and water. We used Milton tablets (the Milton-water ratio was set following the NHS instructions, i.e. 1 tablet containing 780 mg of NaDCC for 5 litres).

2.2.2.3 Procedure

Participants read the consent form set in Qualtrics which also contained a description of the experiment and a screening questionnaire that double checked whether they meet all the eligible requirements. After that, a sheet with the description of the AMEDA task was given to each participant and they were instructed to call the experimenter as soon as they finished to read the instructions. Participants were then asked to sit and relax and the experimenter started the AMEDA task. Each AMEDA trial started with a baseline plug (⌀ 33 mm) placed between the participants' lips at the midline. The participant was asked to 'hold' the baseline plug for few seconds, and then it was quickly replaced with one of 3 test plugs (⌀ 5/6/7 mm). Participants were instructed to make a lip movement around the plastic plugs, as they would when closing their lips onto a drinking straw, and to respond with one of three number options reflecting their judgement on the lip closure movement around plugs of different sizes (option 1 for the longest movement corresponding to a 5 mm stimulus; option 3 for the shortest movement corresponding to the largest 7 mm stimulus). A cardboard shield placed under the participants' nose was used to avoid visual feedback; participants held the shield stabilising the head and upper limbs. Familiarisation sessions were run before the task to make the subjects acquaint the plugs' size. Familiarization sessions were 3 in total: one from the smallest to the biggest movement, one from the biggest to the smallest movement, one in a randomize order. The actual test included 30 trials, in randomised order. A short rest occurred after each block of 10 trials and subjects could ask for a rest whenever they wanted. The answers were manually input by the experimenter in a pre-prepared template with pre-randomized trials on Qualtrics.

After the AMEDA task, participants took part in a facial expression recognition task while their facial mimicry was monitored using EMG. The EMG recordings and the emotion recognition task were conducted in another room with a secondary screen connected to the experimenter pc running the PsychoPy program (Peirce & MacAskill, 2018). The EMG measurements were recorded while the participants performed a facial expression recognition task. Before electrodes placement participants were informed about where and how electrodes would be attached to ease possible anxieties. GSR electrodes were used as ground for the EMG. All the EMG and GSR (left index and middle finger) spots were rubbed with alcohol wipes before the placement. Conductive gel was used to ensure the signal detection.

After the electrode placement (see 2.2.2.4 below) the participants received oral and written instructions about the recognition task on the screen. The task was programmed using Psychopy v1.83.04. The stimuli were presented for 2 seconds and before each trial a fixation cross was presented at the centre of the screen for 1 second. Each trial was followed by 1 second of blanc screen so that the physiological signals had 2 seconds to recover after the stimulus offset (1s fixation cross – 2s image – 1s blank screen; see Figure 2.3). The stimulus was presented for 2 seconds regardless of whether the target button was pressed or not. Under each image there were 4 labels corresponding to 4 buttons in the keyboard. Subjects responded using their right hand. Trials were 104 in total. A training session of 40 trials was run at the beginning. Subjects received instructions again after the training session. The labels-buttons correspondence was counterbalanced subject by subject to avoid different fingers' reaction time confound. Stimuli were presented on a 27 x 34 cm LCD monitor at a distance of approximately 70 cm from the computer's screen. The task was administered in an isolated room where a screen connected to the experimenter pc displayed the Psychopy task.

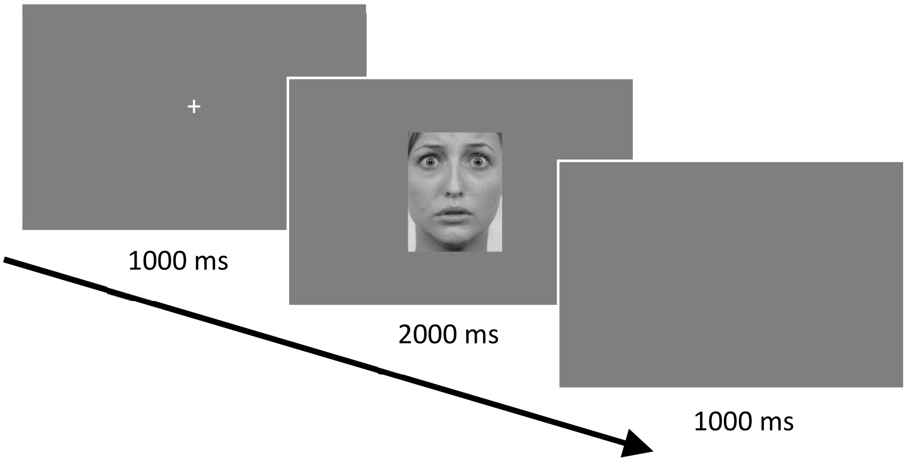
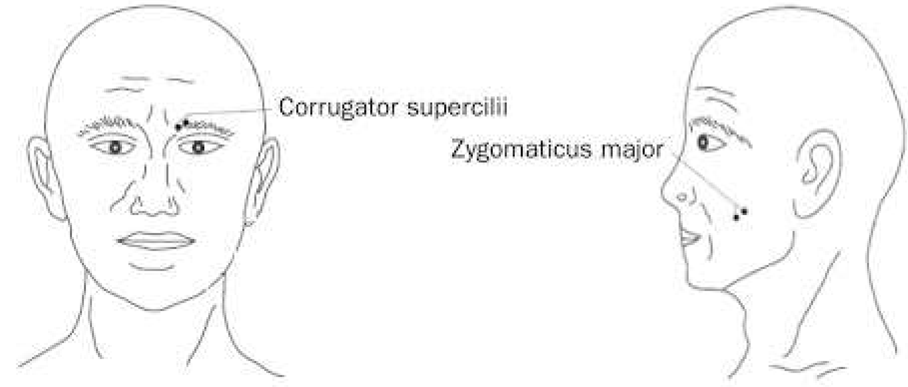


Figure 2.3. Timeline of a trial (images not in scale)

2.2.2.4 Facial EMG recordings

Facial mimicry was measured recording the activity of the participants' left *corrugator supercilii* and *zygomaticus major* muscles We used the bipolar apparatus with 4-mm Ag/AgCl active electrodes filled with NaCl gel connected to a Biopac MP150 (BIOPAC Systems, Santa Barbara, CA) amplifier system. The raw analogue signal was amplified (x 5000), online filtered (High: 10Hz; Low: 500Hz) and sent to a PC in which it was recorded by Acqknowledge software with a sampling rate of 2000 Hz. Triggers of the stimuli's onset were sent automatically from the Psychopy program operating in another PC. Galvanic skin responses served as reference electrodes and was recorded with two EL507 disposable EDA/GSR electrodes (filled with isotonic gel) placed on the left index and middle finger tips (Fridlund & Cacioppo, 1986). The GSR signal was filtered (HPF: 0.05 Hz; LPF: 1.0 Hz), amplified (x 5000) and sampled at 2000 Hz with the Biopac system. The electrodes were placed in correspondence of the *corrugator supercilii* and *zygomaticus major* muscles as indicated in the Fridlund and Cacioppo guidelines (Fridlund & Cacioppo, 1986; see Figure

2.4). For the Corrugator, the first electrode was placed directly above the left brow on an imaginary vertical line starting from the inner commissure of the eye; the second electrode was placed along the brow line, 1 cm apart. For the zygomatic, the first electrode was placed midway on an imaginary line from corner of the left lips to the left preauricular pit. The second electrode was placed 1 cm from the first, along the same imaginary line, towards the lips corner.



Source: Cacioppo *et al.*, 1990

Figure 2.4. Electrodes placement over the corrugator supercilii and the zygomaticus major.

2.2.2.5 EMG Pre-processing and data analysis

The pre-processing of the raw EMG signal was run in Acqknowledge. A notch filter (50 Hz) was used offline to filter out power line noise of the signal. Raw EMG data was rectified and then filtered with a linear phase filter using a low frequency cutoff of 400 Hz and a high frequency cutoff of 20 Hz (Van Boxtel, 2010). The root-mean-square (RMS) was then calculated using a moving window of 30 ms to smooth the signals.

The relevant literature does not always provide information regarding the fractioning procedure of EMG signal time bins and, when it does, it is not often coherent and consistent. Studies investigating facial mimicry during facial expression recognition tend to adopt rather discretional values allegedly depending on the purpose of the experiment. In regards to this, studies could be broadly be categorized into two main categories: studies adopting a fractioned selection of time bins, with time bins going from 100 up to 500 ms intervals often starting after 200-500 ms after SO up to 1 or 2 seconds after SO on average, but sometimes even up to 5 seconds after SO (e.g. Davis et al., 2017; U. Dimberg et al., 2000, 2002; U. L. F. Dimberg & Thunberg, 1998; Kirkham et al., 2015; Korb et al., 2010; Mavratzakis et al., 2016; Rychlowska et al., 2014; Sato et al., 2008; Soussignan et al., 2012); and studies analysing the whole time bin extracted or very large time bins, with 1 second time bins on average analysing time windows of 2 seconds on average (e.g. Chan et al., 2013; Korb et al., 2014, 2015; Krumhuber et al., 2014; Oberman et al., 2007). A unique 5 seconds time bin has also been used (Oberman et al., 2007).

In light of this, given the purpose of our experiment we decided to examined the EMG activity during a 900 ms time window (200-800 ms). As for the purpose of this study we are not specifically interested in the EMG activity time course (chapter 5 of this thesis will be fully dedicated to this), to perform the statistical analyses, the signal was further segmented into two time-windows of 300 ms each, starting from 200 ms after the stimulus onset (early: 200-500 ms; late: 500-800 ms; see Bailey et al., 2009). A baseline of 500 ms before the stimulus onset was extracted in order to compare the signal before and during the stimuli presentation; the EMG activity during the early and late time bins was expressed as a percentage of baseline activity.

2.2.3 Results

2.2.3.1 Behavioural results

Single trials were excluded from the analyses when responses were faster than 200 ms or slower than 2SD over the overall mean (8.7% of trials). A two-way mixed ANOVA was conducted to investigate the impact of facial proprioception ability on accuracy scores at the facial expression recognition task. To perform this analysis, we split the sample in two groups below and above the median of the AMEDA scores (low proprioceptors, mean age = 21.35, SD = 3.83; high proprioceptors, mean age = 22.65, SD = 8.28). Facial proprioception was the between subject factor with two levels (high: N = 20; and low: N = 14) and emotion was the within subject factor with 4 levels (angry, fearful, happy and neutral). Moreover, we calculated non-parametric Spearman correlations between behavioural responses (accuracy and RTs) of all emotions (angry, fearful and happy) and facial proprioception scores. All p values given in 'Results' are not corrected for multiple comparisons (Frayne et al., 2016b; Hess, U., Fischer, 2014a; Korb et al., 2017; Seibt et al., 2015).

2.2.3.1.1 Accuracy

The ANOVA conducted on accuracy did not reveal any significant main effect of emotion, $F(1.8, 58.8) = 2.26$, $p = .118$, $\eta_p^2 = .066$; proprioception, $F(1,32) = .003$, $p = .995$, $\eta_p^2 = .000$; or interaction between emotion and facial proprioception, $F(1.8, 58.8) = 1.07$, $p = .343$, $\eta_p^2 = .033$ (see Figure 2.5).

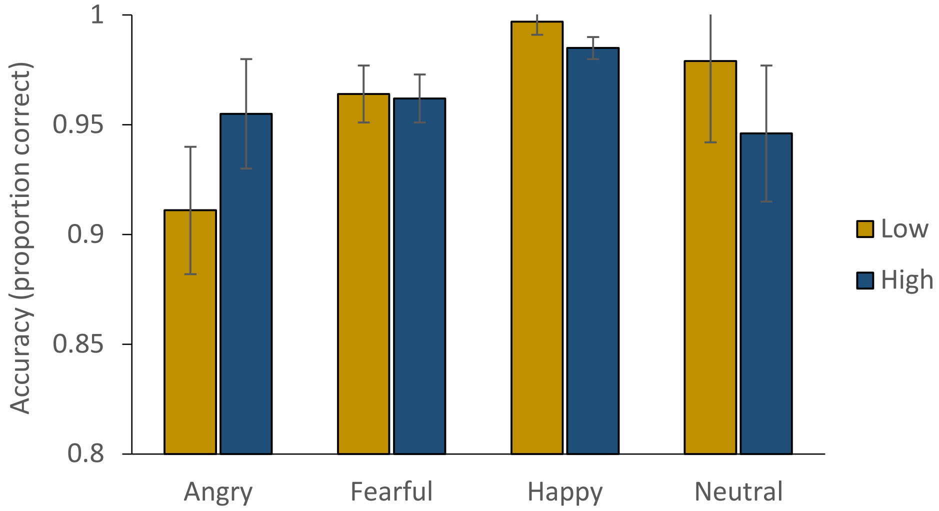


Figure 2.5. Mean accuracy scores of participants with low and high facial proprioception as a factor of facial expression. Error bars indicate standard error of the mean.

Non-parametric Spearman correlations between facial proprioception and accuracy (angry: rs (34) = .237, *p*= 177; fearful: rs (34) = .107, *p*= .548; happy: rs (34) = .150, *p*= .396) did not reveal any significant correlation (see Figure 2.6)

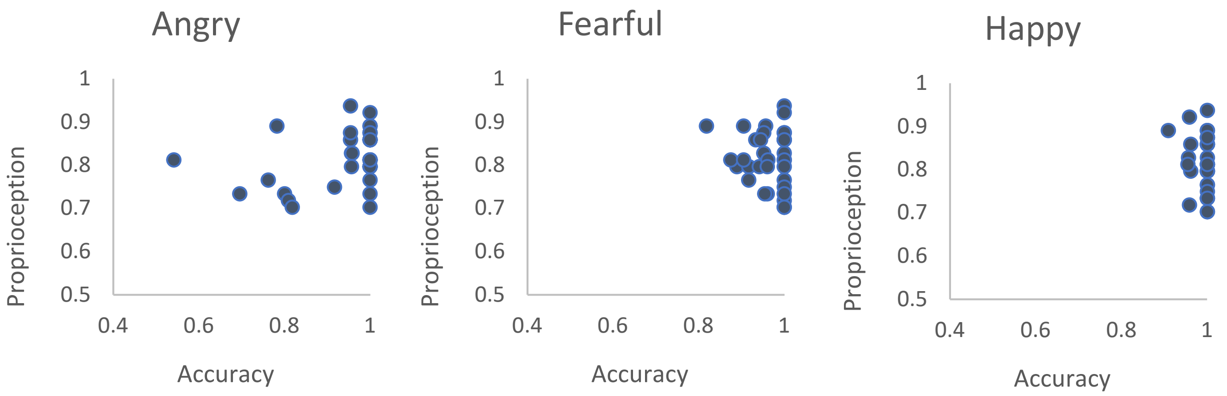


Figure 2.6. Scatterplots showing the relationship between accuracy at recognising Angry, Fearful and Happy facial expressions (x axis) and proprioception levels (y axis).

2.2.3.1.2 Reaction times

The ANOVA conducted on reaction times revealed a significant main effect of emotion: $F(3,96) = 25.011$, $p < .000$, $\eta_p^2 = .493$, with fearful faces (M = 1132.47, SD = 172.9) being recognized slower than happy (M = 953.85, SD = 160.46, $t\,(33) = 7.18$, $p < .001$) and neutral faces (M = 1030.58, SD = 185.53, $t\,(33) = 4.44$, $p < .001$) and, similarly, with angry faces (M = 1103.3, SD = 178.44) being recognized slower than happy faces, $t\,(33) = 6.49$, $p < .001$ and neutral faces, $t\,(33) = 3.07$, $p = .004$. Happy faces were recognized quicker also with respect to neutral faces, $t\,(33) = 3.66$, $p = .001$. Results did not show a significant main effect of facial proprioception, $F(1,32) = .084$, $p = .774$, $\eta_p^2 = .003$, nor an interaction effect between emotion and facial proprioception, $F(2.9, 93) = 1.34$, $p = .266$, $\eta_p^2 = 0.40$ (see Figure 2.7).

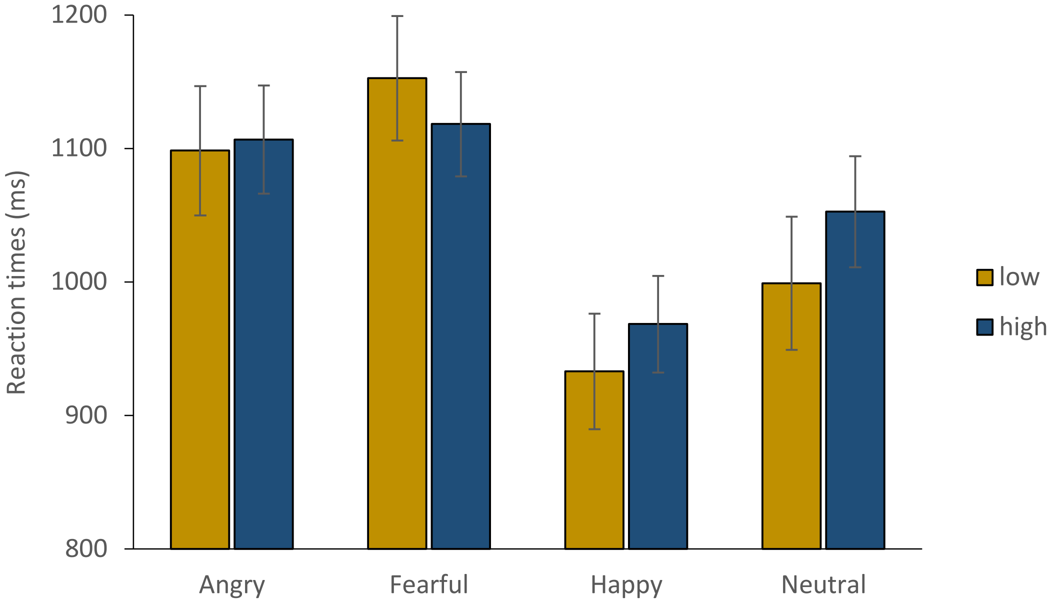


Figure 2.7. Mean reaction times of participants with low and high proprioception as a factor of facial expression. Error bars indicate standard error of the mean.

Non-parametric Spearman correlations between facial proprioception and RTs (angry: rs (34) = .053, *p*= .765; fearful: rs (34) = .005, *p*= .977; happy: rs (34) = .119, *p*= .503) did not reveal any significant correlation (see Figure 2.8).

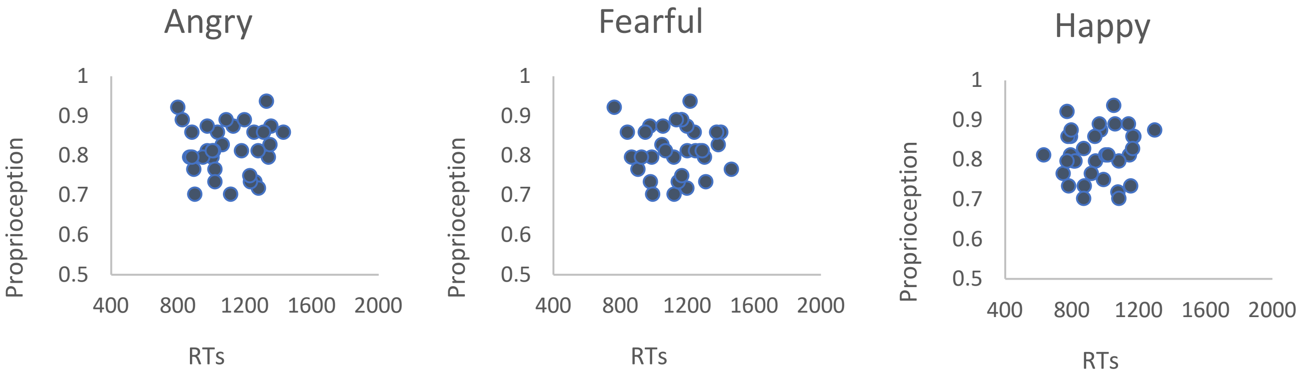


Figure 2.8. Scatterplot showing the relationship between mean RTs at recognising Angry, Fearful and Happy facial expressions (x axis) and proprioception levels (y axis).

2.2.3.2 Facial EMG

The EMG data were averaged for each condition of each participant (4 condition in total: angry, fearful, happy and neutral expressions), and expressed as percentage of the average of the baseline (Korb et al., 2015). For both muscles, we excluded trials whose baseline had an average amplitude of more than 2 SDs of all trials' baseline.

First, we tested whether the EMG activity of both muscles after stimulus onset was significantly different from the activity during baseline, using one-sample two-tailed t-tests (test value: 100), separately for the low and high proprioception groups. Then, we performed separate ANOVAs and for each muscle (corrugator supercilii and zygomatic) for time 1 (200-500 ms after SO) and time 2 (500-800 ms after SO) with facial expression (angry, fearful, happy, neutral) as within-subject variable and proprioception as between-subject variable. Finally, we calculated two sets of non-parametric Spearman correlations: first, we looked at the correlation between participants' facial proprioception and EMG activity, separately for the two muscles and the two time windows. Then, we looked at the correlation between behavioural responses (accuracy and RTs) to each the four facial expressions and EMG activity during exposure the same expressions, separately for low- and high-proprioception participants.

2.2.3.2.1 Corrugator supercilii

Corrugator activity for of participants with low and high proprioception levels as a factor of facial expression and time window is illustrated in Table 2.1.

For the low-proprioception group, the corrugator activity at Time 1 (200-500 ms) was significantly different from baseline only for fearful faces, (M = 101.58, SD = 2.47; t(13) = 2.397, *p* = .032). Time 1 activity for all other facial expressions, as well as activity as Time 2 (500-800 ms) for all facial expressions were not significantly different from baseline levels (all *p* > .05).

The corrugator activity of the high-proprioception group, instead, was significant at Time 1 (200-500 ms) for angry (M = 102.23, SD = 4.73; *t*(19) = 2.112, *p* = .048) and, marginally, neutral faces (M = 101.7, SD = 4.04; t(19) = 1.882, *p* = .075). Similarly, corrugator activity at Time 2 (500-800 ms) was significantly different from baseline for angry (M = 104.65, SD = 8.63; *t*(19) = 2.412, *p* = .026) and, marginally, neutral faces (M = 104.07, SD = 9.41; t(19) = 1.935, *p* = .068).

Table 2.1. Average corrugator activity of low- and high-proprioception groups during time windows 1 (200-500 ms) and 2 (500-800 ms) for angry, fearful, happy and neutral facial expressions (standard deviations in parentheses next to means).

Time window	Facial expression	Low Proprioception	High Proprioception
1 (200-500 ms)	Angry	100.19 (4.81)	102.23 (4.73)
	Fearful	101.59 (2.48)	101.24 (5.52)
	Happy	99.66 (5.79)	97.93 (7.08)
	Neutral	101.61 (7.34)	101.70 (4.05)
2 (500-800 ms)	Angry	101.6 (9.58)	104.66 (8.63)
	Fearful	103.39 (9.41)	107.81 (21.33)
	Happy	103.30 (13.12)	100.30 (8.93)
	Neutral	102.05 (7.92)	104.07 (9.40)

The ANOVA on corrugator activity showed a main effect of emotion on the activation of the corrugator during the first time window (200-500 ms), *F(*3, 96) = 3.24, *p* = .025, η_p^2 = .092, with greater corrugator activity for angry faces (M = 101.39, SD = 4.8) as compared to its activity during happy faces (M = 98.64, SD = 6.54), *t* (33) = 2.611, *p* = .013 and fearful faces (M = 101.38, SD = 4.476), *t* (33) = 2.4, *p* = .022. Corrugator activity for neutral faces (M= 101.66, SD = 5.53) was also greater as compared to its activity during happy faces, *t*(33) = 2.53, *p*= .016. The analysis did not show a significant main effect of proprioception, *F(*1, 32) = .000, *p* = .992, η_p^2 = .000, nor a significant interaction between facial expression and proprioception, *F(*3, 96) = 1.11, *p* = .348, η_p^2 = .034 (see Figure 2.9, left panel). No significant main effect of facial expression on corrugator activity was found on the second time window (500-800 ms), *F(*2.02, 64.79) =.876, *p* = .423 η_p^2 = .027. Similarly, there was no significant main effect of proprioception, *F(*1, 32) = .291, *p* = .593, η_p^2 = .009, and no interaction between facial expression and proprioception ability, $F(2.02, 64.79) = .907$, p = .410, η_p^2 = .028 (see Figure 2.9, right panel).

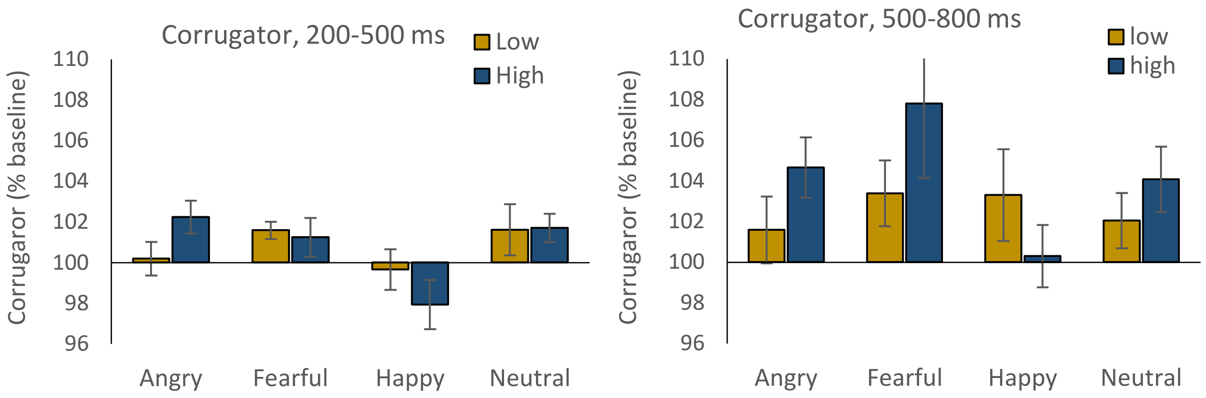


Figure 2.9. Corrugator activity at time 1 (200-500 ms, left) and time 2 (500-800 ms, right) of low- and high- proprioception participants during recognition of angry, fearful, happy and neutral facial expressions. Error bars indicate standard error of the mean.

2.2.3.2.2 Zygomaticus major

Zygomaticus activity for of participants with low and high proprioception levels as a factor of facial expression and time window is illustrated in Table 2.2.

For the low-proprioception group, the zygomaticus activity at Time 1 (200-500 ms) was significantly different from baseline only for angry faces (M = 106.79, SD = 10.7; t(13) = 2.375, p = .034). Time 1 activity for all other facial expressions, as well as activity as Time 2 (500-800 ms) for all facial expressions were not significantly different from baseline levels (all $p > .05$).

The zygomaticus activity of the high-proprioception group, instead, was not significantly different from baseline levels for any facial expressions at either time window (all p > .05)

Table 2. Average zygomaticus activity of low- and high-proprioception groups during time windows 1 (200-500 ms) and 2 (500-800 ms) for angry, fearful, happy and neutral facial expressions (standard deviations in parentheses next to means).

Time window	Facial expression	Low Proprioception	High Proprioception
1 (200-500 ms)	Angry	106.79 (10.7)	102.46 (8.18)
	Fearful	103.30 (7.31)	99.59 (5.41)
	Happy	101.27 (7.37)	102.28 (16.57)
	Neutral	105.56 (21.57)	99.29 (7.77)
2 (500-800 ms)	Angry	107.6 (22.22)	105.58 (22.15)
	Fearful	105.21 (15.34)	103.88 (18.14)
	Happy	106.48 (13.73)	105.37 (20.52)
	Neutral	105.20 (21.65)	101.23 (11.83)

The ANOVA on the zygomaticus activity during the first time window (200-500 ms after SO) did not show a main effect of emotion, $F(1.8, 66) = .641$, $p = .591$, or interaction with proprioception $F(1.8, 66) = .749$, $p = .470$ (see Figure 2.10, left panel). Similarly, no face emotion effect $F(1.8, 66) = .327$, $p = .707$ or interaction with face proprioception, $F(1.8, 66) = .062$, $p = .930$ was found on activation of the zygomaticus muscle at the second time window (see Figure 2.10, right panel).

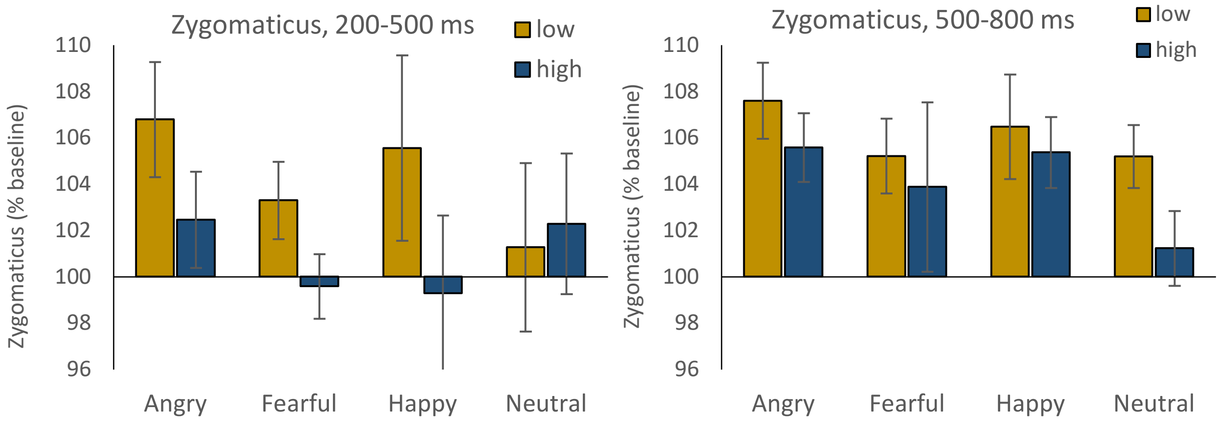


Figure 2.10. Zygomaticus activity at time 1 (200-500 ms, left) and time 2 (500-800 ms, right) of low- and high- proprioception participants during recognition of angry, fearful, happy and neutral facial expressions. Error bars indicate standard error of the mean.

Finally, non-parametric Spearman correlations between facial proprioception and the EMG activity of both muscles at the two time windows did not reveal any significant correlation (all *p*s > .05).

However, the correlations between behavioural responses and EMG activity in participants with low and high levels of proprioception revealed interesting differences. In low-proprioception participants, RTs for angry faces significantly correlated with zygomaticus activity during angry faces at time 2 (rs(14) = .575, *p* = .032). RTs also correlated with zygomaticus activity at time 1 (rs(14) = .657, *p* = .011) for neutral faces. Finally, accuracy to neutral faces negatively correlated with corrugator activity at time 2 (rs(14) = .566, *p* = .035) There was no significant correlation between EMG activity and behavioural responses for fearful and happy expressions.

In high-proprioception participants, there was a significant negative correlation between accuracy for angry faces and zygomaticus activity at both time 1 (rs (20) = -.530, p = .016) and time 2 (rs (20) = -.470, p = .036). RTs to neutral faces also correlated with zygomaticus activity at both time 1 (rs (20) = .534, p = .015) and 2 (rs (20) = .615, p = .004). There was no significant correlation for between behavioural responses and EMG activity for fearful and happy faces.

The scatterplots illustrating the relationship between corrugator and zygomaticus activity and behavioural performance in low and high-proprioception participants are shown in Appendix A.

2.2.4 Discussion

The aim of the present study was twofold: first, we aimed to examine the relationship between the ability to recognise facial expression and the ability to perceive one's own facial movements and positions (i.e. facial proprioception). Second, we aimed to investigate whether facial proprioception modulates the occurrence and/or intensity of congruent facial EMG reactions to facial expressions (mimicry), during an emotion recognition task. In this study, the activity of the corrugator and the zygomaticus muscles was measured while participants were taking part in an emotion recognition experiment, with angry, fearful, happy and neutral facial expressions. To measure facial proprioception, we adapted the Active Movement Extent Discrimination Apparatus (AMEDA) ideated by Frayne and colleagues (Frayne et al., 2016a) for the purposes of this study. This method proved to be able to provide with a reliable measure of buccal-lips proprioception. We assumed that proprioception of such part of the face is representative of the proprioception of all craniofacial movements (Cobo et al., 2017).

With regards to the first research question, we did not find significant differences between low- and high-proprioception groups in both accuracy and reaction times. Facial proprioception also did not correlate with behavioural performance for any of the emotional expressions.

We did find, however, differences between low- and high-proprioception groups when it comes to EMG activity in response to facial expressions. Participants with low proprioception activated the corrugator supercilii significantly more during fearful faces compared to baseline only in the early time window, between 200 and 500 ms from stimulus onset, while participants with high proprioception responded with significantly greater corrugator activity to angry and, marginally to neutral faces at both 200-500 and 500-800 ms from stimulus onset. With regards to the zygomaticus activity, we only found activity significantly higher than baseline in the low-proprioception group, interestingly for angry faces in the early time window.

These analyses showed that the exposure to an angry facial expression elicited the activation of the corrugator supercilii, a muscle involved in the production of the very same emotion, only in participants with high facial proprioception. Such modulation occurred from early on, at 200-500 ms from stimulus onset, and persisted up to 800 ms. Low-proprioception participants showed a bizarre activation of the zygomaticus during early processing of angry facial expressions, which is inconsistent with previous literature and with the facial mimicry hypothesis (Dimberg et al., 2000).

When looking at the overall sample independently of proprioception differences, the ANOVA on corrugator activity revealed a significantly greater activity for angry faces as compared to happy and fearful faces as early as 200-500 ms from stimulus onset, indicating an early differentiation across emotions during early perceptual processing. Interestingly, the corrugator activity in the early time window was also higher for neutral as compared to happy faces. An activation of the corrugator during the processing of neutral faces is not unheard of in the literature (e.g. Tottenham et al., 2013). Indeed, neutral faces are considered ambiguous (Leppänen et al., 2004; Said et al., 2009; Somerville et al., 2004) and are often interpreted as slightly positive or slightly negative. One hypothesis is that our participants might have interpreted the neutral face as negative most often, and therefore reacted with a congruent facial expression. This would be in line with Hess and Fischer's hypothesis of mimicry reflecting a valence evaluation (Hess & Fischer, 2003) more than being a perceptual-motor matching. However, accuracy on neutral faces was quite high for both low and high-proprioception participants, so an interpretation of the corrugator activity based on recognition errors seems implausible. Another possible explanation is that the corrugator activity during neutral faces might be due to frowning produced by an increase of the task attentional demand. Indeed, the activity of the corrugator muscle has been previously linked to increased cognitive load (e.g., Elkins-Brown et al., 2016; Lindström et al., 2013). We believe that perceiving a neutral, ambiguous face might have requested an additional cognitive effort in order to correctly classify it as neutral, especially soon after stimulus onset. We hypothesize that participants increased their attentional resource allocation from the appearance of neutral faces.

Our results did not show significant congruent EMG activity on the zygomaticus for happy faces as compared to the signal baseline and as difference across emotions. This finding, together with the high accuracy and speed of happy faces recognition suggests that recognition ability was not challenged by the task. We argue that during happy faces conditions participants did not engage in a simulation process, given the ease of the recognition required by the task. In line with what has been postulated by Wood and colleagues (Wood, Rychlowska, et al., 2016) we hypothesize that facial mimicry was not in this case crucial during the recognition process. On the other hand, angry faces were recognized less accurately and slower by both participants with low and high proprioception levels. This finding together with the greater corrugator activity from 200 to 500 ms suggests that participants might have engaged a sensorimotor simulation during the detection of angry faces, in order to supplement the recognition process with an additional source of information (Wood et al., 2016). This idea is also supported by the fact that, as mentioned at the beginning of the discussion, participants' recognition ability did not seem to be related to their facial proprioceptive ability. This, together with the high accuracy scores across all facial expressions, might be explained by the facility of the task. The most recent theories on the role of facial mimicry posit that it occurs, or at least it is beneficial, especially when the observer is trying to decode ambiguous and vague emotional expressions (Wood et al., 2016). The present study task featured clear cut facial expressions that, supposedly, did not stimulate significantly the participants' attentional involvement or incentive to pay more cognitive resources. If facial mimicry is considered a supplementary aide that enhances the effectiveness of the recognition process rather than a core factor of sensorimotor simulation, mimicry would be purposeless if the understanding process is straightforward. On the other hand, we did find that only participants with high proprioception activated the corrugator significantly more during angry faces than during baseline. It might be that the relationship between mimicry, proprioception and behavioural performance is more complex than what we initially imagined. Rather than mimicry facilitating recognition *through* proprioception, it might be the case that participants with higher intrinsic proprioceptive abilities mimic more because they can make better use of the proprioceptive feedback coming from the muscles, compared to individuals with low proprioceptive abilities. Future studies should further investigate this relationship.

Another important point to make is that the AMEDA task only measures proprioception of the lips, which are innervated by the buccal branches of the CNVII and, marginally, by the mandibular and the zygomatic/buccal branches of the CNVII (Cobo et al., 2017). As mentioned in the introduction to this chapter, other facial muscles are innervated by different branches of the facial nerve. The upper part of the face, namely the *frontalis, procerus, depressor supercilii,* and *corrugator supercilii muscles* are innervated by the temporal brunch of the CNVII, the *orbicularis oculi* muscle is innervated by the temporal and zygomaticus branches of the CNVII, the *zygomaticus major, zygomaticus minor, levator labii superioris aleque nasi, and levator anguli oris* are innervated by the zygomaticus and buccal branches of the CNVII, the *buccinator and risorius muscles* are innervated by the buccal branches of the CNVII, the *orbicularis oris muscle* is innervated by the marginal mandibular and buccal branches, the *depressor anguli oris depressor, labii inferioris, and mentalis muscles* is innervated by the marginal mandibular branch of the CNVII and the platysma is innervated by the cervical branch of the CNVII (Cobo et al., 2017).

It might be the case that, if AMEDA is able to provide with a measure of buccal-lips proprioception, this measure is not representative of the proprioception of all craniofacial movements. A better way to measure proprioception of the whole face would be to adapt tasks used to measure proprioception of the limbs. One type of proprioception task commonly used in the clinical setting is the ipsilateral limb-matching task: the patient’s limb is passively moved to a target location while the patient’s eyes are closed, and the patient needs to memorise the target position and replicate it soon afterwards. One way this paradigm could be adapted to the measure of facial proprioception could involve a computer task with automatic detection of the participants' facial features, and a grid of points that the participant needs to reach with either the corner of the lips, or the inner edge of the brows. A similar, albeit simpler setup was used by Cook, Johnston and Heyes (2013) who devised a self-imitation task: participants had to replicate their own facial expressions recorder beforehand. Perhaps, such a task could be used to measure how well participants can reach a certain facial muscle configuration without perceptual aids. We originally planned to conduct such a study as part of this chapter, however unfortunately due to time constraints and the limited availability of collaborators in the Computer Science department, it was not possible to conduct the study within the timeframe of this PhD.

In conclusion, the present findings showed that the exposure to emotional facial expressions elicits the activation of congruent facial EMG reactions (facial mimicry), at least in the corrugator supercilii. Mimicry was detected only on corrugator activity expressed as difference from the baseline during recognition of angry faces, interestingly only for high-proprioception participants. However, participants' recognition ability was not modulated by their facial proprioceptive ability. The high accuracy scores suggest that the task was too little demanding and perhaps not able to produce conditions that can account for the utility of a potential simulation process (Wood et al., 2016). Research on mimicry needs to consider study designs that contemplate facial expression recognition tasks with both easy to read and difficult to read expressions (e.g. with ambiguous expressions, when the context does not provide enough information).

Chapter 3

The role of context on facial expression recognition and mimicry

3.1 General introduction

Every emotional response is a reaction to an event for which one forms attitudes, interests, worries or motivations (Frijda, 1986). The process of emotional understanding occurs always in an interactive situation in which one part tries to extract information about the nature of the other part's evaluation regarding an event or acquisition of a certain knowledge. Not only the recogniser tries to obtain information about the appraisal of the expresser, but they also try to get an insight regarding the expresser's intentions as consequence of that given event or knowledge (Scherer, 1987). Therefore, any emotional expression is a communication channel that has an intrinsic intention of conveying a message. The expression finds its meaning in the interaction with another person and its sense in the social context. Emotional signs can also act as factors of regulation of other's behaviour, suggesting a change of attitude in the recogniser. A smile could, for example, suggest approach while a frowning could suggest aversive intentions (Hess & Fischer, 2014).

As illustrated in Chapter 1, extensive research has observed facial mimicry of emotions during the act of recognition. Mimicry has traditionally been defined as a matching emotional display between expresser and observer (Chartrand & Barg, 1999); it occurs shortly after the expresser's manifestation of the emotion (e.g. within a fraction of a second; Dimberg & Thunberg, 1998) and it has been reported even following subliminal presentation with emotional faces (Dimberg, Thunberg, & Elmehed, 2000), suggesting it is automatic. Early accounts of mimicry postulate that the tendency to mimic emotional expressions is based on an automatic action-perception link (e.g. the matched motor hypothesis; Chartrand & Barg, 1999). This account predicts that mimicry reflects a mirrored "copy" of the observed expression based on the amount of perceptual information available: the more intense the emotional expression, the more intense the mimicry response. In the case of more subtle emotional displays, therefore, the matched motor hypothesis would predict an attenuated mimicry response that matches the limited amount of visual information available.

However, other research suggest that mimicry tend to occur when there is the intention of sharing the expresser's emotion by the recognizer (Hess & Fischer, 2014). Hess and Fischer distinguish mimicry from a mere muscle reaction (or contagion), and define it as an attempt to establish an affective appraisal or connection. Therefore, even in case of concurrence of similar emotional displays by the two parts and in case of related timing, an emotional imitation cannot be considered mimicry if it does not involve any intention to sympathize with the expresser and understand their emotion.

In Hess and Fischer's view, an activation of the *corrugator supercilii* could be due to the recogniser's reaction to anger or fear perceived in the face of the expresser, rather than to facial mimicry. Similarly, facial reaction can produce activation of smiling muscles in the face of the perceiver to counterbalance the effects of a perception of an angry face. It has been shown that people can cover up overt facial mimicry in cases where reacting with negative expressions might be considered improper. For instance, the mimicry of anger tends to occur less than mimicry of smiles or sadness if the perceiver knows well and cares about the expresser (Häfner & Ijzerman, 2011).

In this framework, it appears clearly that the more the perceiver is motivated to understand the expresser the more likely is the occurrence of facial reaction and mimicry at the same time, that's why the two phenomena are very often difficult to disentangle (Wood et al., 2016). Hatfield and colleagues considered the phenomenon of mimicry as an aspect or a kind of emotional contagion that they describe as 'the tendency to automatically mimic and synchronize expressions, vocalizations, postures, and movements with those of another person, and consequently, to converge emotionally' (Hatfield et al., 1992, page 96). This view has been criticized by Hess and colleagues who define emotional contagion as 'the matching of subjective emotional experience' whereas mimicry would be a 'matching nonverbal display' (Hess & Fischer, 2014). Hess and Fischer affirm that mimicry is generated by the feeling of affiliation towards the expresser, which increases with social and/or personal involvement (the perception of a facial expression seen in a friend's face is more likely to trigger mimicry than that of a stranger). Hess and Fisher also highlight the importance of investigating mimicry considering the context in which the expression is displayed. Seibt and colleagues suggest that facial mimicry is modulated by visual as well as social elements, such as the vagueness of the expresser's facial signals as well as the quality and intensity of the affiliation with the expresser or the argument and attitude of the interaction (Seibt et al., 2015). Hence, these authors strongly affirm the determining role of context-specific factors in the mimicry occurrence and modulation.

Research exploring the function of social context revealed that negative emotions tend to be mimicked more if expressed by an ingroup member, whereas positive emotions are not (Bourgeois and Hess (2008). Moreover, it has been shown that cooperation and competition also influence facial reactions (Hess & Fischer, 2013; Likowski et al., 2011; Seibt et al., 2013). Furthermore, repeating an emotional word, such us 'anger' out loud to reduce or increase the access to that word semantic network modulate the recognition of that emotion expressed in faces. More specifically, less accessibility was associated with slower and less accurate recognition (Lindquist et al., 2006). However, in the traditional way of measuring mimicry, most of the studies do not give any additional context information that allows the researcher to disambiguate whether the observed congruent facial muscle activity could be defined as mimicry of emotional reaction.

In particular, mimicry has mostly been investigated using smiling or frowning faces (i.e. displaying happiness and anger) to observe respectively zygomaticus and corrugator muscles activation during tasks of emotional facial expression recognition, in which the participant is simply instructed to indicate which is the emotion displayed in a face appearing on a screen. This procedure does not therefore provide any kind of contextual information that would allow the perceiver to link the expression perceived to an appraisal of an emotional event that in which the expresser is involved. The inclusion of contextual information would also, among other things, decrease the poor ecological validity of these studies.

Using the aforementioned paradigms, there is little evidence that mimicry is not simply a valence-specific reaction. In other words, there is little evidence that the concurrent activation of *zygomaticus* and the *corrugator* muscles during the perception of emotional expressions, is not simply a reaction to the fact that the emotion perceived is negative, such as angry, fearful ect. (in the case of activation of the *corrugator*) or positive, such as happy (in case of activation of the *zygomaticus*). Moreover, Hess and Fischer argue that mimicry does not occur with the same intensity for all the emotions (2014). Facial reactions that deliver messages of connection and attachment appear to be more likely to occur; whereas reactions to negative emotional expressions are less likely to occur (Hinsz & Tomhave, 1991; Jakobs et al., 1997).

Indeed, smiles transfer intentions of affiliation and have ‘low social cost’ (Hess & Fischer, 2014) as sends no messages of alarm or complications. The observation of expressions that display negative emotions could activate internal mechanisms of action in response to that social signal. A facial expression of anger, for example, if perceived with the intention to understand that emotion, can trigger feelings of defence, escape, guilt or anger. The same for expressions of sadness that may trigger feelings of help and assistance or fear that may trigger feelings of danger. Smiles, instead, do not trigger any feeling that would need an action. Not only smiles communicate that no active participation is required by the perceiver, but they reassure the perceiver and send the message that the current situation is harmless. Despite the traditional line of research (U. Dimberg, 1982) stated that mimicry of anger was more frequent than mimicry for positive emotions displays, Hess and colleagues argue that this line of research cannot be considered accurate as it did not consider the factor ‘context’. If we consider mimicry as the result of a motivated attempt to create an emotional link, it looks like emotional signals that are more likely to be interpreted as threatening are less likely to be mimicked (Hess & Fischer, 2014). It is worth noticing that a smile might also communicate smugness, haughtiness or scorn, but also humiliation, mortification or indecision (Niedenthal et al., 2010). Therefore, the interpretation of a smile and, presumably, of an emotion in general is highly dependent on the framework in which that emotion is perceived.

Thus, the phenomenon of mimicry is not likely to refer only to the semantic and sensorial meaning that a given expression representation triggers. It is rather more likely to be triggered by the interpretation of other emotional signals coming from the internal (e.g. mood disposition) and external context.

Niedenthal and colleagues also postulated that facial mimicry of smile can be affected by the judgment of the observer on the expresser’s smile depending on social context. They hypothesise that the interpretation of the emotional signal can produce three main different outcomes: affiliative, enjoyment and dominance smile. These three interpretations activate different neural patterns and therefore different sensorimotor reactions (Niedenthal et al., 2010).

In light of these recent theories, mimicry is not a reflex-like response, but rather a social-modulated response influenced by contingent factors of the reader and the expresser and the interaction they are having.

Carr and Winkielman (2014) have similarly claimed that facial mimicry is intrinsically social and context-dependent, but without the influence of higher-order representation. Therefore, according to the authors, although mimicry is highly dynamic and flexible as it is influenced by both the nature and the culture of the observer as well as by the environmental contingencies, it is still substantially an embodied phenomenon, defining its peculiar nature as both ‘simple and smart’ (Carr & Winkielman, 2014).

In light of the contrasting theories and findings, in a recent review Wood and colleagues (2016) argue that the simulation process might occur more often in case of demanding mindreading. In this view, simulation occurs only when the available perceptual and semantic information alone does not allow the reader to mentalize the observed emotion. The authors suggest that simulation is mostly determined by the reader’s motivation to understand the person they are interacting with as well as by difficulty of the recognition. Such difficulty is most of the times given by the ambiguity of the emotion and of the context in which it is embedded.

With the ‘language-as-a-context hypothesis’ Barrett and colleagues suggest that the perception of others’ emotions is greatly conditioned by what the observer knows about the expresser. This knowledge is conceptual and linguistically assimilated. This knowledge can shape both the external and internal context of emotion recognition (Barrett et al., 2007). The external context is mediated by all the elements in which the face is embedded, while the internal context represents the emotional state of mind of the perceiver. Such semantic knowledge is acquired prior to the perception, but it’s ‘re-enacted’ during the perception (Barrett et al., 2007).

The theories discussed above suggest that facial mimicry aids the simulation process whenever the expression is difficult to read, such as when the context is not offering sufficient information or when the expression is too ambiguous. The studies described in this chapter investigate whether the knowledge of recent biographical information about the expresser, change the mindset of the perceiver and modulate her/his judgement (and mimicry reactions) during a facial expression recognition task.

3.2 Study 2

An effective interpretation of others' emotional displays during our daily social exchanges ensures our ability to empathise and better understand the other person's point of view. Interestingly, the lack of this ability has been found associated with poor health of relationships and depression (Carton, Kessler & Pape, 1999).

Communication, whether verbal or not, very often encompasses not only the integration of general semantic information deriving from the content of communication, but also the integration of emotional cues that allow a more complete understanding of what the other person is trying to convey (Kirkham et all. 2015). In the attempt to do so, the integration of non-verbal social cues or previously stored social information might facilitate social cohesion. As mentioned in the general introduction to this chapter, recent assumptions view the influence of social context as a strong determinant as well as modulator of the occurrence and nature of facial mimicry in response to the observed facial expressions (Wood et al., 2016).

On one hand the perception of positive affective displays, such as happy expressions, appears to be more likely to elicit mimicry as opposed to facial reactions (see chapter's introduction), if presented in affiliative contexts, due to the low social cost of smiles (Hess & Fischer, 2014). On the other hand, the perception of negative affective displays, such as angry expressions, appears to be more likely to elicit facial reactions rather than mimicry, if presented without any other social context information (Häfner & Ijzerman, 2011). It has been suggested that the congruency between the expresser's emotion and the emotional state of the environment modulate the occurrence and nature of mimicry reactions (Hess & Fischer, 2014). Context, both internal and external, has been shown to affect both the way one interprets another's emotion, and facial mimicry in response to it. For example, it has been reported that modulating the emotional mental setup (internal emotional context) of the perceiver helped the recognition of small affective variations in expressions going from happy to sad, otherwise not detected (Niedenthal et al., 2010). In a study by Philip and colleagues (2018) the incongruency between the emotions exhibited in facial expressions and words shown subliminally elicited poorer mimicry reactions as compared to congruent pairs of words-expressions. Moreover, there is evidence that giving information that primed the perceiver with negative emotional context about the expresser lead to rate as more negative neutral faces of the expresser (Suess, Rabovsky & Rahman, 2015).

According to the 'language-as-a-context hypothesis' (Barrett, Lindquist & Gendron, 2007) language has a significative influence on emotion recognition abilities as well as the capacity to alter the perception of the semantic valence of facial expressions' morphology.

In light of these findings, our study was designed to further investigate the effect of affective contextual information on emotion recognition ability. To increase ecological validity, rather than priming participants with words or images as in previous studies (e.g. Philip et al., 2018), we used brief sentences providing information about an event occurred to the person expressing the emotion. We also used subtle facial expressions, to better assess the potential effects of contextual information on emotion recognition, and also to investigate Wood and colleagues' (2016) hypothesis that mimicry might be more intense when the perceptual information available as well as the knowledge about the situation are not informative enough to allow recognition via mentalisation.

3.2.1 Aims and hypotheses

This study intends therefore to explore the potential impact explicit communication of biographical information about the expresser has on the way the expression is perceived. That is, the potential effect of conscious acquisition of affective situational information that presumably can inform the perceiver of the likely emotion of the expresser. In order to do so, this study considers timely induced associations between fictional characters and brief biographical stories attached to them. In this way, the task considered very short happy, upsetting or neutral scenarios that characters just experienced. Descriptions were then followed by the characters' facial expressions which were either congruent or incongruent with the affective valence of the scenarios presented before.

A second purpose of the present study is to investigate the occurrence of mimicry and the potential effect of receiving contextual information on mimicry intensity. Given the preponderant literature on facial mimicry for happy and angry expressions, we decided not to consider in this study other emotional facial expressions beside these two, in order to facilitate the prediction and interpretation of our results. The contextual information was given trough a short scenario directly referring to the character (e.g. 'Giulia just submitted her PhD thesis'). To increase the sense of familiarity, each story, and the face associated to it, was referring to a named person (such as 'Laura' or 'Richard'). Participants completed an emotion rating task by selecting with the mouse one of seven-points-Likert-scale ranging from angry to happy. Therefore, the study included three context conditions (positive, negative, neutral) and two facial expressions' condition (happy, angry).

From a behavioural point of view, we expect the valence of the scenarios to affect the ratings participants provide on the subtle facial expressions they observe, in line with previous findings on the interpretation of neutral faces (e.g. Suess et al., 2015). As far as mimicry is concerned, the literature does not allow us to make exact predictions on whether or how context will affect the activation of the observer's *zygomaticus* and *corrugator* muscles. According to the motor-matching hypothesis (Chartrand & Bargh, 1999) mimicry should reflect a copy of the perceptual information available, therefore it should not be influenced by contextual knowledge and should, in our case, be quite subtle as we use low-intensity facial expressions. However, other theories (e.g. Hess & Fischer, 2014; Wood et al., 2016) postulate effects of context on mimicry. We might find that, as in Philips et al. (2018), contextual information reduces the activation of mimicry when this is incongruent with the emotion displayed, compared to when it is congruent. On the contrary, we might find that incongruent contextual information enhances the mimicry, as suggested by Wood and colleagues (2016).

3.2.2 Methods

3.2.2.1 Participants

Forty healthy adults (31 females; mean age = 19.6, SD = 1.87, range = 18-26) participated to this study. Participants were recruited through the University of Kent Research Participation Scheme on the university website and therefore all were students at the University of Kent. All participants declared to be right-handed and with normal or corrected-to-normal-vision. Participants declared to not have allergies to metal or wear a pacemaker. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

3.2.2.2 Materials

3.2.2.2.1 Facial stimuli

20 pictures displaying static angry and happy facial expressions from 10 actors (5 males, 5 females) were selected from the Karolinska Directed Emotional Faces Database (Lundqvist, Flykt, & Öhman, 1998). Each picture of emotional expressions was morphed with the neutral face of the same actor using Morpheus Photo Morpher to create low-intensity facial expressions (frames between 4 and 7 were selected out of 21 frames, with frame 1 being the neutral face and frame 21 being the fully emotional facial expression; the exact frame for each expression was selected via a small informal pilot involving 5 undergraduate students). The pictures were cropped in order to remove the hair from the pictures and leave visible only the face. Each identity was given a fictitious name.

3.2.2.2.2 Contextual scenarios

The contextual scenarios were one sentence-long stories (20 words max) describing a recent past event occurred to the fictional character. The stories described an action or an event in 3rd person and started all with the name of the character (e.g. “Daisy’s job application for a top law firm was successful”). Stories were 60 in total, 20 per condition (i.e. positive/negative/neutral). An example of neutral story is ‘Andy installed Microsoft Office on his computer at home’; an example of positive story is ‘Daisy’s job application for a top law firm was successful’; an example of negative story is ‘Jessica found out that her car had been vandalised’. A full list of the scenarios used in this study can be found in Appendix B.

3.2.2.3 Procedure

Participants read and signed the consent form set in Qualtrics. They then read a description of the experiment and filled in screening questionnaire that double checked whether they meet all the eligibility requirements. Once they signed the questionnaire was complete, participants took part in a computer task while their facial muscles activity was monitored using EMG. The task and EMG recording tool place in an isolated room on a secondary screen connected to the experimenter PC which run the task on Psychopy v. 1.83.04 (Peirce & MacAskill, 2018). Before the electrode's placement participants were informed about the procedure and the nature of the measurement. The EMG and GSR (left index and middle finger) spots were rubbed with alcohol wipes before the placement. Electrodes were filled with conductive gel. After the electrode placement, the participants received verbal instructions about the task and then were left alone to start the task once the task was clear.

Participants received again written instructions on the screen at the beginning of the experiment. The task required participants to rate how angry or happy the emotional facial expressions displayed were. Each facial expression was preceded by a contextual scenario, that could be either congruent in valence with the facial expression (e.g. positive with an happy face, negative with an angry face), incongruent (i.e. positive with an angry face, negative with an happy face) or neutral. The study had 60 trials in total, with 20 congruent trials, 20 incongruent trials and 20 neutral trials. The order of appearance was randomised.

Each of the 20 morphs (10 happy, 10 angry) was presented with each context condition (positive/negative/neutral). Each character face was therefore presented six times, with each singular face stimulus appearing three times during the whole task. Stimuli were presented randomly, and the rating scale was counterbalanced (the order of the two values, namely angry and happy).

Each trial started with a 1000 ms fixation cross followed by the scenario appearing up until the subject clicked to continue (see Figure 3.1). Each story appeared on the screen till subjects selected to continue. Then, after a 500 ms blank screen, the image was displayed for 1500 ms at the centre of the screen. After that, a 7-point Likert scale appeared till a response was given by clicking the mouse on one of the seven points. Participants were instructed to base their judgement on the face, ignoring the scenario. The scale used for the rating was a 7-point Likert scale ranging from very angry (1) to very happy (7), with the central value (4) as neutral. The order of stimulus presentation was randomised and the emotion rating scale was counterbalanced, so that half sample responded with happy on the leftmost edge and *vice versa*. For the sake of a cleaner baseline, carryover effects were reduced with a 4000 ms intertrial interval with a blank screen of 3000 ms and the 1000 ms fixation cross appearing at the beginning of each trial. The task had a break halfway through to increase attentional focus. All actions had to be performed with the mouse. Stimuli were presented on a 27 x 34 cm LCD monitor at a distance of approximately 70 cm from the computer's screen.

Electrodes were removed right after the completion of the task. All participants received a debrief about the experiment aims and broader explanations about the purpose of facial EMG measurements.

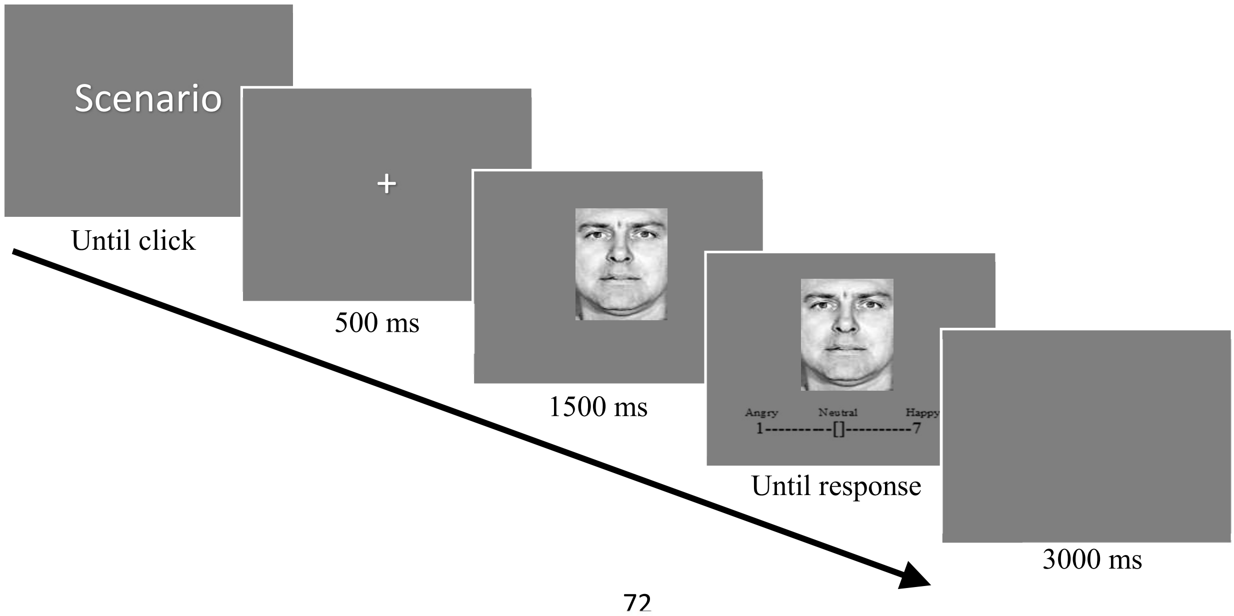


Figure 3.1. Timeline of a trial (images and text not in scale).

3.2.2.4 Facial EMG recordings

The activity of the left *corrugator supercilii* and *zygomaticus major* muscles was recorded with facial EMG. The electrodes were placed in correspondence of the *corrugator supercilii* and *zygomaticus major* muscles as indicated in the Fridlund and Cacioppo guidelines (Fridlund & Cacioppo, 1986) (see Figure 3.2; see also Chapter 2 for exact placement). We used a bipolar apparatus with 4 mm Ag/AgCl active electrodes filled with NaCl gel connected to a Biopac MP150 (BIOPAC Systems, Santa Barbara, CA) amplifier system. Skin areas under the electrodes were cleaned form makeup and excessive grease with alcohol wipes. The raw analogue signal was amplified (x 5000), filtered (High: 10Hz; Low: 500Hz) and sent to a PC in which it was recorded by Acqknowledge software with a sampling rate of 2000 Hz. Stimuli onset markers were sent automatically from the Psychopy program operating on another PC, via parallel port. Galvanic skin response electrodes served as reference electrodes and were recorded with two EL507 disposable EDA/GSR electrodes (filled with isotonic gel) placed on the left index and middle finger tips (Korb et al., 2015). The GSR signal was filtered (HPF: 0.05Hz; LPF: 1.0Hz), amplified (x5000) and sampled at 2000 Hz with the Biopac system.

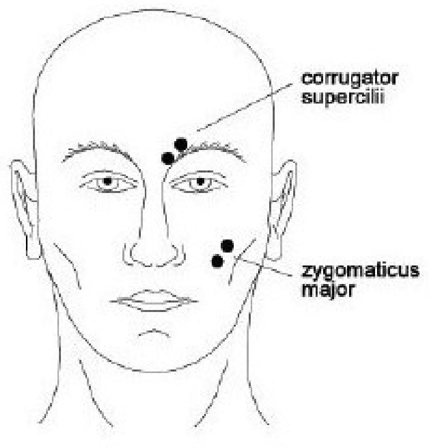


Figure 3.2. Facial EMG electrodes placement. Bipolar electrodes were placed over the corrugator supercilia and the zygomaticus major.

3.2.2.5 EMG preprocessing

The pre-processing of the raw signal was run in Acqknowledge. Firstly, a notch filter of 50 Hz was applied offline to filter out power line noise of the signal. EMG data was rectified with a 30 ms moving average filter. The signal was then filtered with a linear phase filter using a low frequency cutoff of 400 Hz and a high frequency cutoff of 20 Hz (van Boxtel, 2010). The signal was then smoothed using a moving window of 30 ms.

Given the purpose of our experiment, similarly to what has been done in study 1 we decided to examined the EMG activity during a 900 ms time window. As discussed for study 1 for the purpose of this study we are not specifically interested in the EMG activity time course (please see chapter 5 for this), to perform the statistical analyses, the signal was further segmented into two time-windows of 300 ms each: 300-600 ms and 600-900 ms after the stimulus onset. We shifted the 900 ms time window of 100 ms after SO as greater relevant facial EMG activation has been observed occurring later in the first second after SO (Philip et al., 2018).

We have not used a whole time window to observe weather an early and late mimicry could have been detected and further investigated (J. D. Davis et al., 2017; U. Dimberg et al., 2000a; U. L. F. Dimberg & Thunberg, 1998; Kirkham et al., 2015; Korb et al., 2015; Krumhuber et al., 2014a; Mavratzakis et al., 2016; Soussignan et al., 2012; Spapé et al., 2017). For both muscles the signal was baseline-corrected with a baseline period of 500 ms before the stimulus onset. For both muscles we excluded trials whose baseline had an average amplitude of more than 2 SDs of all trials' baseline. Sixteen participants were excluded for the statistical analysis due to excessive signal noise during baseline. The EMG data was expressed as percentage of the baseline's average (Frijda, 1986).

3.2.2.6 Design

The study was a within-subject design involving the measurement of facial EMG to detect potential facial mimicry and the recording of rating of expressions. The study included three context conditions (congruent, incongruent, neutral) x 2 facial expression conditions (happy, angry). Dependent variables were the emotional rating provided by participants, and the *zygomaticus major* and *corrugator supercilii* activity. All p values given in 'Results' are not corrected for multiple comparisons (L. F. Barrett et al., 2007; Beffara et al., 2012; F. C. Davis et al., 2016; Hess, U., Fischer, 2014a).

3.2.3 Results

3.2.3.1 Behavioural results

Before analyses, all ratings were converted so that 1 = Angry, 7 = Happy. A repeated measures ANOVA with scenario (negative, positive and neutral) and facial expression (angry, happy) as within-subject factors was conducted on ratings scores. This analysis revealed a significant main effect of scenario, $F(1.08, 23.9) = 29.279, p < .001, \eta_p^2 = .571$, with facial expressions following negative scenarios (M = 3.04) being rated as significantly angrier than those following neutral scenarios (M = 3.94; $p < .000$) and positive scenarios (M = 4.33; $p < .000$). Faces were also rated as happier when following positive scenarios compared to neutral, $p < .000$. The main effect of facial expression was also significant, $F(1, 22) = 125, p < .001, \eta_p^2 = .850$, with happy faces (M = 4.51) rated as significantly happier than angry faces (M = 3.03). More importantly, there was a significant interaction between facial expression and scenario, $F(2,41.8) = 6.7, p = .003, \eta_p^2 = .234$ (see Figure 3.3). Post-hoc pairwise comparisons further informed that angry faces were rated as angrier after negative scenarios (M = 2.4, SD = .08) compared to angry faces shown after neutral scenarios (M = 3.2, SD = .08; $t(23) = 5.37, p < .001$) and positive scenarios (M = 3.5, SD = .15; $t(23) = 4.42$, $p < .001$). Whereas, post hoc t-tests on happy faces rating scores revealed that happy faces were rated as happier after being presented with positive scenarios (M = 5.2, SD = .09), compared to happy faces shown right after neutral (M = 4.7, SD = .08, t (23) = 4.17, $p < .001$) and negative scenarios (M = 3.7, SD = .15; t (23) = 6.33, $p < .001$).

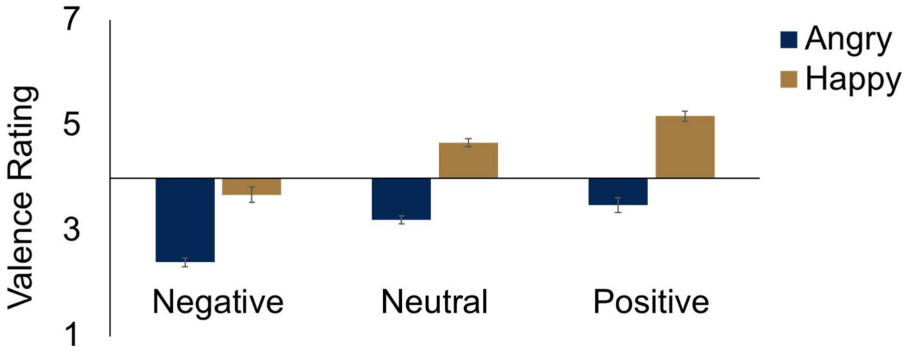


Figure 3.3. Participants' mean rating as a function of facial expression and scenario. Error bars indicate standard error of the mean.

3.2.3.2 Facial EMG

First, we tested whether the EMG activity of both muscles after stimulus onset was significantly different from the activity during baseline, using one-sample two-tailed t-tests (test value: 100), separately for each time window. Then, separate repeated measures ANOVAs were conducted with scenario (negative, positive and neutral) and facial expression (angry, happy) as within-subject factors to investigate each muscle activation as a function of context and facial expression from 300 to 900 ms after stimulus onset. Then, we explored the time course of EMG activity with 3-ways ANOVAs with scenario (negative, positive and neutral), facial expression (angry, happy) separately for each time bin (300-600, 600-900) and muscle.

3.2.3.2.1 Corrugator

Comparison with baseline. At 300-600 ms, corrugator activity was higher than the baseline when angry faces appeared after negative scenarios, $t(23) = 3.68$, $p = .001$. Corrugator activity was higher than the baseline also when angry faces appeared after positive scenarios, $t(23) = 2.48$, $p = .021$, and after a neutral scenario $t(23) = 2.76$, $p = .011$.

One sample t-tests on corrugator activity means from 600 to 900 ms after stimulus onset during exposure of angry faces, revealed that corrugator activity was higher than the baseline, when angry faces appeared after negative scenarios *t(*23) = 3.17, *p* =.004. Corrugator activity was also found higher than the baseline when angry faces appeared after positive scenarios, *t(*23) = 3.36, *p* = .003, but the difference was not significant after a neutral scenario, *t(*23) = 1.89, *p* = .071 (see Table 3.1).

Table 3.1. Corrugator activity during angry facial expression expressed as percentage of baseline activity.

Time bin	*Neutral / Angry*		*Negative / Angry*		*Positive / Angry*	
	M	SD	M	SD	M	SD
300 – 600 ms	107.75	5.71	113.45	5.12	108.8	4.01
600 – 900 ms	105.74	4.62	109.36	4.12	107.11	3.49

Overall ANOVA. The ANOVA on the whole time window did not reveal any significant effect and interactions, scenario: *F(*1, 23) = .979, *p* = .383; emotion: *F(*1,23) = .87, *p* = .359; scenario x emotion: *F(*1,23) = .971, *p* = .386; see Figure 3.4.

300-600 ms. The ANOVA on early corrugator's activity did not reveal a significant effect of the factor 'emotion', *F(*1, 23) = .954, *p* = .339. The analysis did not reveal a significant modulation by the factor 'scenario', *F(*1.6, 39) = .525, *p* = .595 or scenario x emotion interaction, *F(*1.6 ,38) = .304, *p* = .694.

600-900 ms. Similarly, no main effects or interaction was found on corrugator activity from 600 to 900 ms after face onset, emotion effect: *F(*1, 24) = 996, *p* = .328; scenario effect: *F(*1, 24) = 1, *p* = .327; scenario x emotion: *F(*1, 24) = .982, *p* = .332.

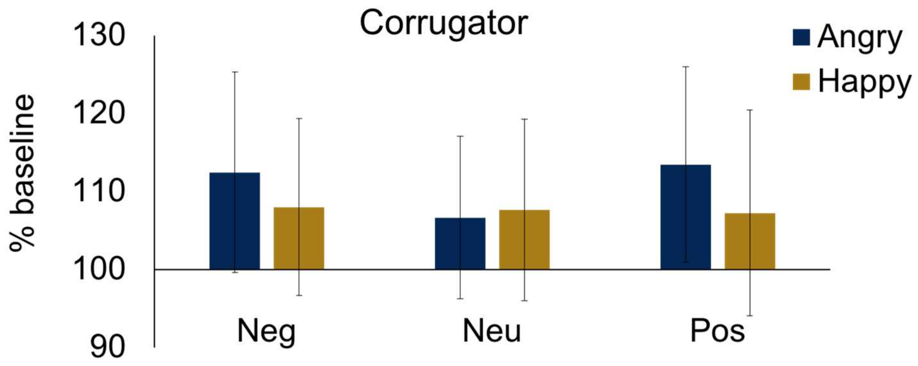


Figure 3.4. Mean Corrugator activity (% baseline) as a function of scenario and facial expression, across the whole 300-900 ms time window.

3.2.3.2.2 Zygomaticus

Comparisons with baseline. One sample t-tests on zygomaticus activity means from 300 to 600 ms after stimulus onset during exposure of happy faces, revealed that zygomaticus activity was higher than the baseline, when happy faces appeared after positive scenarios, *t(*23) = 3.587, *p* =. 002, after negative scenarios, *t(*23) = 4.24, *p* < .001 as well as neutral scenarios, *t(*23) = 4, *p* = .001.

One sample t-tests on zygomaticus activity means from 600 to 900 ms after stimulus onset during exposure of happy faces, revealed that zygomaticus activity was higher than the baseline also when happy faces appeared after positive scenarios, *t(*23) = 3.65, *p* = .001, after negative scenarios, *t(*23) = 5.84, *p* < .001 a neutral scenario, *t(*23) = 3.99, *p* = .001 (see Table 3.2).

Table 3.2. Zygomaticus activity during happy facial expressions expressed as percentage of baseline activity.

Time bin	*Neutral Happy*		*Congruent Happy*		*Incongruent Happy*	
	M	SD	M	SD	M	SD
300 - 600 ms	113.16	3.54	114.67	6.88	114.6	6.07
600 - 900 ms	109.43	4.33	116.18	5.24	112.1	4.24

Overall ANOVA. The ANOVA on the whole time window did not reveal any significant effect and interactions, scenario: *F(*1.4, 32) = 1,1, *p* = .34; emotion: *F(*1,23) = .98, *p* = .331; scenario x emotion: *F(*1.6, 38) = .198, *p* = .781; see Figure 3.5.

300-600 ms. The ANOVA on zygomaticus activity did not show significant main effects or interactions from 300 to 600 ms after face onset. Emotion effect: *F(*1, 24) = .993, *p* = .329; scenario effect: *F(*1.8, 44.6) = .199, *p* =.805; scenario x emotion: *F(*1.8, 43.9) = .527, *p* =.579.

600-900 ms. Similarly, no main effect or interaction was found on zygomaticus activity from 600 to 900 ms after face onset. Emotion effect: *F(*1, 24) = 1.138, *p* =.297; scenario effect: *F(*1, 24.1) = .923, *p* = .347; scenario x emotion: *F(*1, 24.1) = .849, *p* =.366.

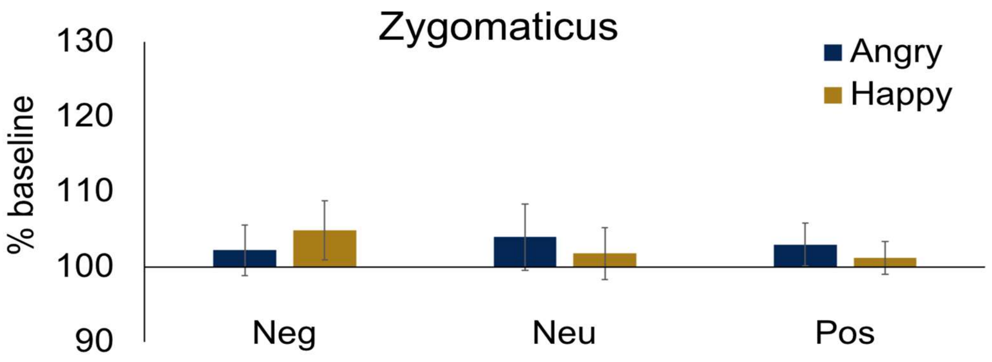


Figure 3.5. Zygomaticus average activity across the 300-900 ms time window.

3.2.3.2.3 Comparison between Corrugator and Zygomaticus activity

In light of the above results, we ran paired sample t-tests to explore differences between zygomaticus activations and corrugator activations across all conditions, for the two time bins separately. The two muscle did not activate differently except in the late time window (from 600 to 900 ms after faces onset) when the zygomaticus activated more than the corrugator during presentation of happy faces preceded by positive scenarios (zyg.: M = 131.22, SD = 52.54, corr.: M = 105.66, SD = 18.94, *t(*23) = 2.7 *p* = .012) and neutral scenarios (zyg.: M = 132.29, SD = 53.06, corr.: M = 101.52, SD = 14.83, *t(*23) = 3.03 *p* = .006); and, interestingly, even during recognition of angry faces linked to positive scenarios (zyg.: M = 127.46, SD = 55.49, corr.: M = 104.15, SD = 14.69, t(23) = 2.1 *p* = .046).

3.2.4 Discussion

This study was designed to further investigate the role of explicit expresser-specific contextual information on facial expression processing. Participants were presented with angry and happy subtle facial expressions, preceded by a brief contextual scenario describing a recent event involving the expresser, and were asked to rate how angry or happy they thought the face was. This study manipulated the facial expression-scenario valence congruency by creating facial expression-scenario associations with matching and unmatching valences. In this way we had our participants having to rate happy or angry faces both shown after positive, negative and neutral scenarios. Consistently with relevant literature (e.g. Suess, Rabovsky, & Rahman, 2015), and in line with our hypotheses, the present study found a modulatory effect of contextual information about the expresser on the perception of emotional facial expressions. Our results showed that both valence-congruent associations (negative scenarios preceding angry faces, and positive scenarios preceding happy faces) led to higher ratings of the facial expressions as compared to valence-incongruent associations. In other words, participants rated happy faces as happier when the scenario was positive instead of disappointing or neutral. Similarly, participants rated angry faces as angrier when the contextual scenario was upsetting instead of positive or neutral. Thus, if previous literature showed that positive or negative social related information modulates the way emotionless facial expressions are perceived (Schwarz et al., 2013; Wieser & Brosch, 2012), our findings indicate that this modulation occurs also in case of subtle emotional facial expressions (being our facial expressions 20-30% emotional intensity), whereby the contextual knowledge augments or diminishes the emotion expressed.

As regards to our facial EMG, we found greater zygomaticus activity in response to happy faces and greater corrugator activity in reaction to angry faces, expressed as significant difference of activation from the baseline. Zygomaticus activity for happy faces was found greater than baseline levels in all scenario conditions and across the whole time period (from 300 up to 900 ms), indicating that the activity of the zygomaticus was not differentially affected by the valence of the scenarios. However, when looking at the comparison between muscles, we found that the zygomaticus was more active than the corrugator not only for happy faces following positive and neutral scenarios, but also for angry faces following positive scenarios. Corrugator activity, on the other hand, showed a modulation based on scenario. Corrugator activity for angry faces was found greater than baseline from 300 up to 900 ms after face onset when angry faces followed negative scenarios. Corrugator activity was also significantly greater than baseline when angry faces appeared associated with positive scenarios, but only in the early time window (300-600 ms).

The classic view on mimicry theorizes that facial mimicry imitates a directly perceived behaviour (Chartrand & Bargh, 1999). If this was the case, we should have found corrugator and zygomaticus activation that reflected the emotion expressed by the actor, with no effect of scenario whatsoever. Our results do not seem fully compatible with a perceptual-motor matching. However, studies reported mimicry of emotions perceived through other sensitive modalities, such us vocal stimuli (Hess & Fischer, 2014), suggesting that emotional mimicry can occur in absence of direct visualization of an expression. Moreover, Hess and Fischer report that neutral faces associated with emotional labels elicited mimicry, even though participants did not report to have experienced relevant emotional states. This led the authors to exclude the possibility that EMG reactions were the result of an emotional contagion (Hess & Fischer, 2014). Thus, emotional mimicry is not merely an automatic reaction to a perceived expression and it is not an expression caused by the observer’s emotion (emotional contagion). The present study result that showed zygomaticus activity during angry faces associated with positive scenarios further confirms this hypothesis. Observers in fact showed mimicry of what they expected or what they thought they knew about the character’s state of mind. In line with Hess and Fischer theory, our results show a case of mimicry of the interpretation of an emotional signal.

We also found in general more significant activations of the zygomaticus for happy faces, compared to the corrugator for angry faces. These results are in line with the hypothesis that supports positive facial expressions’ priorities for relevant EMG reactions as compared to negative expressions, due to the lower social cost (Bourgeois & Hess, 2008). However, it was not found a significant difference between scenario conditions for mimicry activity. Thus, if mimicry occurred, it did not interact with face-scenario congruency. These findings suggest that social context information do modulate the way emotions are perceived and processed even enhancing or reducing the perceived emotional intensity of facial expressions, but this modulation is not moderated by mimicry.

It is worth noting that the majority of previous relevant literature found mimicry influencing recognition ability depending on implicit encoding of contextual information (e.g. Philips et al., 2018). The present study, instead, considered the consciously appraisal, temporary storage in memory and subsequent application of recent contextual situations to faces. This might suggest that the simulation eliciting mimicry moderates the influence of affective contextual information on recognition differently depending on whether the information is acquired consciously or implicitly.

However, according to more recent theories, mimicry is more likely to occur in case of demanding recognition task and/or ambiguity of the expression to decode (Wood et al., 2016). If this was the case, we would have expected to find an increase in mimicry activity when the context was not informative of the emotion expressed (Wood et al., 2016). Rather, relevant enhancement of EMG activity was not found during incongruent face-scenario associations. Another prediction based on Wood et al. (2016) theory is that mimicry would be more intense when it comes to decode more ambiguous facial expressions. In this study, however, all the stimuli we used were subtle facial expressions so we cannot conclude whether our participants activated their facial muscles more than what they would have done with more straightforward facial expressions to recognise. We will address this limitation in Study 3 below.

Lastly, when considering our behavioural and EMG results together, we can observe that mimicry, where it occurred, did not seem to aid facial expression recognition. To be more specific, despite the zygomaticus was active for happy faces in incongruent conditions, emotional facial expressions were still rated as less intense. Even more, happy facial expressions have been rated as negative (< 4) following negative scenarios. This result suggests that recognition of smiling faces during this condition has been disrupted by the incongruent scenario. We therefore assume that simulation seem not to have occurred during these trials. If, in fact, simulation arisen, according to the STs, it would have significantly aided the recognition process.

Overall, we speculate that sensorimotor simulation measurable with mimicry did not occur during these trials as well as during congruent face-scenario associations. The incongruency of unmatching associations might have been too resounding with emphatically dissonant (for instance) negative scenario-happy face associations making it difficult to engage in a fruitful effort to decode the expressions. On the other hand, the congruency of matching associations might have been too consonant with (for instance) negative scenario-angry face associations making it needless to engage in a simulation process.

The 'contextual view of emotional mimicry' by Hess and Fischer (2014) postulates that mimicry is not simply a copy of the emotion perceived in the face of the observer, but it is rather aimed at understanding the emotion perceived or to increase the sense of affiliation with the expresser (Hess & Fischer, 2014). The most recent theories on emotional mimicry posit that mimicry as a sensorimotor simulation supports more the processing of emotions when expressions are ambiguous and 'when the context does not clearly predict what the expresser may be feeling' (Beffara et al., 2012; Niedenthal et al., 2010; Wood, Rychlowska, et al., 2016).

In light of this, we hypothesize that we detected emotional contagion instead of mimicry whereby simulation did not occur. Consequently, facial muscle activity might have acted as an automatic default like response. Indeed, even if EMG reactions steadily occurred across conditions, the extent of recognition decline between neutral scenario and incongruent scenario- happy faces was higher that the recognition increases between neutral scenario and congruent scenario happy faces. If simulation occurred aided by mimicry, recognition ability would have been supported. However, EMG reactions for angry faces have only been triggered by congruent associations, that is when angry faces were expected to be angry. Concurrently, the corrugator did not react when angry faces where not expected to be angry, suggesting that EMG reactions might not be correspondingly present in the corrugator and in the zygomaticus.

3.2.5 Conclusions

The present study aimed to investigate whether contextual knowledge affects the perception of emotional expressions and the occurrence and/or intensity of facial mimicry. From a behavioural point of view, we found that the valence of the biographical information which provided context to the emotional expressions affected quite significantly the ratings participants provided on the subtle facial expressions they observed, in line with previous findings on the interpretation of neutral faces (e.g. Suess et al., 2015). As far as mimicry is concerned, different theories make different predictions on whether or how context might affect the activation of the observer's facial muscles, ranging from theories postulating no effect at all (Chartrand & Bargh, 1999) to theories which instead postulate effects of context on mimicry, albeit in different directions (e.g. Hess & Fischer, 2014; Wood et al., 2016). While we found significant activation of both the zygomaticus and the corrugator during the observation of facial expressions when compared to baseline activity, the two muscles seemed to be differentially affected by context. At least for the corrugator, we found modulation of the contextual scenario. However, looking at the overall results, both behavioural and EMG, we can conclude that mimicry, when it occurred, did not have any facilitatory effect on facial expression recognition in incongruent scenarios. Further studies are needed to clarify the role of mimicry and the effect of contextual information. Study 3 will address some of the limitations of Study 2, and hopefully will shed more light on the interplay between contextual knowledge and embodied information on facial expression recognition.

3.3 Study 3

In the previous study we tested whether social context influenced facial mimicry during the attempt to rate the valence of subtle emotional facial expressions. In order to do so, we presented very brief contextual information prior to faces manipulating the valence congruency between the two variables (facial expressions and contextual information). Our findings suggested that knowledge of contextual information affects observers' perception of facial expressions. We found that providing biographical information incongruent with the emotional valence of the expression impedes the recognition, making emotions appearing less expressive. However, these finding were not significantly associated with relevant mimicry trends, that is mimicry did not seem to play a significant role when the recognition was facilitated or disrupted by the coherence or incoherence of contextual information. This led us to infer that, even if occurring, mimicry was not playing a crucial role during the attempt to read a facial expression.

Given the confirmed influence of contextual information during the formation of an emotional appraisal, it is reasonable to infer that social context might be consulted in a selective way. Recent theories (discussed in the introduction of this chapter) suggest that facial mimicry aids the simulation process whenever the expression is difficult to read, such as when the context is not offering sufficient information or when the expression is too ambiguous (Wood et al., 2016). In light of our previous findings and of the context-dependent mimicry hypotheses (Hess & Fischer, 2014; Niedenthal et al., 2010; Wood et al., 2016), it is arguable that ambiguity not only lies in the incongruency of contextual information (with the emotion seen), but also in the unclarity of the facial display in itself. In fact, the act of recognition translates mainly in the effort of deciphering a facial muscle configuration. The cognitive charge of this effort seems to be the main task assigned to the sensorimotor simulation (Beffara et al., 2012; Seibt et al., 2015). It is when the prototypical muscle arrangement vanishes and the contextual information is unreliable that the cognition might be calling for a sensorimotor simulation in support to the recognition process (Wood et al., 2016). Most of the literature on mimicry use standardized datasets of images of idealized expressions, exhibited unmistakeably. Supposedly, in actual social situations the likelihood to deal with such definite facial expressions is very low (Calvo & Nummenmaa, 2015). Real life face-to-face emotion reading involves the perceptual and semantic integration of subtle and often equivocal expressions that presumably ask for more attentional resources. Such attentional allocation might be not evoked in laboratory experiments using fully expressive emotions. Findings of facial EMG reactions seem to lead towards the hypothesis of an expression intensity-related mimicry together with a valence-specific mimicry. The use of ambiguous facial expressions together with easy-to-read facial expressions is crucial for a more accurate distinction between emotional contagion and mimicry, whereby mimicry is an emotion congruent EMG reaction that serves to the sensory motor simulation. It is crucial to systematically investigate type, latency and intensity of EMG reaction together with type, latency and intensity of the expressions mimicked and observe whether this occurs embedded or not in a social context (Krumhuber et al., 2014).

The present study investigates the effect of affective contextual information (i.e. information about the events that might have elicited the emotions expressed) on affective ratings and on the occurrence and intensity of facial mimicry timely linked to it. This study also aims at investigating whether the congruency of facial expressions and contextual information affects emotion recognition and facial mimicry. Our study consisted in an emotional expressions rating task in which each facial expression is associated to a brief story about the recent past of the character. As Study 2, this study features happy and angry facial expressions only as the vastity of the literature on mimicry for these expressions allows a more accurate prediction of results and facilitates their interpretation. However, this time we included both subtle and clear-cut facial expressions, to investigate potential differences in mimicry intensity between the two conditions.

The biographical information was given trough a sentence-long story associated with a fictional character, followed by a picture of their facial expression. Faces appeared expressing obvious or ambiguous happy or angry faces. The main assumption is that the close timely association between scenarios and the following facial expressions will affect the way participants primed their cognitive resources towards the recognition process. To facilitate the attentional and motivation engagement of participants in the characters' state of mind, stories were accompanied with the question 'How do you think s/he feels?'. Similarly to Study 2, to increase the sense of familiarity, each scenario and the following face referred to the same identifiable actor. Each actor had therefore a fictional name consistent throughout the task. Participants had to complete am emotion recognition task by rating how angry or happy they thought the facial expression was. The scale was a seven-point Likert scale ranging from angry to happy passing from neutral. The study had three context conditions (positive, negative, neutral), two emotion conditions (angry, happy), and two intensity conditions (full emotional/ambiguous). Stimuli were presented randomly and the rating scale was counterbalanced (the order of the two values, namely angry and happy). Data was then converted for data analysis so that rating ‘1’ always corresponded to angry (having 4=neutral and 7= happy). Facial EMG was recorded during the experiment. Electrodes were placed over the *zygomaticus major* and the *corrugator supercilii*.

3.3.1 Aims and hypotheses

Building on Study 2, this study aims to clarify the impact of explicit contextual information on the perception of emotional facial expressions, and the extent to which participants mimic them. While in Study 2 we only used subtle facial expressions, we realised that we could not attempt to answer some of the outstanding questions in the literature without including fully emotional expressions. For example, the perceptual-motor matching hypothesis (Chartrand & Bargh, 1999) would assume that mimicry reflects a copy of the facial expression as it is perceived; in the case of subtle facial expression, where the perceptual information available is minimal, this theory would predict much lower mimicry intensity compared to fully emotional facial expressions, where the perceptual information to “copy” is much more. On the other hand, more recent hypotheses (e.g. Wood et al., 2016) see mimicry (and sensorimotor simulation in general) as an additional aid to the recognition process that would be more engaged in case of ambiguous or insufficient information provided by both the context in which the emotion is expressed, and the clarity of the perceptual information available. In this view therefore, mimicry would be more useful (and therefore presumably more intense) when the facial expressions are more subtle.

Also, using subtle facial expressions only we could not really provide a convincing account of instances in which mimicry did not occur, aside from speculations, as some of our subtle stimuli might have been too subtle and therefore might have been perceived as neutral. In Study 3, therefore we address some of these limitations by adding high-intensity facial expressions, and also by selecting all stimuli to be used in the study via a formal pilot study. We also increased the interval between the presentation of the scenario and the presentation of the facial expression, in order to minimise any carry over effect of any facial reaction to the scenarios. This will only allow us to see if we can replicate the findings of Study 2 with a slightly longer (1 sec) gap between the explicit acquisition of the contextual information and the perception of the emotion.

Therefore, the study included three context conditions (positive, negative, neutral), two facial expressions conditions (happy, angry), and two intensity conditions (low, high). Based on Study 2 results, we expect the valence of the scenarios to affect the ratings participants provide on the subtle facial expressions they observe. With regards to mimicry, the findings of Study 2 provided mixed support to either theory: on the one hand we found significant (compared to baseline levels) activation of the zygomaticus regardless of scenario, which would support the perceptual-motor matching hypothesis (Chartrand & Bargh, 1999), on the other hand we found significant modulations of scenario on the corrugator activation, which instead would support context-based theories (e.g. Hess & Fischer, 2014). The inclusion of high-intensity facial expressions will also allow us to test Wood et al.'s (2016) hypothesis that mimicry is more intense when the stimulus is more ambiguous: the high-intensity facial expression should be easy enough to recognise without the assistance of embodied processes.

3.3.2 Pilot studies

3.3.2.1 Pilot study to extract standardised ambiguous faces

3.3.2.1.1 Participants

Participants were 87 adults (40 females, mean age = 27.69, SD = 8.3) recruited through Prolific Academics who were compensated £1.25 for their participation. Participants gave their consent to participate in the study and were informed that the study did not involve any emotional discomfort. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

3.3.2.1.2 Stimuli

The facial expressions selected for the pilot study were static posed emotional facial expressions from the Karolinska Directed Emotional Faces Database (Lundqvist, Flykt, & Öhman, 1998). Pictures displayed facial expressions captured from the frontal angle selection of the KDEFD dataset. Angry and happy facial expressions were selected from 10 actors (5 males, 5 females); using Morpheus Photo Morpher, each picture was then morphed with the neutral face of the same actor, to create 21 frames per morph (with frame 1 = neutral and 21 = original expression). 8 of these frames (frames 2 to 10) were selected for the pilot. The resulting pictures were cropped at the hairline, the earlobes, and under the chin, so to leave visible only the face features; they were resized to 322 x 462 pixels, aligned so that the eyes would always be on the imaginary line delineating the top third of the picture, and converted in black and white.

3.3.2.1.3 Procedure

The pilot featured 160 pictures (8 frames x 10 characters) per emotion (angry, happy), for a total of 320 faces, which were divided into 4 Qualtrics surveys.

Subjects participated by accessing a Qualtrics link accessible via Prolific Academic. Participants were shown each picture, one at a time, and were asked to rate how much they thought each expression was exhibiting happiness, fear or anger, on a scale from 1 to 10, where 1 represented ‘not at all’ and 10 ‘extremely’. Each trial consisted in a picture and three questions posed right below it, one *per* emotion. In this way, during each trial, each face was rated three times according to how much it was displaying happiness, fear and anger. Participants had all the time to respond by clicking with the mouse to one of the 10 points displayed horizontally going from 1: not at all (e.g. ‘not fearful at all’) to extremely (e.g. ‘extremely fearful’).

3.3.2.1.4 Data analysis and stimuli selection

We first excluded subjects whose mean exceeded of 3 standard deviations or more the overall mean (N = 1). We then selected 10 faces per emotion, based on the average rating for the target emotion being moderate (about 5) and the average rating for the non-target emotions being as close as possible to 1 (“not at all”). For the selection of ambiguous happy faces, we extracted the 10 faces with the closest ratings on point ‘5’ for the emotion ‘happy’ and concurrently the closest ratings on point ‘1’ for both the emotions ‘fear’ and ‘anger’. Whereas for the selection of ambiguous angry faces, we extracted the 10 faces with the closest ratings on point ‘5’ for the emotion ‘anger’ and concurrently the closest ratings on point ‘1’ for both the emotions ‘fear’ and ‘happy’.

3.3.2.2 Pilot study to extract standardised scenarios

3.3.2.2.1 Participants

Participants were 94 adults (47 females, mean age = 27.7, SD = 8.6) who were recruited through Prolific Academic. Participants were compensated £2 as a reward for their time. Participants gave their consent to participate in the study and were informed that the study did not involve any emotional discomfort. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

3.3.2.2.2. Stimuli

The stories were one sentence stories (20 words max) describing an event occurred to a fictional character. The stories described an action in third person and all began introducing the name of the protagonist (e.g. “Daisy’s job application for a top law firm was successful”). Stories were either describing a neutral scenario, that is a scenario that should not trigger any particular strong emotional engagement (e.g. ‘Andy installed Microsoft Office on his computer at home’); or an upsetting scenario, that is a scenario that could trigger emotional engagement with anger (e.g. ‘Jessica found out that her car had been vandalised’).

Stories had overall similar grammatical and syntax structure across all characters and same length per character. The pilot included 240 scenarios, 24 per fictional character, where each character was the protagonist of 8 happy stories, 8 neutral stories and 8 upsetting stories.

3.3.2.2.3 Procedure

The 240 scenarios were divided into 3 Qualtrics surveys. Subjects participated by accessing a Qualtrics link accessible via the Prolific advertisement. Participants were asked to read the short stories one by one and indicate how they though the character might have felt after having experienced that event. Each trial consisted in a sentence describing the scenario, followed by the question ‘How do you think s/he feels?’ and a 7-point Likert scale going from angry (1) to happy (7) passing from neutral (4). In his way, during each trial, each scenario was rated according to how much it was triggering an angry, happy or a neutral state of mind in the protagonist. Participants had all the time to respond by clicking with the mouse to one of the 7 points displayed horizontally having 1 on the left edge.

3.3.2.2.4 Data analysis and stimuli selection

We first excluded participants with values that exceeded of 3 standard deviations or more from the overall mean (N =2). We then selected 120 scenarios, 40 scenarios per emotion (happy, angry, neutral) with each character being protagonist of 12 scenarios (4 *per* emotion). Criteria for selection were that the average rating for each scenario was the closest to the target emotion.

For the selection of neutral scenarios, we extracted the scenarios with the closest ratings on point 'I think s/he feels neutral' (4 in the Likert scale). For the selection of upsetting scenarios, we extracted the scenarios with the closest ratings on point 'I think s/he feels angry' (1 in the Likert scale). Similarly, for the selection of happy scenarios, we extracted the scenarios with the closest ratings on point 'I think s/he feels happy' (7 in the Likert scale).

3.3.3 Methods

3.3.3.1 Participants

Thirty-four healthy adults (33 females) participated in this study (mean age = 19.3 SD = 0.78). Participants were recruited through the University of Kent Research Participation Scheme system on the university website and all subjects were students at the University of Kent. All the participants declared to be right-handed and with normal or corrected-to-normal-vision. Participants declared to not have allergies to metal or wear a pacemaker. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

3.3.3.2 Materials

3.3.3.2.1 Facial Stimuli

Facial expressions were 40 ambiguous facial expressions and 40 full emotional facial expressions (100% of displayed emotion). The ambiguous stimuli were selected through the pilot study as illustrated above (20 angry, 20 happy). The 40 full emotional faces were the original images used to create the morphs for the selected ambiguous faces.

3.3.3.2.3 Scenarios

The contextual scenario consisted in a brief caption describing an event a character experienced. Scenarios depicted neutral, happy or upsetting setups. 40 neutral scenario, 40 upsetting scenarios and 40 happy scenarios were selected through the pilot study as described above. A list of all scenarios used is presented in Appendix C.

3.3.3.3 Procedure

Participants were invited to seat in front of a computer screen where they read and signed the consent form set in Qualtrics. After that, they read the description of the experiment and a filled in screening questionnaire that double checked whether they meet all the eligibility requirements. Participants were then invited to seat more comfortably and get ready for the EMG electrodes placement. The task and EMG recording took place in an isolated room where a screen connected to the experimenter PC displayed the task. Before the electrode’s placement the experimenter explained the placement procedure, the nature of the measurement and answered to all questions posed regarding the facial EMG measurements. The EMG electrodes spots were rubbed with alcohol wipes before the placement and the impedance was checked through an impedance checker (EL-CHECK, BIOPAC Systems, Santa Barbara, CA). After the electrodes' placement subjects received face to face instructions about the task and left alone to start the task only if ensured that the task was clear. At the beginning of the task, subjects received again written instructions on the screen and no limited time was imposed to read them.

The task involved 120 story-face trials. Each trial (see Figure 3.6) started with a 1000 ms fixation cross followed by a scenario which appeared on the screen till subjects selected to continue. After that, a fixation cross of 1000 ms appeared to keep the gaze engaged at the centre of the screen. The image was then displayed for 1500 ms in grey scale at the centre of the screen. A 7-point Likert scale then appeared till the response was given. For the sake of a cleaner baseline, carryover effects were reduced with a 3000 ms intertrial interval . The task had a break halfway through to increase attentional focus. All actions had to be performed with the mouse. Stimuli were presented on a 27 x 34 cm LCD monitor at a distance of approximately 70 cm from the computer screen.

Electrodes removal was done right after the completion of the task. All participants received a debrief about the real experiment purpose and broader explanations about the purpose of facial EMG measurements.

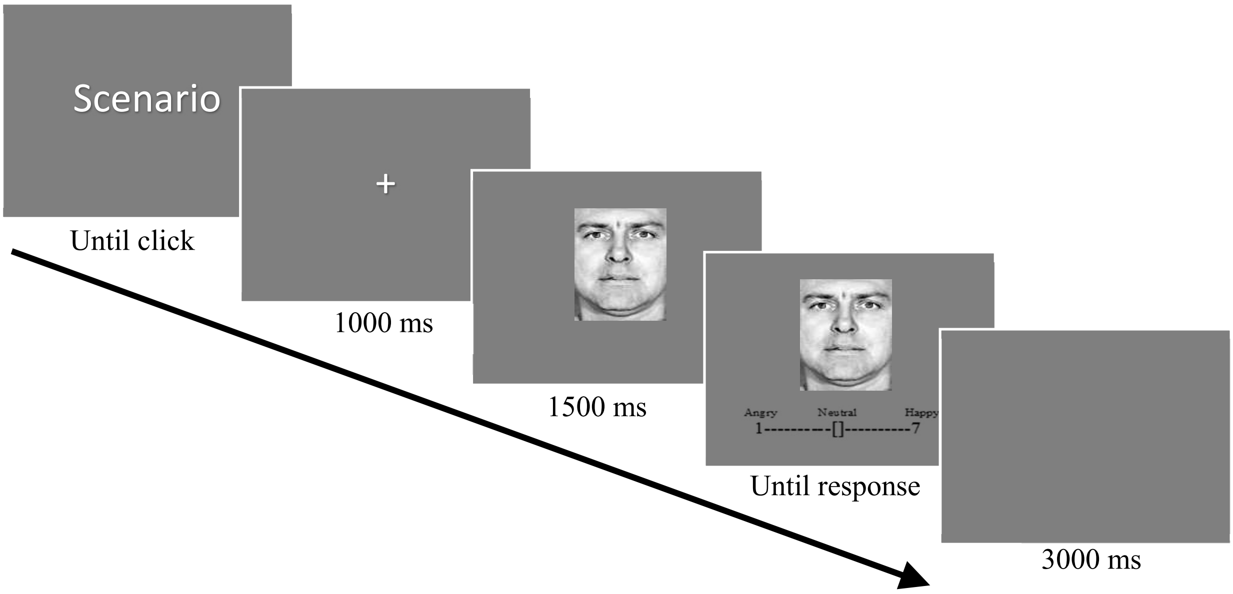


Figure 3.6. Trial timeline (images and text not to scale)

3.3.3.4 Facial EMG

The activity of participants' left *corrugator supercilii* and *zygomaticus major* muscles has been recorded with facial EMG. The electrodes have been placed in correspondence of the corrugator supercilii and zygomaticus major muscles as indicated in the Fridlund and Cacioppo guidelines (Fridlund & Cacioppo, 1986). Facial EMG recording procedure was identical to that reported in the description of previous study. For this study experimenters also took care of cleaning the skin under the areas covered by electrodes until the electrode impedance was brought below 5 kΩ. Impedance was checked through an impedance checker (EL-CHECK, BIOPAC Systems, Santa Barbara, CA).

3.3.3.5 EMG preprocessing

The pre-processing of the raw signal was run in Acqknowledge. Firstly, a notch filter of 50 Hz was applied offline to filter out power line noise of the signal. EMG data were rectified with a

30 ms moving average filter. The signal was then filtered with a linear phase filter using a low frequency cutoff of 400 Hz and a high frequency cutoff of 20 Hz. The signal was then smoothed using a moving window of 30 ms. For both muscles the signal was baseline-corrected with a baseline period of 500 ms extracted from stimulus onset to 500 ms before the stimulus onset. Due to the previous study results and the lack of result suggesting an early and late facial mimicry we decided to analyse the whole-time window, without creating smaller time bins as the purpose of this study was not inspecting the mimicry time course (see section 2.2.2.5 of this thesis). For both muscles we excluded trials whose baseline had an average amplitude of more than 2 SDs of all trials' baseline. The EMG data was then averaged for each condition for each participant and expressed as percentage of the baseline (Korb et al., 2015). Two participants were excluded for the statistical analysis after artefacts rejection. All p values given in 'Results' are not corrected for multiple comparisons (L. F. Barrett et al., 2007; Beffara et al., 2012; F. C. Davis et al., 2016; Hess, U., Fischer, 2014a).

3.3.4 Results

3.3.4.1 Behavioural

A 3-way repeated measures ANOVA with face intensity (full, ambiguous), scenario (positive, negative, neutral) and facial expression (happy, angry) as within-subject variables was conducted on rating scores provided by participants.

A main effect of face intensity was found, $F(33) = 82.6$, $p < .001$, $\eta_p^2 = .715$ with ambiguous facial expressions being rated as generally more negative (M = 3.7, SD = .24) than full emotional facial expressions (M = 4.1, SD = .16; $t(33) = -9$, $p < .001$). A main effect of facial expression was also found, $F(33) = 1249.69$, $p < .001$, $\eta_p = .974$) with angry faces being rated as angrier (M = 2.7, SD = .26) than happy faces (M = 5.1, SD = .27; $t(33) = -35.3$, $p < .001$). The ANOVA also showed a main effect of scenario $F(1.1, 39.2) = 82.6$, $p < .001$, $\eta_p^2 = .498$. Post hoc paired samples t-tests showed that facial expressions were rated as angrier after negative scenarios (M = 3.7, SD = .29) as compared to neutral scenarios (M = 4, SD = .18; $t(33) = -5.6$, $p < .001$) and positive scenarios (M = 4.09, SD = 22; $t(33) = -5.9$, $p < .001$); faces were also rated as happier after positive scenarios as compared to neutral scenarios, $t(33) = -3.8$, $p = .001$.

There was a significant face intensity x scenario interaction, $F(1.9, 65.6) = 4.9$, $p = .010$, $\eta_p^2 = .130$. Exploratory paired samples t-tests showed that (both angry and happy) ambiguous faces were rated as more negative compared to full emotional faces when they were preceded by neutral contextual information (ambiguous faces: M = 3.87, SD = .19; fully emotional faces: M = 4.12, SD = .24; $t(33) = -5.97$, $p < .001$). Ambiguous faces were also rated as angrier than full emotional faces when they were preceded by positive context (ambiguous faces M = 3.94, SD = .28; fully emotional faces M = 4.23, SD = .2; $t(33) = -7.4$, $p < .001$). Similarly, ambiguous faces were rated as angrier with negative scenarios (ambiguous faces M = 3.52, SD = .41; fully emotional faces M = 3.9, SD = .23; $t(33) = -7.33$, $p < .001$). However, ambiguous faces associated with positive scenarios were rated as significantly happier compared to when they were associated with neutral scenarios, $t(33) = -2.24$, $p = .032$ and negative scenarios, $t(33) = 5.43$, $p < .001$. Similarly, ambiguous faces preceded by negative scenarios were rated as angrier as compared to when faces were shown with neutral scenarios, $t(33) = 5.53$, $p < .001$.

On the other hand, fully expressive faces associated with positive scenarios were rated as happier compared to when they were associated with neutral scenarios, $t(33) = -2.96$, $p = .006$ and negative scenarios, $t(33) = 5.7$, $p < .001$. Similarly, fully expressive faces associated with negative scenarios were rated as angrier than when associated with neutral scenarios $t(33) = 4.3, p < .001$.

A face intensity × facial expression interaction was also found, $F(33) = 1407.7, p < .001, \eta_p^2 = .977$, as across all scenarios ambiguous happy faces (M = 4.14, SD = .27) were rated as less happy than fully expressive happy faces (M = 6.21, SD = .38) $t(33) = -32.18, p < .001$. Similarly, across all scenarios ambiguous angry faces (M = 3.42, SD = .3) were rated as less angry than fully expressive angry faces (M = 1.98, SD = .31) $t(33) = 27.83, p < .001$.

Across scenarios ambiguous happy faces were rated as happier than ambiguous angry faces $t(33) = .72 = .000$ see Figure 3.7; the same result was found for fully expressive faces $t(33) = 40.31, p < .001$ see Figure 3.8.

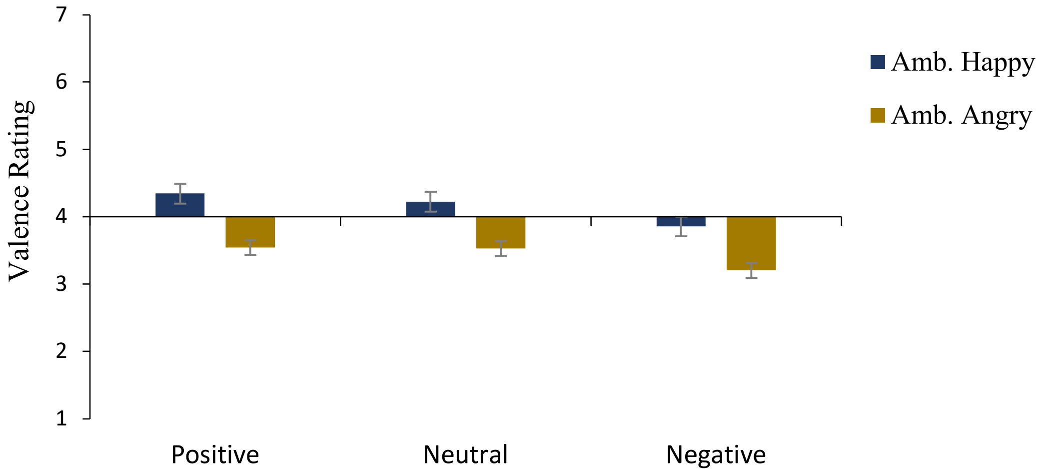


Figure 3.7. Valence ratings of ambiguous happy and angry face expressions; values of the task response Likert – scale: 1 = angry, 4 = neutral, 7 = happy.

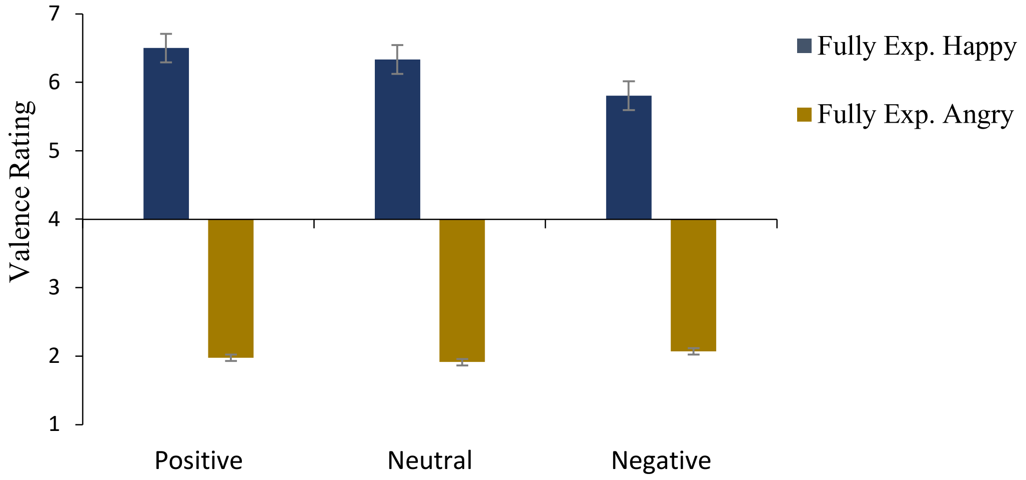


Figure 3.8. Valence ratings of fully emotional happy and angry facial expressions; values of the task response Likert scale: 1 = angry, 4 = neutral, 7 = happy

The ANOVA also revealed an interaction between scenario and emotion, *F(*2.2, .036) = 62.6, $p < .001$, $\eta_p^2 = .655$. Paired samples t-tests showed that both full and ambiguous happy expressions were rated as happier when shown after positive scenarios (M = 5.42, SD = .28), compared to when they were following neutral (M = 5.28, SD = .3; *t(*33) = -3.78, $p < .001$) or negative scenarios (M = 4.83, SD = .38; *t(*33) = -9.02, $p < .001$). Happy faces were rated significantly happier also after neutral scenarios as compared to negative *t*(33) = -9.26, $p < .001$. Interestingly, there was no significant difference across scenarios for angry faces: angry faces associated with negative scenarios (M = 2.63, SD = .32) were not rated as angrier compared to when they followed neutral scenarios (M = 2.72, SD = .29; *t(*33) = -1.56, *p* = .128); angry faces associated with negative scenarios were rated as angrier than when associated with positive scenarios (M = 2.76, SD = .32) only with marginal significance, *t(*33) = -1.93, *p* = .062; angry faces associated with neutral scenario were not rated as angrier than when associated with positive scenarios, *t(*33) =-1.71, *p* = .095.

However, if compared to happy faces, angry faces were rated as angrier following negative scenarios, *t(*33) = -32, *p* < .001, neutral scenarios *t(*33) = -31.91, *p* < .001 and positive scenarios, *t(*33) = -35.88, *p* < .001.

Finally, there was also an interaction between face intensity, scenario and face emotion, *F(*1.2, .033) = 37.9, *p* < .001, η_p = .535. Exploratory paired samples t-tests showed that participants rated ambiguous angry faces shown after negative scenarios (M = 3.2, SD = .46) as less angry compared to fully expressive angry faces associated with negative scenarios (M = 2.07, SD = .26; *t(*33) = 16.57, *p* < .001); likewise, participants rated ambiguous angry faces associated with neutral scenarios (M = 3.52, SD = .28) as less angry than fully expressive angry faces associated with neutral scenarios (M = 1.91, SD = .38; *t(*33) = -22.16, *p* < .001); and participants rated ambiguous angry faces associated with positive scenarios (M = 3.544, SD = .33) as less angry than fully expressive angry faces associated with positive scenarios (M = 1.97, SD = .4), *t(*33) = 27.33, *p* < .001, see Figure 3.9.

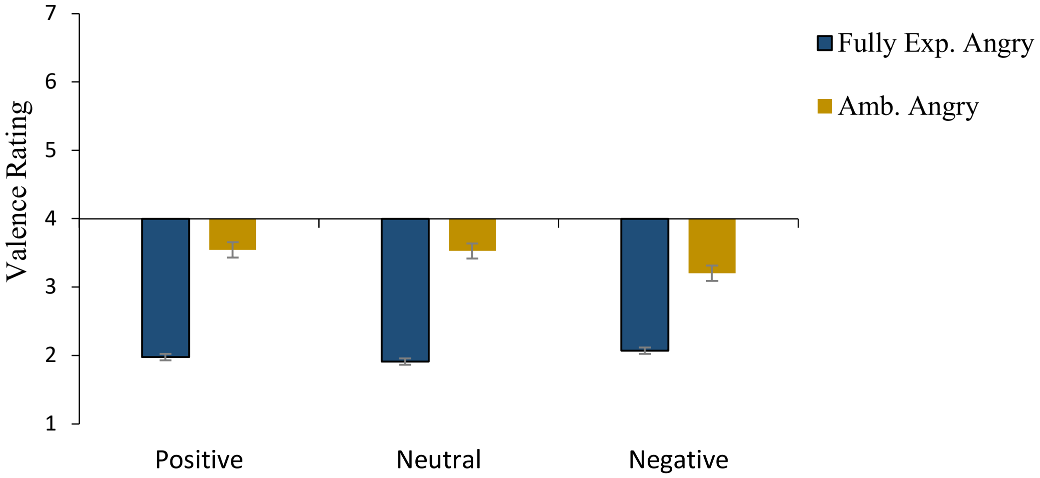


Figure 3.9. Valence ratings of fully expressive and ambiguous angry facial expressions; values of the task response Likert – scale: 1 = angry, 4 = neutral, 7 = happy.

As to happy faces, participants rated ambiguous happy faces associated with negative scenarios (M = 3.85, SD = .46) as less happy than fully expressive happy faces associated with negative scenarios (M = 5.8, SD = .45), $t(33) = -28.86$, $p < .001$; moreover, participants rated ambiguous happy faces associated with neutral scenarios (M = 4.22, SD = .25) as less happy than fully expressive happy faces associated with neutral scenarios (M = 6.33, SD = .45), $t(33) = 27.24$, $p < .001$; and finally, participants rated ambiguous happy faces associated with positive scenarios (M = 4.34, SD = .33) as less happy than fully expressive happy faces associated with positive scenarios (M = 6.5, SD = .37), $t(33) = -30.22$, $p < .001$ see Figure 3.10.

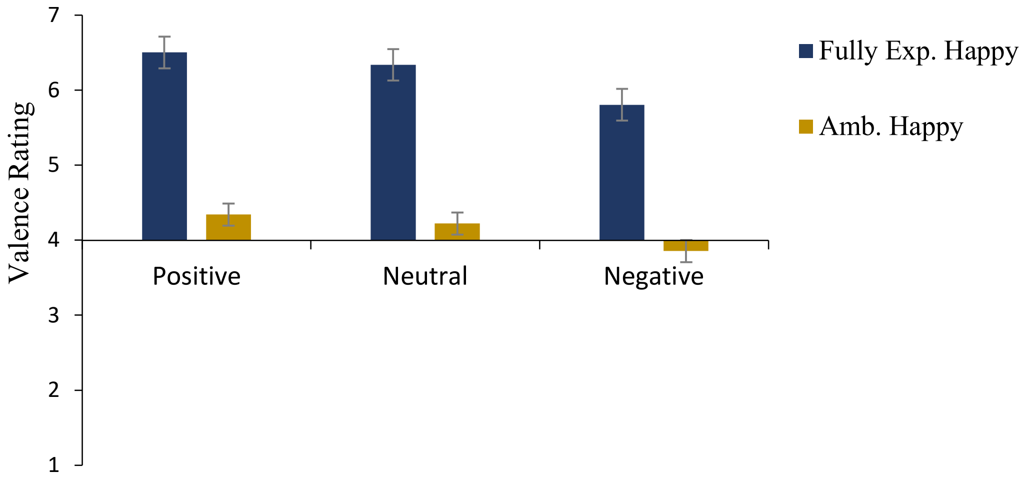


Figure 3.10. Valence ratings of fully expressive and ambiguous happy facial expressions; values of the task response Likert – scale: 1 = angry, 4 = neutral, 7 = happy.

Analyses also revealed that ambiguous angry faces were rated as angrier after negative scenarios as compared to neutral, $t(33) = -4.55$, $p < .001$ and positive scenarios, $t(33) = -4.58$, $p < .001$; however, ratings of ambiguous angry faces shown after neutral scenarios were not significantly different from those of angry faces following positive scenarios *t(*33) = -.43, *p* = .669.

Interestingly, fully expressive angry faces associated with negative scenarios were not rated as significantly angrier than when associated with positive scenarios, *t(*33) = 1.430, *p* = .162 and similarly fully expressive angry faces associated with neutral scenarios were not rated as significantly angrier than when associated with positive scenarios, *t(*33) = -1.62, *p* = .114; however, ratings of fully expressive angry faces following negative scenarios were significantly more negative were compared to those of angry faces following neutral scenarios, *t(*33) = 3.18, *p* = .003. Additionally, exploratory t-tests on happy faces showed that ambiguous happy faces were rated as less happy when preceded by negative scenarios as compared to neutral scenarios, *t(*33) = -5.4, *p* < .001 and positive scenarios, *t(*33) = -5.3, *p* < .001, and were rated as happier when preceded by positive scenarios as compared to neutral, *t(*33) = -3.1, *p* = .004. On the other hand, fully expressive happy faces were rated as less happy if they followed negative scenarios as compared to neutral ones, *t(*33) = -10.37, *p* < .001 and positive ones, *t(*33) = -11.43, *p* < .001; ratings of fully expressive happy faces following positive scenarios were also significantly higher when compared to those following neutral scenarios, *t(*33) = -2.66, *p* = .012.

3.3.4.2 Facial EMG

Separate repeated measures ANOVAs were conducted on *corrugator* and *zygomaticus* activity means with face intensity (ambiguous, full), scenario (negative, positive and neutral) and facial expression (angry, happy) as within-subject factors.

3.3.4.2.1 Corrugator

The ANOVA on corrugator activity showed a main effect of emotion, *F(*33) = 10.94, p = .002, η_p^2 = .249 as the corrugator activated more for angry faces (M = 103.29, SD = 7.61) than happy faces (M = 99.81, SD = 6.17). A significant main effect of scenario, *F(*1.69, 55.89) = 6.34, p = .003, η_p^2 = .191 revealed that the corrugator activated significantly more for faces following negative scenarios (M = 102.84, SD = 7.63) than positive scenarios (M = 100.11, SD = 6.52), *t(*33) = 3.07, p = .001 and more for faces following neutral scenarios (M = 101.71, SD = 5.94) as compared to positive scenarios, *t(*33) = 2.51, p = .017. However, it did not activate significantly more for faces following negative scenarios than neutral scenarios, *t(*33) = 1.24, p = .224. Emotion intensity also modulated corrugator activity, *F(*33) = 10.16, $p < .000$, η_p^2 = .236, as the corrugator activated more for emotions expressed ambiguously (M = 102.54, SD = 6) as compared to full intensity expressions (M = 100.29, SD = 7.2). The ANOVA also showed an intensity × emotion interaction, *F(*33) = 15.42, $p <$ .000, η_p^2 = .318. Exploratory paired samples t-tests showed that the corrugator activated significantly more for ambiguous happy faces (M = 102.36, SD = 6.09) then for fully expressive happy faces (M = 97.27, SD = 7.81), *t(*33) = 4.48, $p < .001$. However, across scenarios, corrugator did not activate significantly more for ambiguous angry faces (M = 103.28, SD = 7.01) then for fully expressive angry faces (M = 103.31, SD = 8.98). Moreover, if fully expressive angry faces triggered corrugator significantly more with respect to fully expressive happy faces, *t(*33) = 4.06, $p < .001$, ambiguous angry faces did not trigger corrugator activity significantly more than ambiguous happy faces, *t(*33) = 1.02, p = .315; see Figure 3.11.

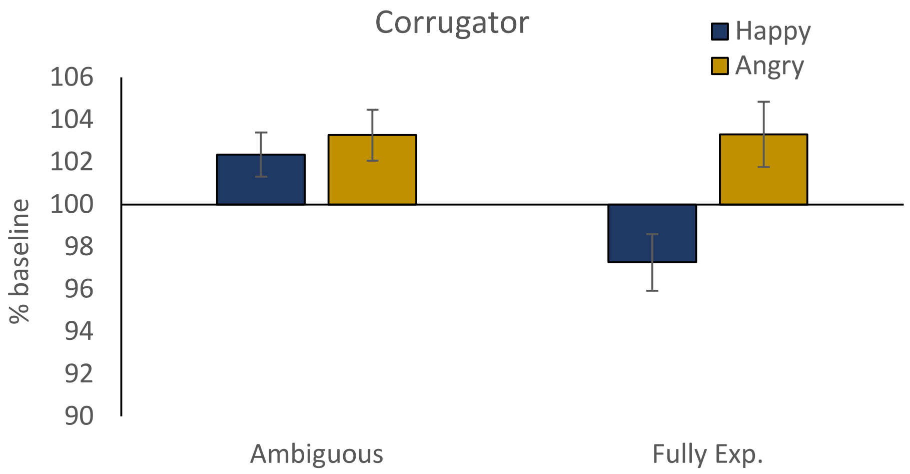


Figure 3.11. Corrugator activity during exposure to ambiguous and fully expressive faces for both emotions.

Lastly, an interaction between scenario and emotion, $F(1.95, 64.37) = 3.84$, $p = .027$, $\eta_p^2 = .104$ was found. Post hoc t-tests showed that, overall, angry faces were not associated with significantly greater corrugator activity across scenarios (negative scenarios: M = 103.58, SD = 8.35; neutral scenarios: M = 103.34, SD = 8.17; positive scenarios: M = 102.96, SD = 8.32). However, angry faces elicited significantly greater corrugator activation as compared to happy faces (M = 100.08, SD = 6.53) following neutral scenarios, $t(33) = 2.15$, $p = .039$ and positive scenarios (M = 97.25, SD = 7.5, $t(33) = 3.71$, $p = .001$). Nevertheless, angry faces did not elicit greater corrugator activation as compared to happy faces (M = 102.1, SD = 8.01) following negative scenarios, $t(33) = 1.46$, $p = .152$. Interestingly, happy faces linked to angry scenarios (M = 102.1, SD = 8.01) elicited corrugator activity significantly more than happy faces linked to happy scenarios (M = 97.25, SD = 7.5), $t(33) = 3.98$, $p < .001$; however they did not elicit greater corrugator activity than happy faces linked to neutral scenarios (M = 100.08, SD = 6.53; $t(33) = 1.51$, $p = .141$); see Figure 3.12.

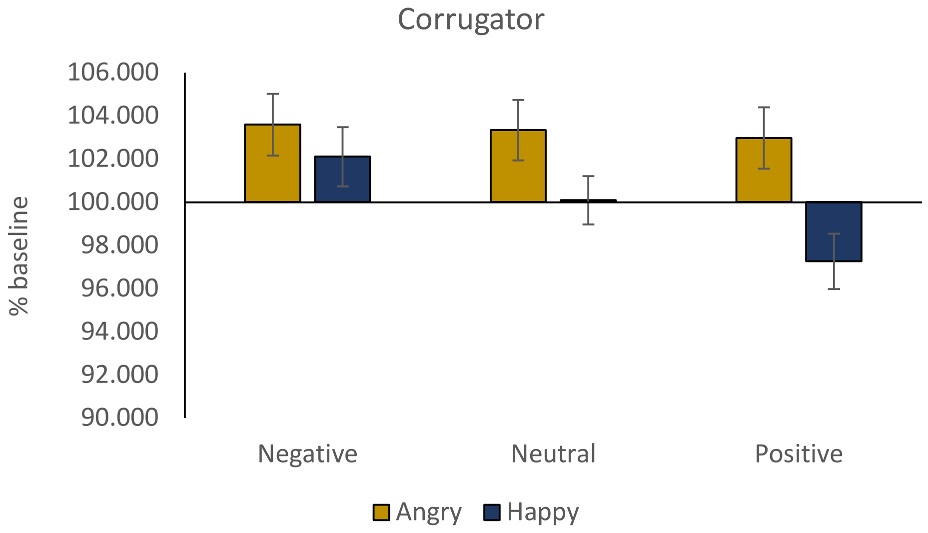


Figure 3.12. Corrugator activity for all happy and all angry faces across scenarios.

3.3.4.2.2 Zygomaticus

ANOVA on zygomaticus activity means showed a marginal main effect of emotion, *F(*33) = 3.44, *p* = .072, η_p^2 = .094 as participants' zygomaticus muscle activated more during exposure to happy faces (M = 101.38, SD = 9.35) compared to angry faces (M = 98.93, SD = 5.93). A main effect of intensity, *F(*33) = 13.81, *p* = .001, η_p^2 = .295 revealed that the zygomaticus had overall significantly greater activations for fully expressive facial expressions (M = 101.46, SD = 7.45) compared to ambiguous facial expressions (M = 98.85, SD = 6.75). The main effect of scenario was also significant, *F(*1.91, 63.2) = 3.81, *p* = .029, η_p^2 = .104, with participants' zygomaticus being activated significantly more during perception of both happy and angry faces following positive scenarios (M = 101.8, SD = 8.34) compared to neutral (M = 99.21, SD = 8.02; *t(*33) = -2.81, *p* = .008) and negative scenarios (M = 99.46, SD = 6.46; *t(*33) = -2.189, *p* = .036). Zygomaticus did not activate significantly more for faces shown with neutral context and negative context *t(*33) = .228, *p* = .821; see Figure 3.13. No significant interactions were found (all *p*s > .05).

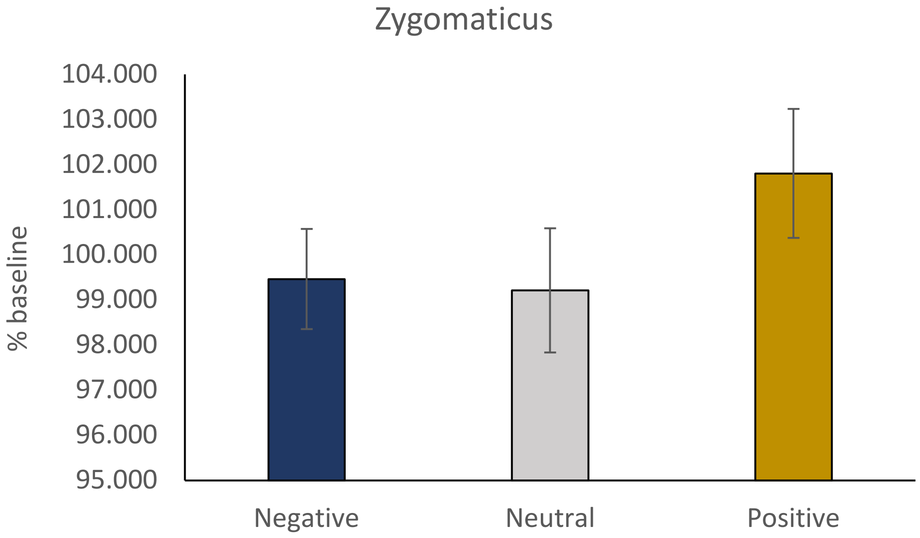


Figure 3.13. Zygomaticus activity for all faces across scenarios.

3.3.5 Discussion

The present study aimed at investigating the role of explicit contextual information on the perception of facial expressions. The study featured both ambiguous and fully expressive facial expressions. The task involved the recognition of happy or angry facial expressions represented either ambiguously or obviously (100% expressive). Recognition was measured with an emotion rating task for which participants had to indicate the valence (if any) of the emotion detected on a 7-point Likert scale going from one emotion to another (happy and angry) passing from neutral. Before giving their response and before seeing the pictures of facial expressions, participants read about expressers' recent life events (e.g. 'Giulia did her laundry this morning'). In this way participants rated each character's facial expressions having just apprehended the specific personal and social context in which the emotion was expressed. This study was based on the assumption that the contiguity of biographical events and pictures of faces expressions fostered the connection between life description and facial expression. With this connection, the study design tried to promote the illusion that the expresser was in fact showing that emotion after having lived the event reported. The facial expression-scenario associations considered in the task were valence congruent (e.g. ambiguous or fully expressive happy faces associated with positive scenarios) as well as valence incongruent (e.g. ambiguous or fully expressive happy facial expressions associated with negative scenarios) or valence neutral (e.g. ambiguous or fully expressive happy facial expressions associated with neutral scenarios). Our participants were asked to recognize happy or angry faces both shown after positive, negative and neutral scenarios. Two pilot studies have been accomplished to create a standardized dataset of ambiguous happy and angry faces as well as a standardized dataset of negative, positive and neutral stories.

Our findings revealed that angry faces were overall rated as angrier, with 1.3 points of difference form neutral. And happy faces were overall rated as happier with 1.1 points of difference from neutral. Results show that when characters expressed their emotions ambiguously, the perception of happiness and anger was lessened. Actors showing ambiguous happy faces have been perceived by participants as less happy. That is, their emotion was rated as lass happy even when they have been introduced by joyful, neutral and upsetting past events. Thus, when characters mildly showed happiness they were judged as less happy, and therefore more emotionally neutral or angrier.

Similarly, ambiguous angry faces have been recognized less than full angry expressions. This effect was found when angry expressions were shown by characters who had negative past life events as well as neutral and positive past life events. In other words, when characters mildly showed anger, they have been judged as less angry, and therefore more emotionally neutral or happier.

Scenarios did, in fact, modulate emotion recognition. Expressions were perceived as angrier when characters were introduced by upsetting life events, with all faces rated as angrier with an average of 0.3 difference from a neutral face; whereas all faces introduced by happy life events have been rated as happier with an average of 0.09 difference from a neutral face. Thus, congruent negative scenarios increased the perception of anger more than congruent positive scenarios did on the perception of happiness.

Our results also showed that the emotional intensity modulated the recognition ability of participants as ambiguous faces were generally rated as angrier. This could indicate that facing an unclear emotion display, the default tendency is to favour the supposition of a threatening attitude. Indeed, characters with happy expressions were considered happier, if participants knew that characters just experienced a positive event rather than a neutral or upsetting event (with ratings consistently decreasing across scenario conditions). So, across all scenarios, characters with happy faces have generally been estimated significantly less angry.

It is worth noting that the same did not occur for angry faces, suggesting that the intensity of the emotional display has a determining role in the perception of anger depending on the context. In fact, fully angry faces were perceived equally angry during both positive and negative scenarios. Characters' anger after upsetting life events was, however, more understandable in respect to neutral life events. That is, anger was perceived as less intense if the expresser did not experience anything upsetting.

As to ambiguous angry faces, the perception of anger was clearer when faces were associated with negative scenarios. Characters' anger after upsetting life events was clearer in respect to both neutral and positive life events. This finding strongly suggests that participants relied much more on the = contextual information when angry faces were ambiguous and difficult to decode. Participants' ability to decode fully expressive anger was in fact not compromised by the positivity of the events the characters just experienced. Hence, knowing about recent neutral or happy life events distorted the perception of ambiguous angry faces, making participants seeing more neutral or happier faces.

An interaction between face intensity and scenario revealed that (both angry and happy) ambiguous expressions have been perceived as angrier (< 4, neutral) than fully expressive emotions. This occurred not only when expressions were linked to negative scenarios, but also when linked to neutral and positive scenarios. Whereas, fully expressive faces were rated as happier (> 4) than ambiguous faces, but only if associated with neutral scenarios, as well as positive.

These findings are in line with literature that reports that ambiguity of expressions can lead to interpret stimuli as negative, giving priority to threatening affective stimuli even if the social context is neutral. On the other hand, obvious expressions, even if angry, bias recognition ability giving priority to positive (or unthreatening) affective stimuli, also when the social context is neutral (e.g. Davis et al., 2016). These findings suggest that participants relied on the contextual information not only when faces were difficult to decode, but also when faces were easy to decode. Indeed, the perception of happiness was greater when characters with ambiguous happy faces just experienced happy events as compared to neutral or negative events (with rating means consistently decreasing across the last two conditions). Obviously happy characters were rated as less happy (and therefore more neutral or angrier) also when they lived neutral or upsetting events (with rating means consistently decreasing across the last two conditions). So, participants rated even obvious happy faces as angrier if the context led towards that interpretation. This suggests that happy faces are easier to be misinterpreted and that the perception of happy faces is more manipulable by context, independently from how equivocal the expression is.

Hence, this study revealed that, in addition to what has been said in the relevant literature, negative scenarios enhanced anger perception more than what positive scenarios did on recognition of happiness. Furthermore, this study revealed that both happy and angry ambiguous faces tend to be perceived as angry. Finally, our results show that participants relied on context during recognition of happy faces, but during recognition of angry faces, participants relied on context only when faces were ambiguous.

Our findings on the corrugator activity means, informed that across scenarios corrugator activated more for angry faces than happy faces. This difference seems to be due to a variance of activation only for fully expressive faces. In fact, fully expressive angry faces increased corrugator activity significantly more than fully expressive happy faces, whereas, ambiguous angry faces have not triggered corrugator activity significantly more than ambiguous happy faces. However, it is worth noticing that corrugator activated equally for all (ambiguous and fully expressive) angry faces, and activated more for ambiguous happy faces than for fully expressive happy faces.

Scenario also modulated corrugator activity as greater activations were found for negative than neutral and positive scenarios (with activity means decreasing accordingly).

Our results also showed that congruency of scenario did modulate the effect of emotions on corrugator activity. Corrugator activated more for happy faces linked to upsetting scenarios than for happy faces linked to happy scenarios. Thus, corrugator activated more for ambiguous happy faces and this activation was greater only when happy faces where shown together with negative scenarios. This last finding is in line with recent theories of simulation that postulate the occurrence of mimicry is critically determined by the ambiguity of the emotion to recognize (Beffara et al., 2012; Seibt et al., 2015).

Findings regarding corrugator activation, strongly suggest that mimicry was elicited, especially when participants had to decode ambiguous faces and in particular during incongruent face-scenario associations. It is remarkable that the corrugator activated even if the actor was not frowning, signifying that facial reactions can occur even without an actual frowning to mimic. This suggests that mimicry is the result of an internal simulation that can be detached from what the recognizer is objectively perceiving. Mimicry might be rather consistent to what the perceiver is 'searching for' (Hess & Fischer, 2014; Korb et al., 2015; Wood, Rychlowska, et al., 2016). In the present case anger was searcher for and clued-up by the upsetting context.

This result is coherent with the fact that, overall, both happy and angry ambiguous faces were rated as angrier. Indeed, corrugator activated more for ambiguous faces than fully expressive faces which have been rated as happier. However, corrugator activation seems to have overall helped recognition of happiness in ambiguous happy faces. Behavioural results confirm that participants' recognition ability for ambiguous happy faces was not disrupted by the ambiguity of expressions. Ambiguously happy characters were judged as less happy when they just experienced negative events as compared to neutral and happy events (with rating means consistently increasing across the last two conditions). This suggests that participants facing ambiguous happy faces not only relied more on the biographical context information, but also on internal emotional simulation.

Our findings on the zygomaticus activity means revealed that zygomaticus activated more for happy faces and for fully expressive emotions which, as mentioned above, have been generally rated as happier. Zygomaticus activated more for faces showed with happy scenarios (with means decreasing progressively for neutral and negative scenarios). However, no interactions have been found between intensity and emotion or scenario. Thus, zygomaticus did not activate significantly more for ambiguous faces or incongruent face-scenario conditions. Behavioural findings indicate that recognition of happy faces has been overall successful across both emotion intensities. If a simulation occurred, it is arguable that it favoured the recognition even of ambiguous happy faces and even if linked to negative scenarios. However, mimicry of ambiguous happy faces, or of happy faces during incongruent scenarios was not detected (i.e. zygomaticus activity was not significantly greater). Moreover, zygomaticus did not activate more for ambiguous angry faces shown after positive scenarios, as it occurred for the corrugator. In light of this, we argue that, if simulation of happy faces occurred, it did not originate mimicry reactions on the zygomaticus. Ambiguous faces have been in fact overall rated as angrier and the corrugator mimicked ambiguous happy faces during incongruent scenarios. This suggests that although the incongruency of scenarios made ambiguous happy faces particularly hard to detect, mimicry on corrugator did facilitate detection of happiness.

3.3.6 Conclusions

In conclusion, ambiguity of facial expressions and incongruent context appear to charge more recognition ability, especially for happy faces. Our findings also suggest that when facial expressions are embedded in an equivocal context, mimicry occurs when an internal simulation might significantly facilitate a laborious recognition (such as with ambiguous expressions). Moreover, we argue that, in these cases, mimicry might play a crucial role in the formation of a final judgement in a trial-and-error step leading to successful recognition. Finally, the present study suggests that mimicry is not a reaction to what the observer is seeing, but to what the observer think they know about the other person's emotion.

3.4 General discussion

Observing emotional facial expressions often produces facial muscular reaction in the observer's face that reflect the emotion seen. Research on facial EMG reactions during facial expression recognition showed that these facial reactions rapidly engage the same muscles activated during the production of the expressions perceived remaining, more or less, timely locked to the period of recognition (Dimberg, 1982; Wingenbach et al., 2020; Wood et al., 2016). Giving the mirroring nature of the reaction, researchers called it mimicry, as an automatic, involuntary and implicit motor response triggered by exposure to facial expressions (U. Dimberg, 1982). Mimicry is involved in many affective as well as social processes, such as empathy and emotional contagion (U. Dimberg et al., 2011; Hatfield et al., 1992). It has been traditionally considered that facial mimicry always occurs in case of appraisal of an affective stimulus (Dimberg et al., 2000) that triggers the activation of corresponding muscles (e.g. an increase of the zygomaticus muscle activation to mimic smiling faces).

Despite the increasing number of studies and authors that suggest the crucial role of situational context during the recognition of facial expressions and on mimicry reactions, there are still few studies that take it into account. Real life sees us interacting with people knowing who they are and their past, or at least the context in which our interaction is surrounded (Philip et al., 2018).

According to the 'Emotion Mimicry in Context Model' proposed by Hess and Fisher (Hess & Fischer, 2014), the appearance and intensity of mimicry is crucially influenced by the contextual signals and the affective intentions deduced by the recognizer. Even though many factors can modulate the recognition and mimicry of facial expressions, such as gaze and hand gestures (Philip et al., 2018), the studies presented in this chapter focused on the influence of social and biographical information consciously acquired from the perceiver before exposure to facial expressions (Moody et al., 2007; Seibt et al., 2015; Weyers et al., 2009).

Our first study aimed at investigating the role of affective biographical information (i.e. information about the recent past of the expresser) on the ability to recognize emotions and facial EMG rapid reactions tendencies. The study explored the effect of conscious acquisition of biographical notions about the expresser. With the ‘language-as-a-context hypothesis’ Barrett and colleagues affirm that the perception of others’ emotions is formed by both the external and internal context of it (L. F. Barrett et al., 2007). The external context is generated by all the semantic elements linked to the face perceived, while the internal context is the emotional mindset of the perceiver. The authors sustain that both contexts are shaped by conceptual knowledge acquired linguistically prior to the perception and that is ‘re-enacted’ during the perception (L. F. Barrett et al., 2007). In light of this hypothesis, the main study assumption was that reading the affective biographical scenario of the expresser would have prepared the perceiver mindset and biased her/his judgement. The study featured timely closed associations of brief biographical stories and pictures of facial expressions. Associations were congruent (i.e. negative scenarios and angry expressions; positive scenario and expressions), incongruent (negative scenario and happy expressions, positive scenarios and angry expressions) as well as neutral (neutral scenarios and happy or angry expressions). The context information was therefore given through language in a sentence-long-story that referred to a fictional character (e.g. ‘Giulia successfully passed her PhD VIVA’). The intent was to give a sense of familiarity supported by the direct association to a named fictional character (such as ‘Giulia’).

In line with the language-as-a-context hypothesis’, our results showed that giving context information through consciously acquired brief life stories modulate the perception of emotional facial expressions. Study 2 results in fact revealed that the contextual knowledge can augment or suppress the emotionality of the expression perceived.

Expression-congruent facial EMG reactions were detected, with greater zygomaticus activity in reaction to happy faces and greater corrugator activity in reaction to angry faces. EMG reactions occurred during both congruent and incongruent scenario-expressions associations. We argued that simulation (measurable through recognition-led mimicry) occurred only during incongruent scenario-expression association for angry faces, whereas valence congruency triggered merely automatic default rapid EMG reactions. Indeed, EMG reactions did not occur concomitantly with the extent of change in recognition ability; presumably, if simulation occurred aided by the EMG reactions found, recognition ability would have been significantly supported.

On the other hand, the difficulty of the recognition task given by incongruent contexts (especially linked to angry faces), led participants to rely more on context information whose valence affected mimicry (Seibt et al., 2013; Lindquist, Barrett, Bliss-Moreau, & Russell, 2006, Halberstadt & Niedenthal, 2001; Barrett, Lindquist, & Gendron, 2007).

In accordance with the Language-As-A-Context Hypothesis (L. F. Barrett et al., 2007), in this study, the context influenced the perception of facial expressions by guiding the perceiver’s processing. Moreover, in accordance with the sensorimotor ST, the difficulty of the task seemed to have triggered an internal simulation consistent with the scenario, but that still led to a successful recognition of the actual emotion perceived.

Given the results discussed above, a second study was carried out, with a similar procedure and methods. This second study considered ambiguous expressions together with clear-cut facial expressions. Results revealed that the ambiguity of expressions as well as the incongruency of scenarios disrupted the recognition. This study too showed results in line with the Language-As-A-Context Hypothesis, as incongruent scenarios made participants perceive angry faces less angry and happy faces less happy. Similarly, congruent scenarios made participants perceive angry faces angrier and happy faces happier.

Findings of Study 3 also informed that the expression intensity has a determining role in the perception of anger (and not happiness) depending on the context. In fact, the perception of anger in ambiguous angry expressions was clear only when faces were associated with negative scenarios, while it was always clear for fully expressed anger.

Moreover, all ambiguous expressions (happy and angry) were rated as (more or less) angry, whereas fully emotional happy and angry expressions have been rated as (more or less) happy. This second study also showed that, characters with happy expressions were considered happier if participants knew that the characters experienced a positive event rather than a neutral or upsetting event (with ratings consistently decreasing across scenario conditions). Fully angry faces have been perceived equally angry during both positive and negative scenarios. The perception of anger in ambiguously angry faces was, however, clear only when faces were associated with negative scenarios. This finding suggests that participants relied more on the context during the recognition of happy faces in general, but, only if ambiguous, for angry faces. In this study, both the corrugator and the zygomaticus showed greater mimicry-like responses for fully expressive faces, with the zygomaticus activating significantly more than the corrugator for happy faces and the corrugator activating significantly more than the zygomaticus for angry faces. Ambiguous angry faces have not triggered corrugator activity significantly more than ambiguous happy faces and ambiguous happy faces have not triggered zygomaticus activity significantly more than ambiguous angry faces. However, corrugator activated during the recognition of ambiguous happy faces linked to incongruent (upsetting) scenarios.

This finding, together with findings of the previous study, strongly suggests that mimicry is elicited when the recognition is particularly difficult, for instance in front of an ambiguous face and/or during incongruent face-scenario associations. All results taken together suggest that recognition ability as well as mimicry are greatly affected by linguistic contexts. Moreover, all results taken together suggest that during a sensorimotor simulation, mimicry can reflect the interpretation of the perceiver, not necessarily mirroring the facial expression displayed. Such a simulation leads to successful recognition.

In conclusion, both the ambiguity of facial expressions and/or the affective incongruency of linguistic context challenge the recognition ability of happy and angry faces. Findings suggest that sensorimotor simulation supported by mimicry occurs especially during laborious recognition. Moreover, we argue that mimicry can promotes recognition via a trial-and-error examination of the emotion perceived, whereby, during the interpretation, an emotion can be mimicked as verification prior to successful recognition.

Chapter 4

The role of mentalising and facial mimicry in emotion recognition

4.1 General introduction

Theories of emotion processing state that the psychological course that leads an individual to identify someone’s state of mind can be divided into an early perceptual stage and a late conceptual state. The first stage involves the formation of a representation from the perceptive element coming from occipital cortex. Once facial features are formed, they are then automatically matched to existing schemas that are linked to emotional classes (Kaminska et al., 2020).

Recent studies suggest that the phenomenon of facial mimicry occurring during the observation of facial expressions has a crucial role during the process of recognition. As described in Chapter 1, according to STs facial mimicry represents an internal simulation necessary for accurate and fast recognition of facial expressions (Oberman et al., 2007; Ponari et al., 2012). Previous results suggest a dissociation between a spontaneous mimicry, which would aid fast adaptive judgements of the other person's expression, and a voluntary modulation over mimicry, which would be at play when a more explicit categorisation of the emotion is needed (Eisenbarth et al., 2011; Korb et al., 2010). Moreover, it has been demonstrated that using posed photographs of straightforward facial expressions does not provide strong reliable experiment conditions to measure the extent to which internal simulation (and eventual mimicry) aid the recognition process (e.g. Hess & Fischer, 2014; Krumhuber et al., 2014; Seibt et al., 2015). Indeed, laboratory experiment need to collect data in an experimental environment that, although as controlled as possible, is able to use stimuli that in so far as possible replicate real life stimuli so that data might reflect what processes are at play during social interactions in our daily life. Real life sees us encountering and having to distinguish everyday a variety of emotions, the majority of them being presumably more subtle and complex than what is often shown in laboratories with standardized datasets of expressions.

The reasons mentioned above are some of the motives for which research in this matter still fails to provide with a clear understanding of how simulation and relevant peripheral facial activation contributes to inferential processes during recognition tasks. One aspect that still continues to be debated in literature is the timing of simulation during the entire process of recognition (Wood, Rychlowska, et al., 2016). Lack of clarity seem to regard in particular not only central-cognitive simulation onset when present, but also peripheral muscle activations representing simulation in respect to stimulus onset (e.g. mimicry onset time). To better understand the underlying process of the understanding of emotional expressions and investigate the existence various stages researchers often used the observation of event related potentials (ERPs). A study by Calvo and colleagues (2013) revealed that faster correct categorization of emotional facial expressions elicited an enhanced ERP component referred to as Early Posterior Negativity (EPN). Greater EPN was elicited by happy and angry faces, but not by fearful, sad as well as neutral faces. This finding suggests that both happy and angry faces recognition process is cognitively salient at this stage. Calvo and colleagues argue that the processing of the affective content occurs quite early, namely between 150 and 180 ms after face expression onset. However, at this stage no actual discrimination between emotions takes place, but only a detection of negative valanced emotions compared to neutral emotions. A finer distinction of expressions occurs between 200 and 320 ms as indicated by EPN greater activity for happy and angry faces as compared to fearful and sad faces.

EPN has been consistently observed to index enhanced attention allocation to emotional stimuli (Schupp et al., 2007). It has been shown that EPN is modulated by both emotional scenes and objects (Schupp et al., 2004) as well as emotional faces (Holmes et al., 2008) EPN is therefore believed to indicate the processing of emotional valence of facial expressions (Calvo & Beltrán, 2013). According to Calvo and Beltran (2013), between 200 and 320 ms EPN is modulated by expression intensity, so that higher intensity makes the encoding easier. However, at this stage there is not still a specific detection of intrinsic affective aspects of facial configurations. Therefore, 'augmented EPN would reveal easiness of expression encoding due to higher arousal' (Calvo & Beltrán, 2013, page 2057). EPN has been, indeed, traditionally reported to be sensitive to emotional arousal (Olofsson et al., 2008), and emotional intensity (Lang & Bradley, 2010).

In a combined EEG-EMG study conducted by Davis and colleagues (2017) it was shown that the N400 ERP component was affected by the interference with face movements during the recognition of facial expressions. N400 is thought to be involved in the retrieval of semantic information form faces (Davis et al., 2017). It is believed that a greater N400 (more negative) represents an effort to extract meaning from a facial configuration (Kutas & Federmeier, 2011). In the study by Davis and colleagues, participants performed a face expression recognition task while holding a chopstick between their lips. Results showed that the detection of facial expressions related to the movement of the lower face (happiness and disgust) was disrupted, and that these same facial expressions elicited greater N400 during the interference conditions.

4.2 Overview of the ERPs involved in emotion recognition

The aim of the following two studies is to investigate occurrence and timing of cognitive-central internal recognition and, if any, occurrence and timing of peripheral simulation related to recognition of emotions expressed through the face. Both studies featured different intensities of emotions to lower in so far as possible the artificiality of face expressions presented through pictures of actors' faces and to investigate a potential modulation of intensity on the recognition ability measured behaviourally and physiologically.

During both studies, EEG activity was recorded together with facial EMG activity of corrugator and zygomaticus while participants had to perform an emotion recognition task. Accuracy and reaction times of participants' response was also recorded.

Measuring EEG and EMG activity concomitantly will allow us to observe whether there is in fact a relationship between peripheral EMG activations and central-cognitive emotion processing occurring during emotion recognition tasks. Furthermore, measuring participants' EEG and facial EMG concomitantly will allow us to investigate whether relevant EMG components change during relevant ERPs augmentation.

The first study aimed at investigating the time course of central cognitive processing and EMG reactions during fast valence judgements. The second study aimed at investigating the time course of central cognitive processing and EMG reactions during explicit categorisation of facial expressions. The two studies, namely the valence task study and the categorization task study were investigated via two separate experiments.

Facial mimicry was measured recording the activity of participants' left *corrugator supercilii* and *zygomaticus major* muscles. The time course of the signal of both muscles will be compared to the time course of ERPs traditionally linked to emotional face expressions processing, as reviewed below. Previous research that reported facial mimicry timing observed the major activation approximately 500 ms after stimulus onset lasting up to 1500-2000 ms after stimulus onset (Spapé et al., 2017). Discrimination of affective arousal (i.e., angry vs happy) has been traditionally observed in the EPN components (200-350 ms) (Kü necke et al., 2014); the conceptualisation/semantic processing independent from valence has been observed in the N400 component (350-540 ms) (Balconi & Lucchiari, 2005; Figure 4.1).

Temporo- occipital EPN- early discrimination of valence (positive vs negative)

Anterior fusiform gyrus N400 – conceptualization /semantic processing

Figure 4.1 – ERPs of interest.

EPN is a negative ERP. Its waveform has its peak around 200-350 ms after stimulus onset. EPN is a component generally modulated by the emotional valence of the stimulus. EPN has traditionally been linked to attempt of a discrimination of the affective intensity or arousal of a stimulus (i.e. angry face or a happy face). Its activity is generally believed to indicate the ongoing attention engagement initiated by the effort to process emotional content (Calvo & Beltrán, 2013). The neuronal substrates of its activity are believed to be groups of neurons in the temporo-occipital cortex.

N400 is a negative ERP. Its waveform has its peak around 400 ms after the appearance of the stimulus. It is generally believed that the neural activity that creates this waveform is in the anterior fusiform gyrus and the closest ventral temporal areas (Schweinberger & Burton, 2003). Hayasaka (2016) links its activity as expression of the lateral prefrontal cortex, superior temporal sulcus and inferior occipital gyri. Previous research has found N400 peaking during emotional faces perception during a medium late recognition process. In other words, its activity should coincide with the occurring attempt to conceptualize the muscle configuration of the face perceived and to assign a semantic value to it (Davis et al., 2017).

4.3 Study 4

Time course of central neurocognitive processing and EMG reactions during fast valence judgements. A simultaneous EEG and facial EMG study.

4.3.1 Introduction

Facial mimicry is considered to crucially influence a successful understanding of others' feelings. According to some studies mimicry occurrence and behaviour would promote particularly fast and 'effortless' detections of facially expressed emotions (e.g. Hess & Fischer, 2013). Facial mimicry is generally believed to be an induced motor resonance determined by a peripheral-central connection between sensorimotor brain regions and facial muscles (Schütz-Bosbach & Prinz, 2007). It has been traditionally though that mimicry is an automatic reflexive reaction that mirrors the muscular activity of the expression observed.

Researchers generally agree with the assumption that subliminally presented affective stimuli are nevertheless processed (e.g. Flynn et al., 2017). A substantial body of research shows that unconsciously detected stimuli are analysed and can affect not only perceptive but also cognitive functions (Lin & He, 2009).

Although the majority of research on recognition of affective stimuli considers consciously appraisal of stimuli, a vast literature is also present that reports that even complex affective processes are carried out with little or without conscious awareness (Epstein, 1994).

A study by Kunst-Wilson and Zajonc (Kunst-Wilson & Zajonc, 1980) for example has reported that affective visual stimuli rapidly presented stimuli modulated judgments of stimuli processed with more awareness. It has also been reported that affective meaning can be modulated without explicit processing measured with EEG and EMG responses (Bunce, 1999). A number of studies show that such EMG reactions can occur even when stimuli were presented subliminally, and even in these cases EMG relevant activity started within 500 ms after face onset (Dimberg et al., 2000). Pictures of happy and angry facial expressions have been found associated with mimicry reactions when shown consciously and unconsciously (Dimberg et al., 2002). Some researchers suggest that recognition of rapidly perceived facial expressions is greatly determined by the activation of amygdala (e.g. Adolphs et al., 1994). In particular, it has been suggested that subliminally presented face expressions are processed without any cortical mediation passing directly form the thalamus to the amygdala (Morris et al., 1999). However, a study by Bailey and colleagues (2009) reports that rapidly presented happy and angry faces expressions are mimicked and they argued that a cortical route is necessary if the task imposes emotion detection. Indeed, Morris and colleagues (Morris et al., 1999) claim that the involvement of a cortical pathway is necessary if the task asks to carry out a linguistically engaged labelling of emotions perceived.

Literature suggests that affective valence detection tasks are the most effective measures of emotion detection and able to explain more variance (Lang et al., 1993). However, literature on sensorimotor simulation and mimicry has not yet fully clarified the way valence detection is processed. For instance, some researchers postulate that valence guided emotional processing is guided by a sole bipolar pleasant – unpleasant trajectory (Russell & Carroll, 1999) or a system that involved separated evaluation processes, one for negative stimuli and one for positive stimuli (Davidson, 1998). A study by Coll et al. (Coll et al., 2019) found that the lowest threshold of stimulus presentation to promotes the integration of the perceptual features of emotional stimuli with actions related to them is 100 ms. This study also found that emotional stimuli are processed together so that the central-cognitive appraisal is integrated with a sensorimotor response when the emotion presented is task relevant. Indeed, even though reactions to affective stimuli may occur rapidly, their central and sensorimotor integration requires at least 100 ms. Therefore, according to this study, 100 ms seems to be time from which the appraisal of visual emotional content can interact with motor responses, as no such effects have been found with stimuli presented for 14 and 28 ms.

The literature that investigated how fast supraliminal face expressions appraisal elicits internal simulation and mimicry reactions during facial expressions still rather poor. According to our knowledge, no study had investigated both neurocognitive and peripheral physiological reactions (i.e. both EEG and facial EMG activity) during recognition of fast presented face expressions. The main purpose of the present study is to examine brain responses as well as facial EMG responses to emotional face expressions presented for 100 ms.

It has been consistently reported that the EPN is a cortical ERP component sensitive to emotional face expressions (e.g. Mavratzakis et al., 2016) and modulated by expression valence (Calvo & Beltrán, 2013). EPN is thought to represent the facilitated processing of emotional stimuli (Harald T. Schupp et al., 2004). EPN amplitude reflects the firing of groups of neurons of the parieto-temporo-occipital regions (Junghofer et al., 2001) revealed that emotional pictures elicited greater activations in the occipital fusiform, cuneus and calcarine, in the temporal gyrus and in the supramarginal gyrus areas which are supposedly the areas activated for EPN. In a recent ERP- facial EMG study by Davis and colleagues (J. D. Davis et al., 2017) the control group performed a face expression recognition task while holding a chopstick between the lips to investigate how interreferences with sensorimotor facial signals influenced central processing of face expressions. The study revealed that the N400 had greater amplitudes during the interference conditions. This result suggest that N400 is sensitive to more demanding emotional processing when the task requires to detect and label emotional face expressions. These results also suggest that there’s more need to activate semantic representations of emotions when mimicry is impaired, suggesting a causal role of mimicry in recognition and an inverse relationship between mimicry and N400 amplitude, which is one of your hypotheses.

4.3.2 Aims and hypotheses

The present study focuses on the aspect of valence of facial expressions (i.e. positive and negative facial expressions). Facial mimicry was measured recording the activity of subjects’ left *corrugator supercilii* and *zygomaticus major* muscles. The time course of the signal of both muscles will be compared to the time course of EPN and N400. Pictures of low intensity, medium intensity and high intensity face expressions have been used together with neutral face expressions. We expect to replicate the finding that facial muscles are activated during observation of correspondent facial expressions. We also hypothesise that higher intensity levels of emotion expressed will be associated with facial expression recognition accuracy and RTs. Furthermore, we expect that mimicry will occur more during conditions of low intensity facial expression. We expect a modulation of EPN and N400 amplitudes related to mimicry occurrence (i.e. before, during or after ERPs onset). The nature of such modulation is, however, unpredictable for us, as no study has ever before explored it.

4.3.3 Methods

4.3.3.1 Participants

Forty-one participants took part in this study (26 females; mean age = 24.4, age SD = 8). Participants were recruited through online adverts (e.g. via Facebook and Kent Union’s

JobShop) and flyers placed in several buildings at the University of Kent. All participants declared to be right handed and with normal or corrected-to-normal vision, were neurologically healthy, and were not under psychoactive medication (e.g. antidepressant medications). They declared not to have allergies to metal, and declared that they were not wearing a pacemaker. They did not have braids/dreadlocks/hair extensions/bold head that would have impeded a proper placement of the EEG electrodes. All participants gave an informed consent to participate to the present study. Participants compensation for participating to the study was 17, 5£ (6£ an hour). Fifteen participants were rejected due to technical problems with the online EMG filtering (subjects 1-15) and 2 participants were excluded due to excessive behavioural missing responses (subjects 33-34) from the task. Consequently, analyses below included data from 26 participants. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

4.3.3.2 Stimuli

Images were static posed emotional face expressions and were selected from the Karolinska Directed Emotional Faces Database (D. Lundqvist et al., 1998). These included pictures of 48 (24 females and 24 males) actors depicting happy, angry, fearful or neutral facial expressions. Each picture of emotional expressions were morphed with the neutral face of the corresponding actor using Morpheus software to create different emotional intensities[1]. Of the 21 resulting frames (where frame 1 = neutral face and frame 21 = original emotional face), we selected frames 5 (low intensity), 9 (medium intensity) and 13 (high intensity) across the neutral-emotional continuum. Faces were shown on frontal display. Pictures were

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[1] From the Karolinska Directed Emotional Faces Database the following actors have been selected: F01, F02, F03, F04, F05, F06, F07, F08, F09, F10, F11, F13, F14, F16, F17, F18, F19, F20, F21, F22, F23, F24, F25, F26, M01, M02, M05, M07, M08, M09, M10, M11, M12, M14, M17, M21, M22, M23, M24, M25, M27, M28, M29, M30, M31, M32, M34, M35.

converted to grayscale, cropped at the hairline to exclude hair and ears so that only the face was visible, resized to 307 x 417 pixels with a resolution of 100 dpi and saved as .jpeg using Adobe Lightroom v.6 (see Figure 4.2 for sample stimuli).

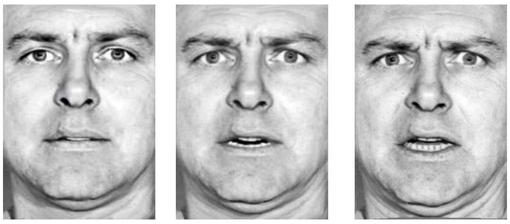


Figure 4.2. Sample stimuli depicting the different emotional intensities: 20% (low intensity), 40% (medium intensity) and 60% (high intensity) across the neutral emotional continuum.

4.3.3.3 Procedure

Subjects read and signed the consent form set in Qualtrics. They then read a description of the experiment and the methods used and a filled in screening questionnaire that double checked whether they meet all the eligible requirements. The EEG/EMG setup then took place. Participants' heads were measured to select the most appropriate EEG cap size. The cap fit quite tightly on the participants head, but not too tight to create discomfort. Skin areas around the mastoids, temples, above/below the right eye, left eyebrow’s hairline and left cheek were wiped with alcohol wipes. Areas of the scalp below the electrodes were lightly abraded using a blunt needle, and then gel was applied with a syringe. Participants were demonstrated every step in advance, so they knew what to expect, and all precautions were taken to avoid causing any discomfort. After all electrodes were placed and impedance was checked, participants received face to face instructions about the task and were left alone to start the task only if ensured that the task was clear.

The task featured a series of 576 trials, split in 10 short blocks of about 5-minute duration to minimise fatigue. Stimuli were presented one at time on a 27x 34 cm LCD monitor at a distance of approximately 70 cm from participant's face. Participants performed the task with the lights off and the room was free from other electrical devises to minimize environment electrical noise. Participant were repeatedly told to stay as still as possible and to keep their gaze at the fixation cross at the middle of the screen to minimize eyes and muscles movement artefacts on the EEG and EMG signal. Participants were free to rest as much as they wanted during each break. Due to the sensitivity of EEG and EMG electrodes to blinks, participants were asked to hold their blinks until a screen that prompted them ("BLINK"). However, they were told that, if they felt restrained or uncomfortable, they could have blinked naturally and ignored the 'BLINK' screen.

Subjects received again written instructions on the screen at the beginning of the experiment. Subjects were invited to read the instructions carefully and press the spacebar to continue once the finished reading. Before the task, participants performed 20 practice trials to practice the speed of the task. The procedure of the training task and the format of the pictures presented was identical to that of the actual task except for the stimuli presented. Practice stimuli were photographs of one single female actor displaying all emotions and intensities. This actor was not used for the experimental trials.

The task involved participants to look at a 500 ms fixation cross, then to a picture of a facial expression (either happy, angry, fearful or neutral) presented for 100 ms, followed by a blanc screen of 1900 ms, after which participants were prompted to perform a valence judgement (see Figure 4.3). Rather than asking participants to indicate whether the face presented was positive or negative, as in a standard valence judgment task, in order to account for the presence of emotionally neutral stimuli in our task we asked participants to indicate whether the face presented expressed a negative emotion. The question 'Is the emotion negative?' appeared on the screen for a period up to 3000 ms and the participant was invited to respond using the buttons M and Z for 'YES' and 'NO'. An adjustable blank screen appeared if the 3000 ms were not used up, filling the remaining time (i.e. 0 ms if all 3000 ms were spent). The ‘Blink’ screen then appeared for 250 ms followed by a 500 ms fixation cross. The appearance of faces was randomized, the response hand as well as the order of the buttons was counterbalanced. Subjects could press the keys to give their answer once they saw the question and the labels on the screen. Subjects were told that faces flashed up very quickly on the screen, so on some trials they might have found it difficult to give an answer. In these cases they were invited to guess. Subjects were invited to try their best to be as fast and as accurate as they could when they were prompt to give their answer.

For each block, the task was started from the experimenter once the EMG and EEG signal was steady enough. The subjects were told that the experimenter would start the task as soon as they found their positions and got still with their eyes on the fixation cross. All participants had a longer break halfway through the task to prevent tiredness. In very rare cases of extremely noisy electrodes or total signals loss the experimenter had to pause the experiment abruptly, rather than wait for the next break, to restore the electrode’s connection. At the end they were provided with shampoo and towels to wash the gel off the hair and a hairdryer. Subjects could wash their hair in the labs’ kitchen located in the same area.

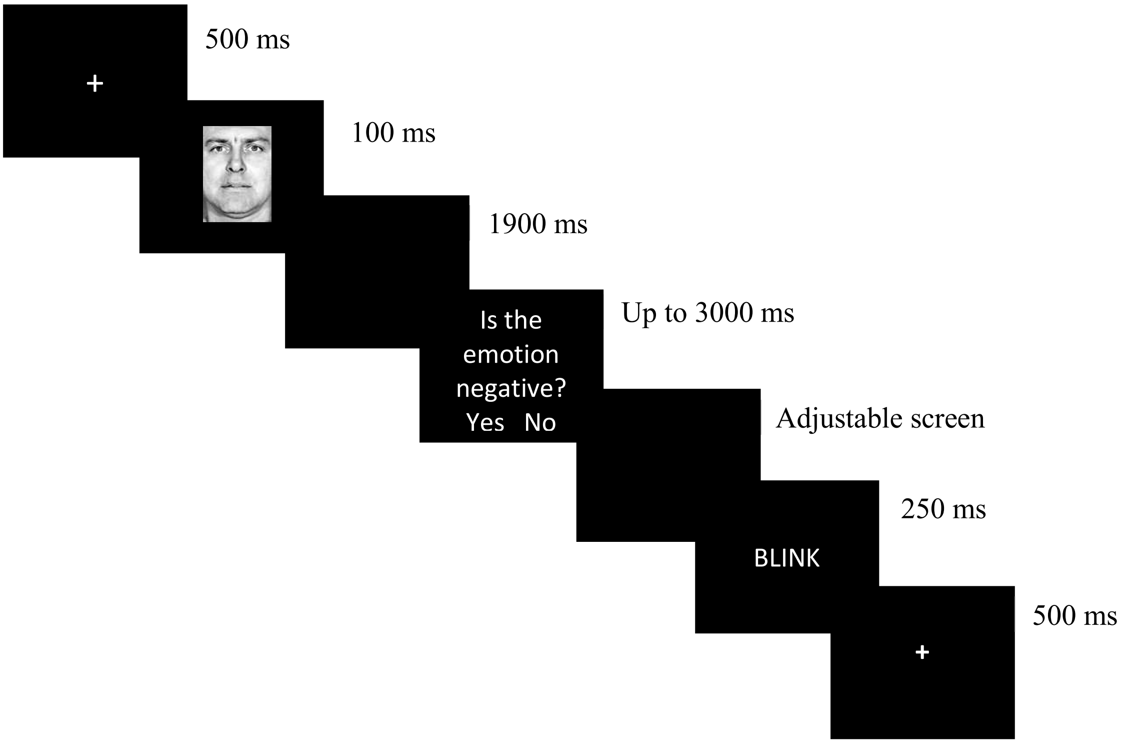


Figure 4.3. A trial of the task. Text and images are not to scale.

4.3.3.4 Facial EMG recording

The activity of participants' left *corrugator supercilii* and *zygomaticus major* muscles was recorded with facial EMG. The electrodes were placed in correspondence of the *corrugator supercilii* and *zygomaticus major* muscles as indicated in the Fridlund and Cacioppo guidelines (Fridlund & Cacioppo, 1986). We used a bipolar apparatus with Ag/AgCl 4-mm electrodes filled with salt free and hypoallergenic abrasive electrolyte gel (Easycap GmbH). Electrodes were connected to Brainvision Quickamp amplifier system (Quickamp – 72, 0128110007, 3,5W – 10 VDC). The raw analogue signal was filtered (high: 0.01 Hz; low: 200Hz) and recorded with a sampling rate of 1000 Hz. An online notch filter of 50 Hz was applied to both channels. The signal was recorded with a Brainvision Recorder (version 1.2). Markers for stimuli onset and accuracy were sent from the Psychopy program operating on another PC. Electrical impedance was brought to less than 5 kΩ at all sites via gentle abrasion with the electrolyte gel.

4.3.3.5 EEG recording

Participants’ brain activity from 29 scalp sites was continuously recorded with Ag/AgCl passive electrodes mounted on a sized elastic cap (Easycap) according to the International 10–20 classification system (FP1, FP2, F7, F3, Fz, F4, F8, T7, C3, Cz, C4, T8, P7, P3, PZ, P4, P8, O1, O2, A1, A2, FC1, FC2, CP1, CP2, FC5, FC6, CP5, CP6; see Figure 4.4). Electrodes were referenced online to the mastoids signal and FpZ served as ground electrode. Blinks and vertical eye movements were monitored with a bipolar electrode above and below the right eye. Electrical impedance was brought to less than 5 kΩ at all sites *via* gentle abrasion with the electrolyte gel. Horizontal eye movements were monitored via a bipolar derivation of electrodes at the outer canthi. All electrodes were filled with salt free and hypoallergenic abrasive electrolyte gel (Easycap GmbH). Electrodes were connected to Brainvision Quickamp amplifier system (Quickamp – 72, 0128110007, 3,5W – 10 VDC). The raw analogue signal was filtered (high: 0.01 Hz; low: 100Hz) and recorded with a sampling rate of 1000 Hz. An online notch filter of 50 Hz was applied to all sites. The signal was recorded with a Brainvision Recorder (version 1.2). Markers for stimuli onset and accuracy were sent from the Psychopy program operating on another PC.

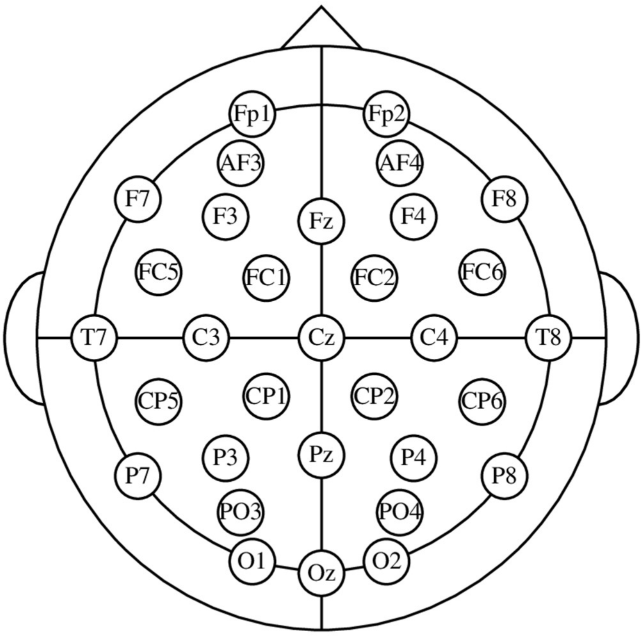


Figure 4.4. The 30 scalp sites of the International 10–20 classification system.

4.3.3.6 Preprocessing of EMG data

The two EMG channels were first separated from the EEG channels. A notch filter of 50Hz was then applied to the data. Data were then filtered with a 20 Hz FIR filter cutoff. The signal was then rectified and resampled to 30 Hz. Epochs were then extracted in bins that range from -500 ms from stimulus onset to 2000 ms from stimulus onset. All epochs were then baseline corrected with a baseline of 500 ms. Averages were then computed for all subjects. We then split the epoch files into condition files. We then manually computed both channels EMG waveform for each participant with ERPLAB.

4.3.3.7 Preprocessing of EEG data

We carried out EEG data pre-processing using EEGLAB (Delorme and Makeig, 2004), a MATLAB toolbox (MATLAB R2017A). All EEG channels were re-referenced to mastoids. We then applied a high-pass filter on the data with a 0.2 Hz FIR filter (middle edge cut off at 0.1Hz). The signal was then epoched with a 500 ms baseline and a 2000 ms epoch. All subjects' datasets were then visually inspected and we manually rejected trials with excessive noise provoked by muscle artifacts, cardiovascular signal or electrode impedance, and trials with severe drifts (N of trials removed from all datasets = 131). Then and independent component analysis (ICA) was performed on all channels. ICA decomposes data to create a collection of components. More specifically, from each channel a component is filtered out that represents the signal that has been most temporally independent. A second visual inspection then allowed us to identify and reject ICA components most likely to represent muscle artifacts (eyes blinks or saccadic movements) or other type of artifacts (N of ICA components removed from all datasets = 53). A Basic FIR low pass filter of 40 Hz was then manually applied to all datasets. Next, we carried out a last visual inspection to verify that all the excessively noisy segments were removed after noise correction (N of trials removed from all datasets = 4). Baseline correction was then performed with a 200 ms baseline. To exclude epochs with remaining artifacts, epochs whose activity was -100 +100 microvolt threshold were rejected (14.8%). To calculate ERPs we then split the epoch files into condition files. We then manually computed the averaged ERPs for each subject. Fifteen participants were excluded from the analyses due to an online low pass filter problem (subjects 1-15). Two participants have been excluded due to excessive behavioural missing responses (subjects 33, 34). The following analysis have therefore been conducted on 26 participants (19 females; mean age = 23.9; age SD = 8.1).

4.3.3.8 ERPs visual inspection

We carried out a visual inspection in order to identify components and crucial time windows. Inspection was conducted on ERPs grand averages of activity during successful valence detection (i.e. trials for which a correct response was given). All ten conditions (happy low-intensity, happy medium-intensity, happy high-intensity, fear low-intensity, fear medium-intensity, fear high-intensity, angry low-intensity, angry medium-intensity, angry high-intensity and neutral) were inspected. The selection of electrodes and time ranges of components' peaks was literature- and data-led. Specifically, we looked at broad time windows in electrodes suggested by relevant studies (Achaibou et al., 2008; Calvo & Beltrán, 2013; J. D. Davis et al., 2017; Dong & Lu, 2010; Hayasaka & Miyachi, 2016; Mavratzakis et al., 2016; Pollux, 2016; Spapé et al., 2017). We then selected electrodes where components activity differentiated the most across conditions. Electrodes activity inspected were the temporal-occipital cluster (left: T7, P7, O1, right: T8, P8, O2) and the parietal cluster (left: P7, P3, right: P4, P8). For N400 we extracted values from both clusters of scalp sites, as the component showed activity in either sites. Analysis conducted on EPN considered only EEG activity means of the temporal-occipital cluster set of electrodes.

4.3.3.8.1 EPN component

For EPN components we looked at waves modulation as compared to the baseline and across conditions from about 200 ms up to about 320 ms after the appearance of the stimulus. Observations on T7 and T8 did not reveal any possible significant modulation of EEG activity in the time frame. Inspection on P7 showed a differentiation across conditions of waves from 280 ms to 350 ms after SO, so did inspection on P8 which showed meaningful activity from 230 up to 270 ms after SO. Inspection on O1 showed relevant waves' modulation across conditions from about 275 up to 230 ms after SO. Finally, O2 waves from 230 up to 350 ms showed too a meaningful trend. We then calculated EPN observed onset and offset means (onset: 255, offset: 300 ms). Our analysis therefore was conducted on P7, P8, O1 and O2 mean activity values extracted from 255 ms to 300 ms after SO. Values were averaged together to create a unique temporal-occipital cluster dataset of values.

4.3.3.8.2 N400 component

For N400, EEG activity was only present from about 400 ms to 530 ms after SO in O1 and O2. Visual inspection on T7, T8, P7 and P8 did not show relevant N400 activity. For our analysis we therefore extracted means of EEG activity values from 400 to 530 ms after SO form O1 and O2.

4.3.3.9 Data analyses

4.3.3.9.1 EEG

Separate 2-way repeated measures ANOVAs with hemisphere (left, right) and emotion (happy, angry, fearful, neutral) as factors were conducted to compare each component activations during low, medium and high intensity emotional conditions against neutral.

Furthermore, a 3-way ANOVA with hemisphere (left, right), emotion (happy, angry, fearful) and intensity (low, medium, high) was conducted to compare activations between intensities. All p values given in are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020).

4.3.3.9.2 EMG

In order to compare the EMG signal during exposure of emotional facial expressions and neutral we first analysed zygomaticus and corrugator activity means across the whole time window from 200 ms to 1000 ms after SO, separately for each intensity (low, medium, high), with three one-way ANOVA having ‘emotion’ (happy, angry, fearful, neutral) as factor.

In order to observe a potential intensity effect we then ran a 2-way repeated measures ANOVA with ‘emotion’ (happy, angry, fearful) and intensity (low, medium, high) as factors on each muscle’s activity means of the same time window (200 to 1000 ms after SO).

Then, the activity time course of each muscle was inspected. Time course inspection was performed only for happy and angry facial expressions (therefore not considering neutral and fearful faces) to analyse mimicry responses on the zygomaticus and corrugator. We did not consider fearful faces here to observe only the most relevant mimicry effects on corrugator. The 200 ms time bins extracted were combined as follows: early activity from 200 to 400, mid-early activity from 400 to 600 ms, mid-late activity from 600 to 800 ms, late activity from 800 to 1000 ms. We then ran two 4-way repeated measures ANOVA with emotion (angry, happy); intensity (3: low, medium, high); time (4: early, mid-early, mid-late, late) on corrugator and zygomaticus activity separately.

Corrugator activity was analysed during conditions featuring angry and fearful face expressions (Mavratzakis et al., 2016). Exceptions will be specified. All p values given in are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020).

4.3.3.9.3 Behavioural

Two 2-way repeated measures ANOVAs with Emotion (happy, fearful, angry) and intensity (high, med, low) as within-subject factors were conducted on accuracy and reaction times. Greenhouse–Geisser correction was used when needed and Bonferroni adjustment was applied for multiple comparisons.

4.3.3.9.4 Combined

We then performed a non-parametric Spearman rank-order correlation between EPN and N400 activations' means and accuracy and RTs of correct responses.

Two non-parametric Spearman rank-order correlation between zygomaticus and corrugator activations' means of each time window and accuracy and RTs of correct responses have also been conducted.

Finally, we ran a non-parametric Spearman rank-order correlation between each ERP component and zygomaticus and corrugator activations' means. All p values given in are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020).

No other study has exhaustively analysed the relationship between EPN and N400 and EMG activity increase during recognition of happy, angry and fearful facial expressions. Similarly, no previous study has explored in a wide manner positive and/or negative correlations between these two components and behavioural responses of a facial expressions' recognitions task.

Therefore, these analyses are aimed at exploring the relationship between the components N400 and EPN and behavioural results as well as EMG enhanced activity in response to different intensities of emotional facial expressions. In particular, given the exploratory nature of these analyses we intend to explore both positive and negative correlations of activity increase of ERP components and corrugator and zygomatic during strictly relevant conditions (e.g. corrugator activity during angry and fearful expressions conditions, zygomatic activity during happy expressions conditions). In particular, some of these correlations may give specific insights on the role of the peripherical EMG activation occurring before or after or cooccurring with central cognitive emotional processing expressed as EPN and/or N400 increased activities during successful recognition.

4.3.4 Results

4.3.4.1 Behavioural

Behavioural statistical analyses were performed on the whole sample. Six subjects were excluded because their accuracy level was less than 80% and we therefore performed our analysis on 35 subjects (females = 23, mean age = 23.84, SD = 8.08).

4.3.4.1.1 Accuracy

The ANOVA on the proportion of accurate responses revealed a main effect of emotion, *F(1, 34)* = 47.017, $p < .001$, $\eta_p^2 = .588$. Exploratory paired samples t-tests showed that participants were more able to detect the positive valence of happy faces (M = .900, SD = .071) as compared to the negative valence of angry faces (M = .722, SD = .110; $t(34) = -6.849$, $p < .001$) and fearful faces (M = .706, SD = .112; $t(34) = -7.505$, $p < .001$), see Figure 4.5.

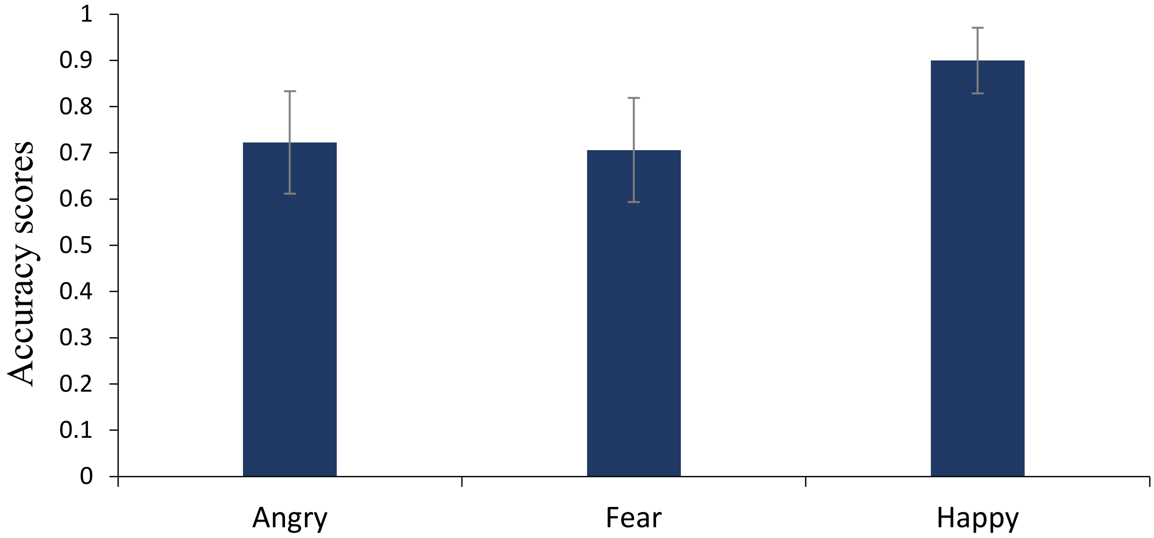


Figure 4.5. Accuracy scores' means of the three emotions.

The analysis also showed a main effect of intensity, *F(1, 34)* 497.703, $p < .001$, $\eta_p^2 = .938$. Participants were more able to detect high intensity facial expressions (M = .919, SD = .045) as compared to medium intensity face expressions (M = .823, SD = .073), *t(*34) = 11.778, $p < .001$ and low intensity face expressions (M = .582, SD = .095), *t(*34) = 25.145, $p < .001$. Recognition accuracy scores for medium intensity face expressions (M = .823, SD = .073) were also higher than for low intensity face expressions (M = .582, SD = .095; *t(*34) = -21.949, $p < .001$, see Figure 4.6).

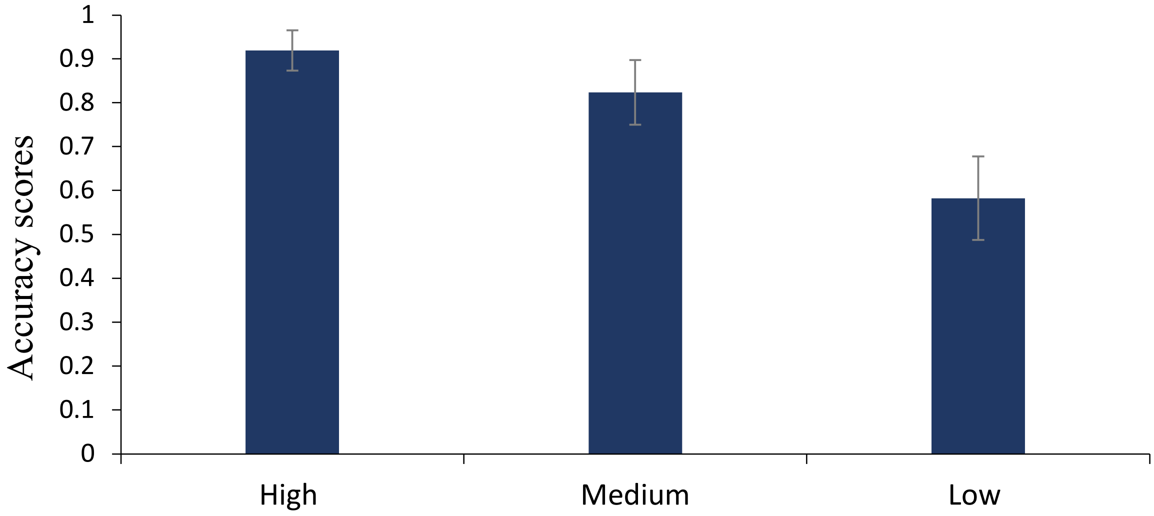


Figure 4.6. Accuracy scores' means of the three intensities.

An emotion × intensity interaction, *F(1.8, 59)* = 29.140, $p < .001$, $\eta_p^2 = .469$, was also found. Post hoc t-tests showed that participants were more able to recognize high intensity happy facial expressions (M = .967, SD = .045) as compared to high intensity angry facial expressions (M = .906, SD = .066; *t(*34) = -4.193, $p < .001$) and to high intensity fearful facial expressions (M = .884, SD = .096; *t(*34) = 4.620, $p < .001$). Recognition was also easier for medium intensity happy face expressions (M = .925, SD = .076) than for medium intensity angry face expressions (M = .780, SD = .125; *t(*34) = -5.526, $p < .001$) and for medium intensity fearful face expressions (M = .766, SD = .114; *t(*34) = 6.373, $p < .001$).

Finally, this pattern was also repeated for low intensity face expressions with happy faces (M = .807, SD = .118) being recognized more than angry face expressions (M = .474, SD = .183; *t(*34) = -7.191, $p < .001$) and fearful faces (M = .465, SD = .185; *t(*34) = -7.278, $p < .001$).

Analyses also showed that participants had stronger detection ability for high intensity angry face expressions (M = .906, SD = .066) as compared to medium intensity angry face expressions (M = .780, SD = .125; *t(*34) = 8.121, $p < .001$) and low intensity angry face expressions (M = .474, SD = .183; *t(*34) = 17.057, *p* < .001). They also detected more frequently medium intensity angry face expressions (M = .780, SD = .125) than low intensity angry face expressions (M = .474, SD = .183; *t(*34) = 13.835, *p* < .001).

Moreover, high intensity fearful face expressions (M = .884, SD = .096) were better recognized than medium intensity fearful face expressions (M = .766, SD = .114; *t(*34) = 8.078, *p* < .001) and low intensity fearful face expressions (M = .465, SD = .185; *t(*34) = 13.756, *p* < .001); similarly, recognition accuracy scores were higher for medium intensity fearful face expressions (M = .884, SD = .096) as compared to low intensity fearful face expressions (M = .465, SD = .185; *t(*34) = 12.912, *p* < .001).

As to the recognition of happy faces, we found similar results having higher recognition accuracy scores for high intensity happy face expressions (M = .967, SD = .045) as compared to medium intensity happy face expressions (M = .925, SD = .076; *t(*34) = 5.277, *p* < .001) and low intensity happy face expressions (M = .807, SD = .118; *t(*34) = 8.771, *p* < .001), and in turn higher recognition accuracy scores for medium intensity happy face expressions (M = .925, SD = .076) than for low intensity happy face expressions (M = .807, SD = .118; *t(*34) = 8.187, *p* < .001), see Figure 4.7.

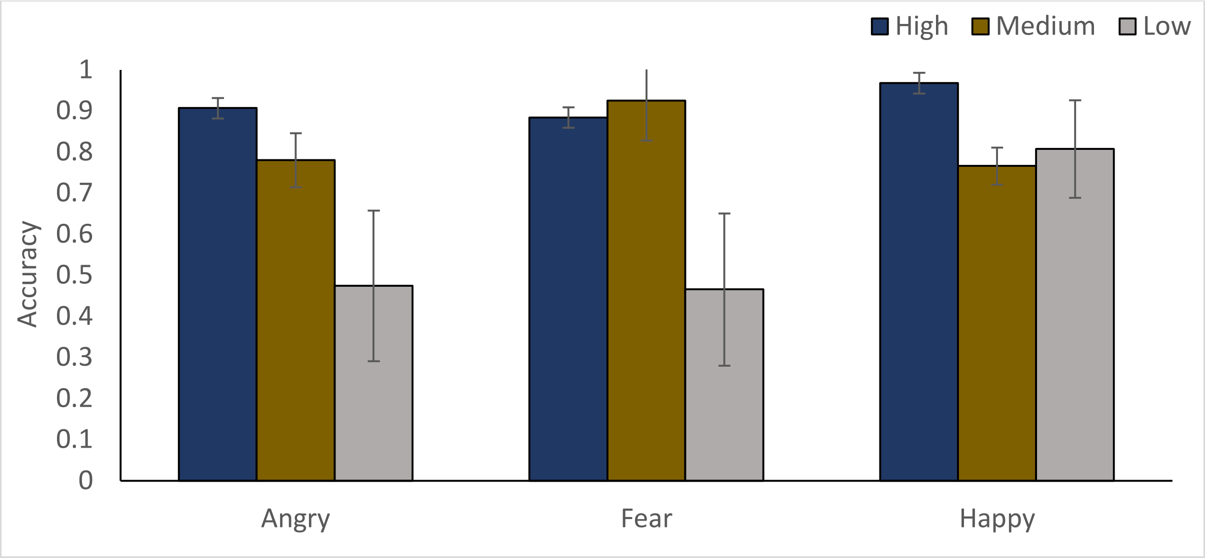


Figure 4.7. Accuracy scores of recognition of low, medium and high intensity expressions for all emotions.

4.3.4.1.2 Reaction times

The ANOVA on RTs revealed a main effect of intensity, *F(*1, 36) = 14.908, $p < .001$, $\eta_p^2 = .311$. Paired-samples t-tests showed that participants judged medium intensity face expressions valence slower (M = .445, SD = .139) than high intensity face expressions (M = .423, SD = .135; *t(*34) = -3.428, *p* = .002). Medium intensity face expressions (M = .445, SD = .139) were correctly recognised as positive or negative quicker than low intensity face expressions (M = .473, SD = .158*; t(*34) = -2.676, *p* = .011). Likewise, the valence saliency of low intensity face expressions (M = .473, SD = .158) took also more time as compared to that for high intensity face expressions (M = .423, SD = .135; *t(*34) = -5.137, $p < .001$), see Figure 4.8.

A main effect of emotion was not found, *F(*1.9, 64) = 2.021, p = .142, $\eta_p^2 = .058$; likewise, the emotion × intensity interaction was also not significant, *F(*3.5, 117) = .574, *p* = .663, $\eta_p^2 = .017$.

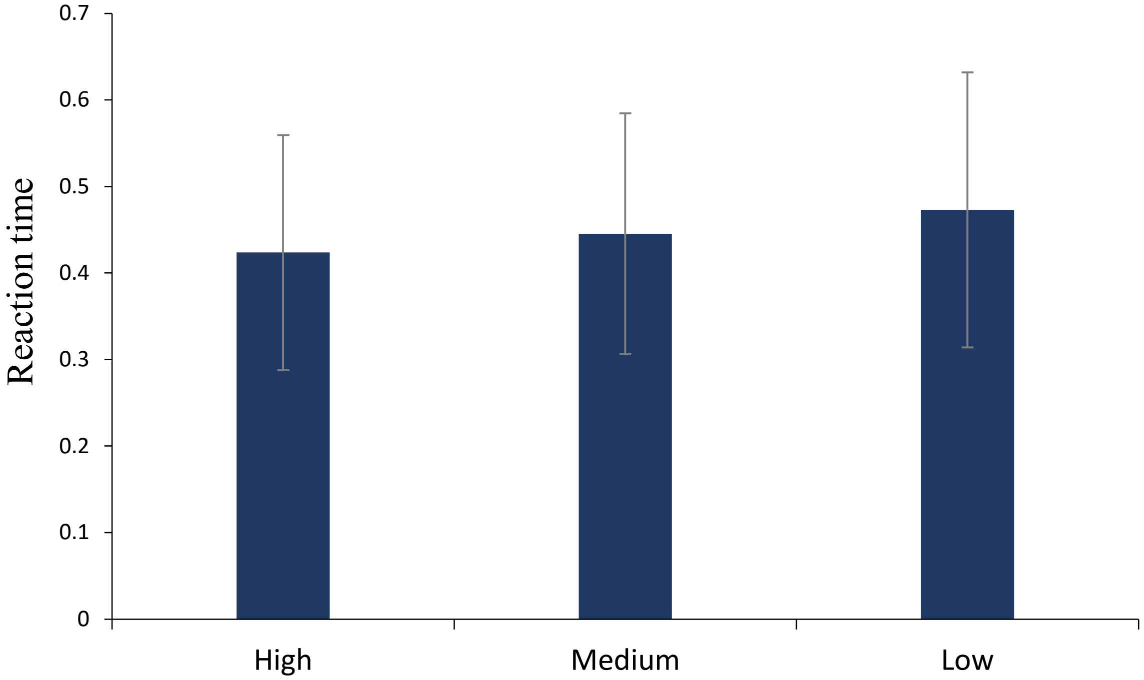


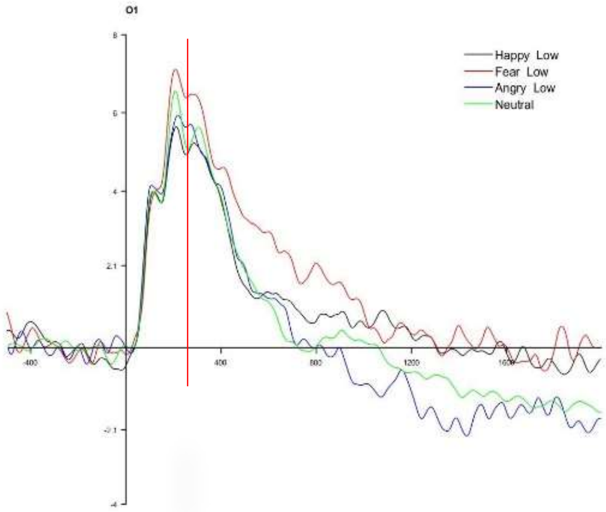
Figure 4.8. Reaction times means of the three intensities.

4.3.4.2 EEG

4.3.4.2.1 EPN

Low intensity vs Neutral

ANOVA on EPN activations during exposure to low intensity face expressions showed a main effect of hemisphere, *F(*1, 25) = 9.997, p = .004, η_p^2 = .286, with EPN waves stronger in the left hemisphere compared to the righ*t* (left EPN: M = 2.541, SD = 2.432; right EPN: M = 4.862, SD = 4.060). The main effect of emotion was not significant, *F(*2, 52.4) = 1.999, p = .144, η_p^2 = .074, as well as the interaction between hemisphere and emotion, *F(*1, 49) = -622, p = .539, η_p^2 = .024, see Figure 4.9.


O1
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2.1
-2.1
-4
-400
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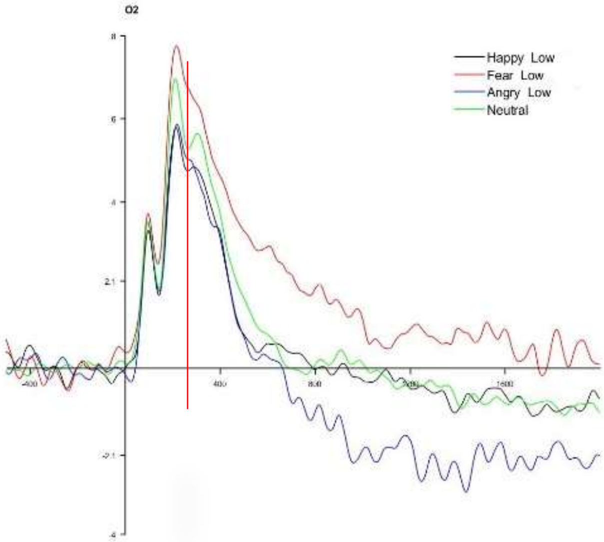
800
1200
1600
Happy Low
Fear Low
Angry Low
Neutral


O2
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-2.1
-4
-400
400
800
1200
1600
Happy Low
Fear Low
Angry Low
Neutral

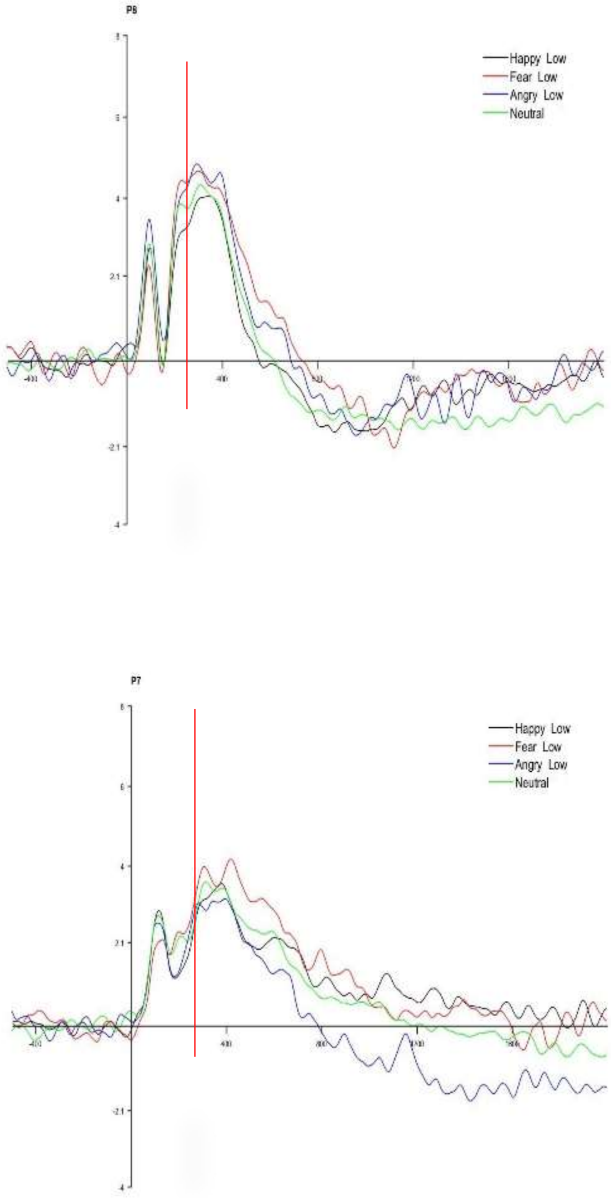
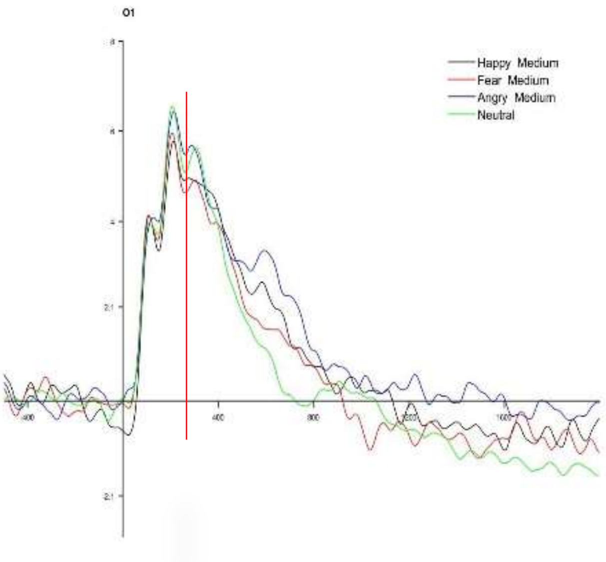
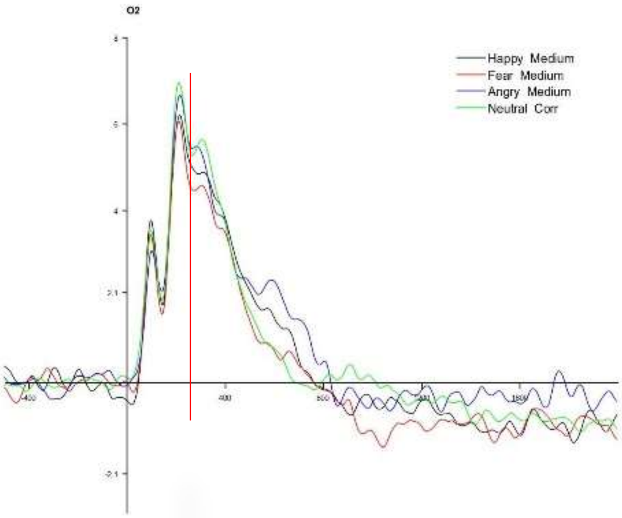


Figure 4.9. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipito-temporal (P7/P8) and occipital (O1/O2) representative electrodes during low intensity conditions and during neutral expressions conditions. EPN (255 ms to 300 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Medium intensity vs Neutral

ANOVA on EPN activations during exposure to medium intensity face expressions showed a main effect of hemisphere, $F(1, 25) = 9.383$, $p = .005$, $\eta_p^2 = .273$, with stronger EPN on left sites (M = 2.283, SD = 2.68) as compared to EPN on right sites (M = 4.579, SD = 3.91). However, this analysis also showed a marginally significant main effect of emotion, $F(2.230, 55.748) = 9.088$, $p = .069$, $\eta_p^2 = .098$; explorative t-tests showed that EPN activated more with medium intensity fearful faces (M = 3.017, SD = 3.025) as compared to EPN during medium intensity angry faces (M = 3.896, SD = 3.018; $t(25) = 2.560$, $p = .017$) and activated more during exposure to medium intensity happy face (M = 3.385, SD = 2.425) as compared to EPN during exposure to medium-intensity angry faces, $t(25) = 2.422$, $p = .023$, see Figure 4.10.




O2
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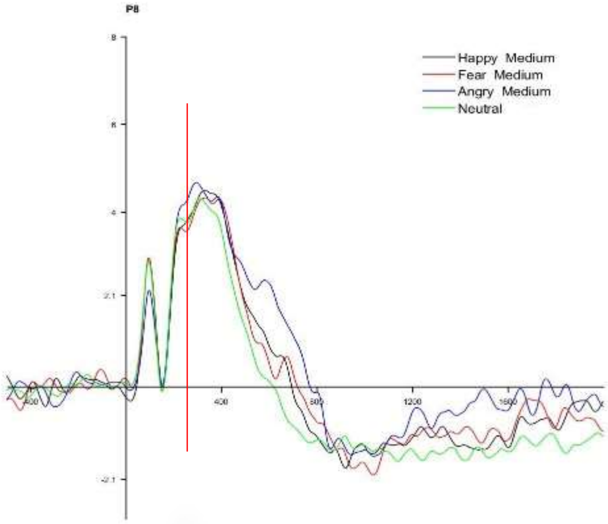
Happy Medium
Fear Medium
Angry Medium
Neutral Corr


P8
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Happy Medium
Fear Medium
Angry Medium
Neutral

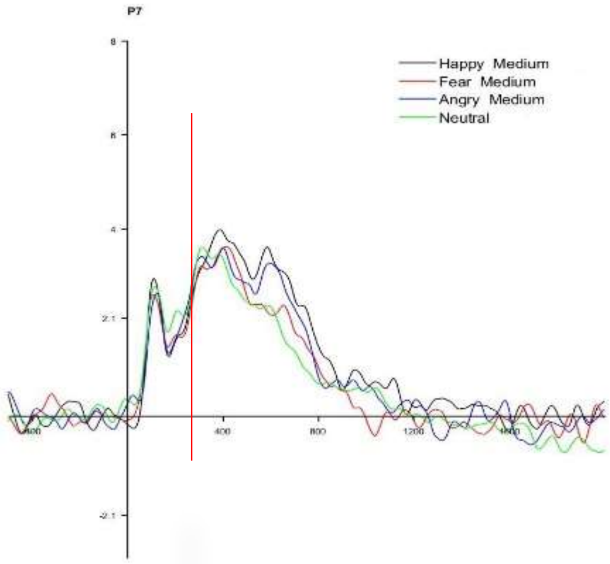
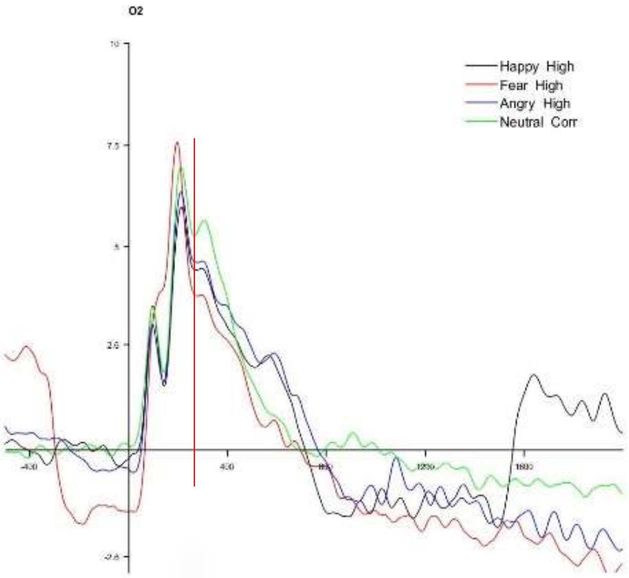


Figure 4.10. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipito-temporal (P7/P8) and occipital (O1/O2) representative electrodes during medium intensity conditions and during neutral expressions conditions. EPN (255 ms to 300 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

High intensity vs Neutral

ANOVA on EPN activations during exposure to high intensity face expressions only showed a main effect of hemisphere, $F(1, 25) = 7.602, p = .011, \eta_p^2 = .233$, with EPN stronger on left sites during exposure to high intensity facial expressions (M = 2.472, SD = 2.606) as compared to its activation on right sites (M = 4.542, SD = 3.952). The main effect of emotion was not significant, $F(10, 67) = 1.8, p = .160, \eta_p^2 = .067$ as well as the interaction between hemisphere and emotion, $F(2,3) = 1.8, p = .168, \eta2 = .067$, see Figure 4.11.


O2
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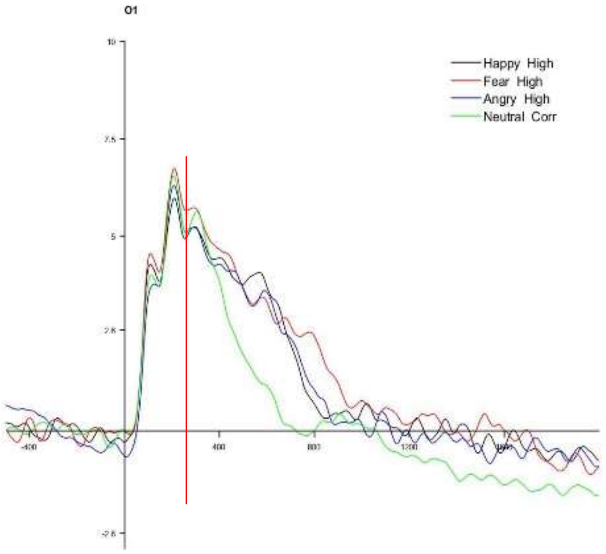
Happy High
Fear High
Angry High
Neutral Corr


O1
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Happy High
Fear High
Angry High
Neutral Corr

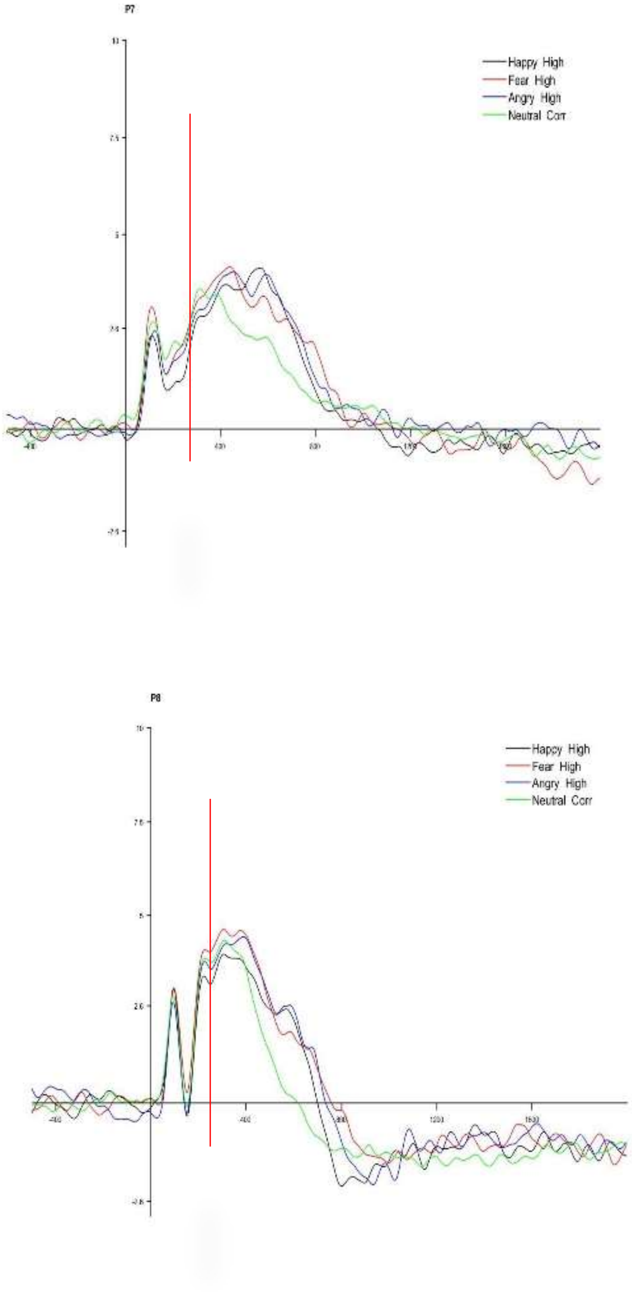


Figure 4.11. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipito-temporal (P7/P8) and occipital (O1/O2) representative electrodes during high intensity conditions and during neutral expressions conditions. EPN (255 ms to 300 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Comparisons between intensities

A 3 way repeated measures ANOVA with hemisphere (2), emotion (3: happy, fearful, angry), and intensity (3: low/medium/high) as factors on EPN was performed to explore main effects of intensity and interactions with it.

This ANOVA showed a main effect of hemisphere, *F(*1, 25) = 8.408, p = .008, η_p^2 = .252, with stronger left EPN (M = 2.48, SD = 2.50) as compared to EPN on right sites (M = 4.67, SD = 3.84). A marginally significant emotion × intensity interaction was also showed, *F(*2.941, 73.528) = 2.546, p = .064, η_p^2 = .092. Explorative t-tests for this interaction showed stronger EPN activations during exposure to medium intensity fearful faces (M = 3.017, SD = 3.025) as compared to high intensity fearful faces (M = 3.755, SD = 3.104; *t(*25) = -2.069, p = .049), which in turn were stronger as compared to activations during low intensity fearful faces (M = 4.324, SD = 3.197; *t(*25) = 2.589, p = .016). No difference was significant for the other emotions (all p > .05). See Figure 4.12 for isovoltage maps of the difference between the three intesities conditions for anger, fear and happiness.

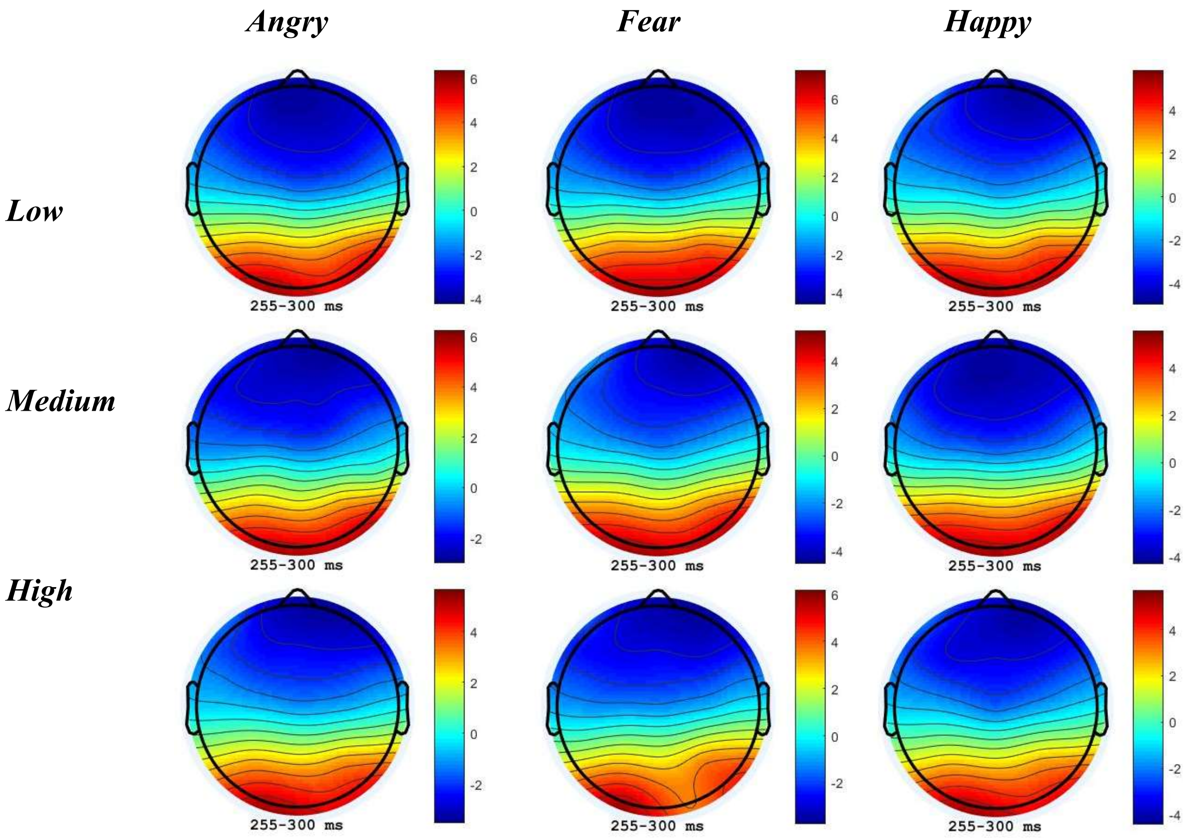
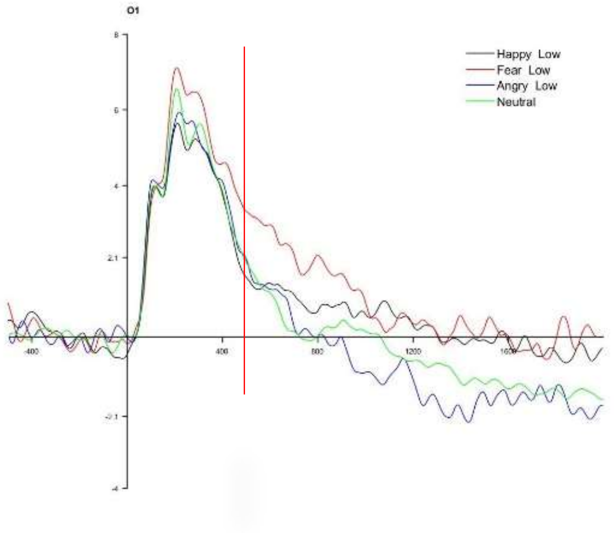


Figure 4.12. Topographic representations of the difference in mean amplitude across the scalp between the three intensities (low, medium and high) during EPN interval (255-300 ms after faces onset) during correct recognition of emotions (anger, fear and happiness). Results revealed stronger left EPN as compared to EPN on right sites.

4.3.4.2.2 N400

Low intensity vs Neutral

We then performed a 2-way repeated measures ANOVAs with hemisphere (2) and emotion (4) as factors N400 activation means during low intensity emotional conditions and neutral. This ANOVA on N400 activations during exposure to low intensity facial expressions did not show main effects or interactions, see Figure 4.13.



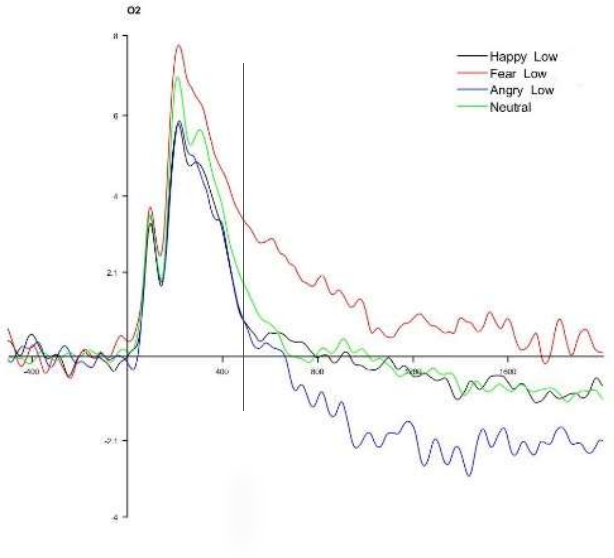
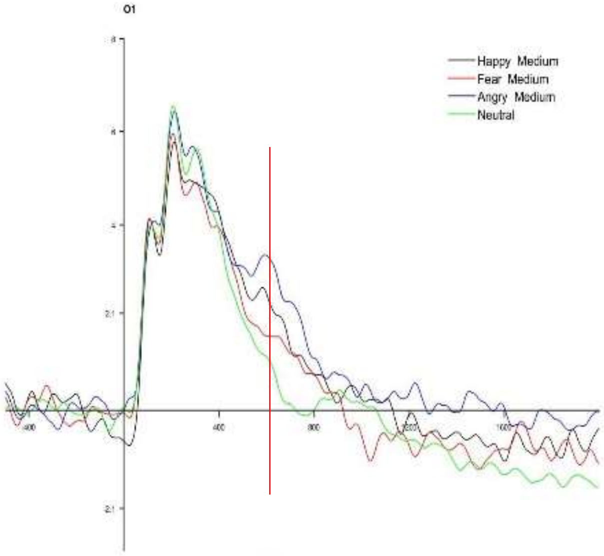


Figure 4.13. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2) representative electrodes during correct recognition of low intensity emotions and neutral expressions. N400 (400 ms to 530 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Medium intensity vs Neutral

We then performed a 2-way repeated measures ANOVA with hemisphere (2) and emotion (4) as factors on N400 activation means during medium intensity emotional conditions and neutral. This second ANOVA on N400 activations during exposure to medium intensity face expressions did not show main effects or interactions, see Figure 4.14.



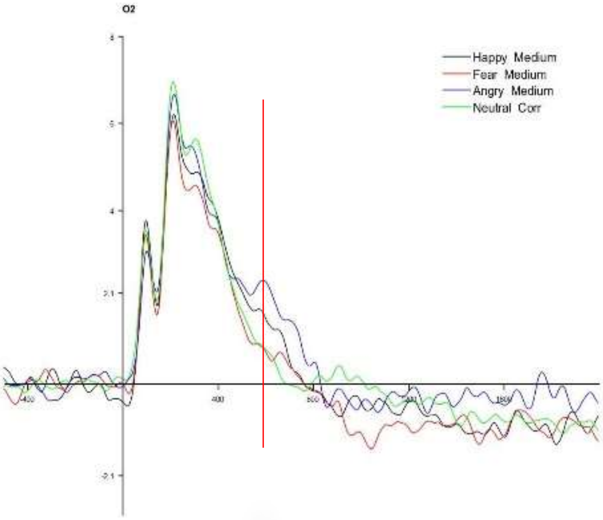


Figure 4.14. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2) representative electrodes during correct recognition of medium intensity emotions and neutral expressions. N400 (400 ms to 530 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

High intensity vs Neutral

ANOVA on N400 activations during exposure to high intensity face expressions showed a main effect of emotion, $F(2.546, 63.649) = 7.038$, $p = .001$, $\eta_p^2 = .220$. Paired samples t-tests exploring this effect showed more negative N400 component during exposition to neutral face expressions (M = 2.309, SD = 3.077) as compared to N400 activations during exposition to high intensity angry face expressions (M = 3.780, SD = 3.845; $t(25) = 3.681$, $p = .001$) as well as to activations of the N400 component during exposition to high intensity fearful face expressions (M = 3.634, SD = 3.355; $t(25) = 4.638$, $p < .001$) and to high intensity happy face expressions (M = 3.333, SD = 2.934; $t(25) = 3.192$, $p = .004$), see Figure 4.15.

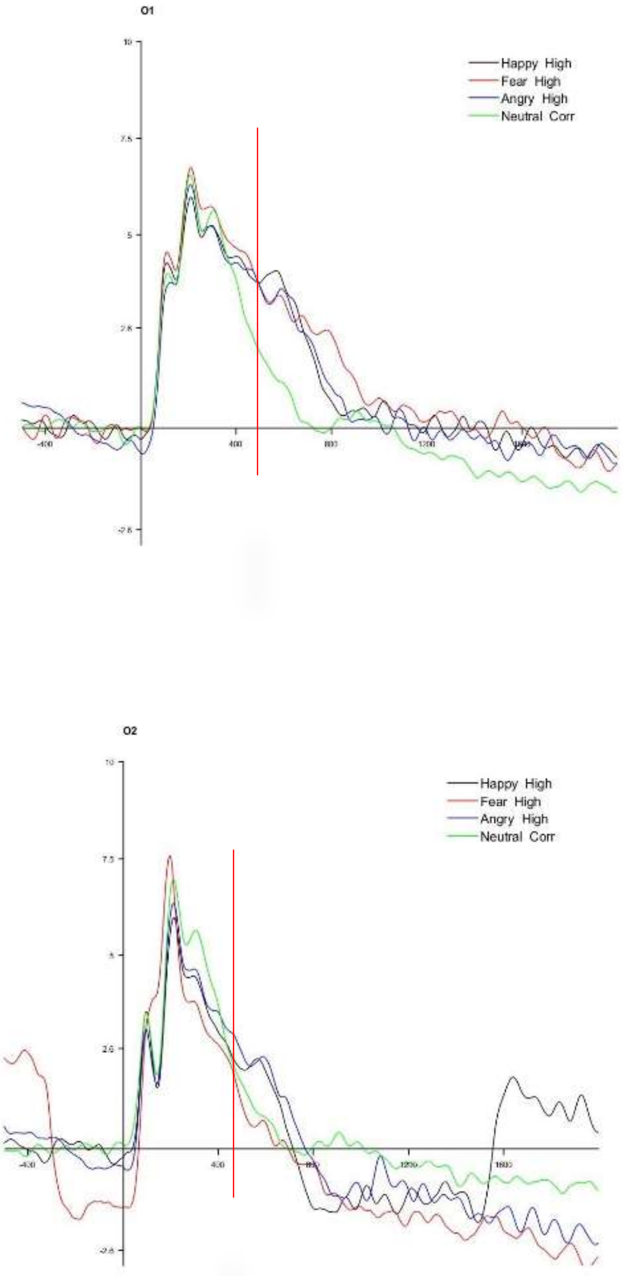


Figure 4.15.ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2) representative electrodes during correct recognition of high intensity emotions and neutral expressions. N400 (400 ms to 530 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Comparisons between intensities

A 3 way repeated measures ANOVA with hemisphere (2), emotion (3: happy, fearful, angry), and intensity (3: low/medium/high) as factors showed a main effect of intensity, *F(*1.540, 38.489) = 7.255, p = .004, η_p^2 = .225. Paired samples t-tests exploring showed stronger N400 waves during exposure to medium intensity facial expressions (M = 2.871, SD = 2.806) as compared to high intensity facial expressions (M = 3.583, SD = 3.221; *t(*25) = -2.908, p = .008) as well as stronger N400 component during exposition of low intensity facial expressions (M = 2.515, SD = 2.278) as compared to high intensity facial expressions, *t(*25) = 3.008, p = .006. See Figure 4.16 for isovoltage maps of the difference between the three intesities conditions for anger, fear and happiness. The main effect of hemisphere was not significant, *F(*1, 25) = .580, p = .454, η_p^2 = .023 and the main effect of emotion was not significant, *F(*1.8, 46) = 1.141, p = .325, η_p^2 = .044. None of the interactions was significant (all p > .05).

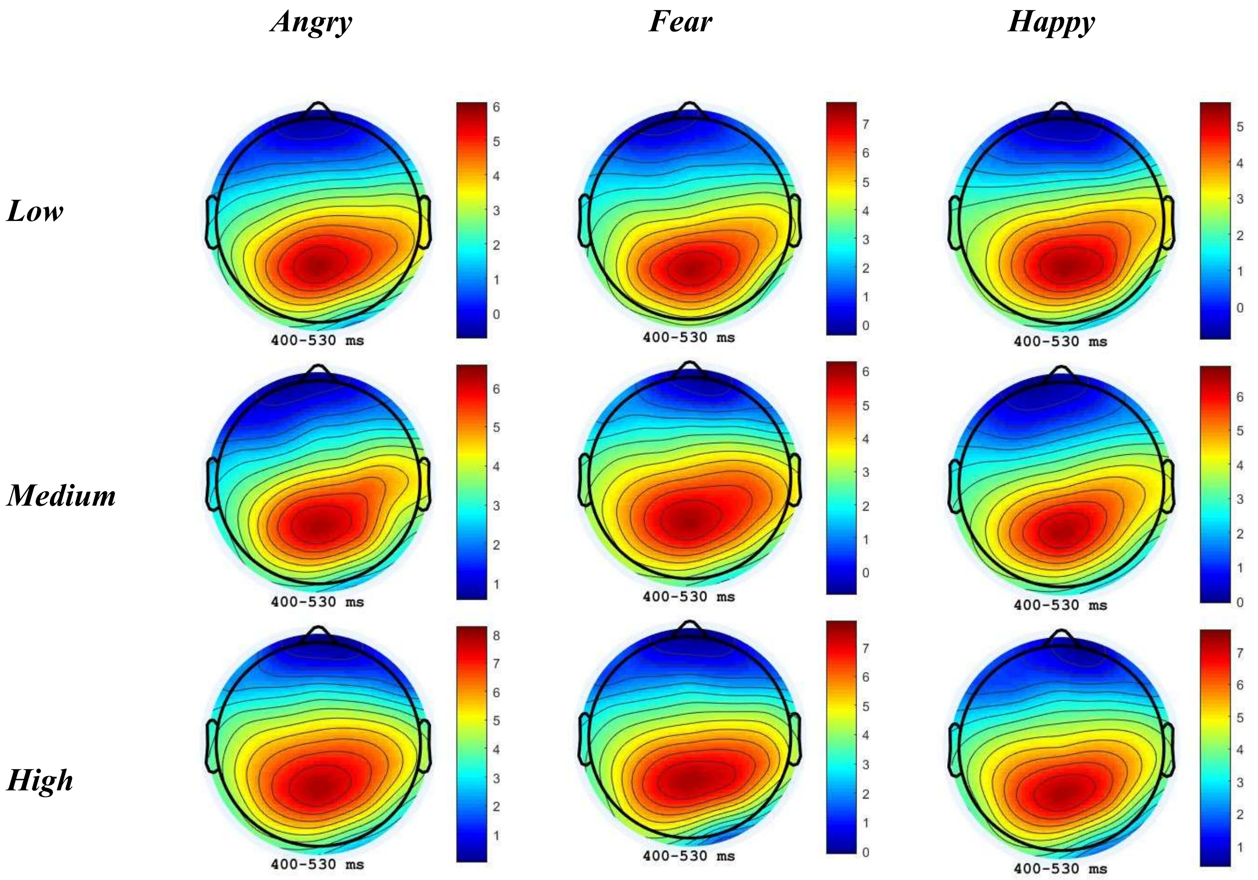


Figure 4.16. Topographic representations of the difference in mean amplitude across the scalp between the three intensities (low, medium and high) during N400 interval (400-530 ms after faces onset) during correct recognition of emotions (anger, fear and happiness). Results revealed stronger N400 waves during exposure to medium intensity facial expressions as compared to high intensity facial expressions and stronger N400 component during exposure to low intensity facial expressions.

4.3.4.3 EMG

We conducted separate analysis to assess the activity of the *Corrugator supercilii* and the *Zygomaticus major*. First, we analysed the entire time window going from 200 to 1000 ms after SO for each intensity (low, medium, high) separately, with two sets of one-way ANOVAs having ‘emotion’ (happy, angry, fearful, neutral) as factor.

To explore potential intensity effects we then ran a 2-way repeated measures ANOVA with ‘emotion’ (happy, angry, fearful) and intensity (low, medium, high) as factors on each muscle’s activity means of the same time window (200 ms to 1000 ms after SO).

Then, to explore the time-course of mimicry activation we extracted EMG activity means of 4 time windows: an early time window going from 200 to 400 ms after SO, a mid-early time window going from 400 to 600 ms after SO, a mid-late time window going from 600 to 800 ms after SO and a late time window going from 800 to 1000 ms after SO. We analysed the time-course of mimicry by performing two 4-way repeated measures ANOVA with emotion (angry, happy, fear); intensity (3: low, medium, high); time (4: early, mid-early, mid-late, late) on corrugator and zygomaticus activity separately.

4.3.4.3.1 Corrugator supercilii

High intensity

A main effect of emotion on corrugator activations during exposure to high intensity face expressions, $F(1.6, 40.1) = 6.17$, $p = .002$, $\eta_p^2 = .198$ was found. Paired samples t-tests exploring this result showed a stronger activation of the corrugator muscle during exposure to high intensity fearful faces (M = .01, SD = .07) as compared to its activation during the recognition of high intensity happy faces (M = -.14, SD = .29; $t(25) = -2.83$, $p = .009$); corrugator showed greater amplitudes for neutral faces (M = -.021, SD = .24) than for high intensity happy faces, $t(25) = 3.2$, $p = .009$.

Medium intensity

The ANOVA performed on the corrugator activity during the 200-1000 ms window revealed a very marginal main effect of emotion on corrugator activations during exposure to medium intensity face expressions, *F(*1.6, 42.3) = 2.8, p = .093, η_p^2 = .101. Exploratory t-tests showed a stronger EMG corrugator reaction during exposure to medium intensity fearful faces (M = .057, SD = .272) as compared to reactions to medium intensity happy faces (M = -.114, SD = .338; *t(*25) = -1.9, p = .068; stronger EMG corrugator reaction during exposition to medium intensity angry faces (M = .068, SD = .35) as compared to reactions to medium intensity happy faces, *t(*25) = -1.995, p = .057; reactions to medium intensity happy faces were also less strong than those to neutral faces (M = -.021, SD = .024; *t(*25) = 2.3, p = .030).

Low intensity

No main effect of emotion was found on corrugator activity means during exposure to low intensity face expressions, *F(*1.7, 42.8) = .799, p = .439, η_p^2 = .031.

Comparison between intensities

The 2-way ANOVA did not reveal a main effect of intensity, *F(*1.8, 45.1) = 2.11, p = .131, η_p^2 = .078 or an interaction between emotion and intensity, *F(*2.8, 70) = 1.78, p = .139, η_p^2 = .066; however, a main effect of emotion was found, *F(*1.8, 45.1) = 4.92, p = .026, η_p^2 = .164. Paired samples post hoc t-tests showed that the corrugator activated more during fearful faces (M = .001, SD = 22) and angry faces (M = .009, SD = .23) compared to happy faces (M = -.1, SD = .3; fearful vs happy: *t*(25) = -2.15, p = .041; angry vs happy:, *t(*25) = -3.41, p = .002), see Figure 4.17.

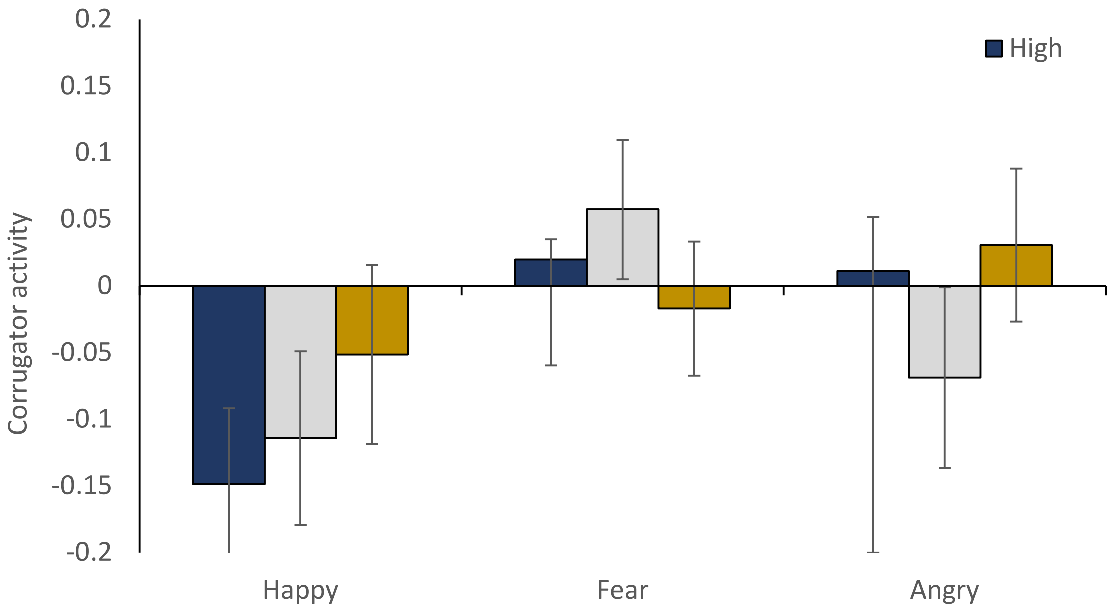


Figure 4.17. Corrugator activity during recognition of low, medium and high intensity expressions for all emotions.

Mimicry time course

We analysed the time-course of mimicry by performing two 4-way repeated measures ANOVA with emotion (angry, happy); intensity (3: low, medium, high); time (4: early, mid-early, mid-late, late). Results showed a marginally significant main effect of time*, F(*1.6, 43) = 2.95, p = .072, η_p^2 = .102). Post hoc t-tests revealed the corrugator activation from 200 ms to 400 ms after faces onse*t* (M = .001, SD = .28) was greater than activations from 400 to 600 ms (M = -.11, SD = 35; *t(*26) = 3.7, p = .001).

A significant main effect of emotion was found*, F(*1, 26) = 11.977, p = .002, η_p^2 = .315, with corrugator activating more for angry faces (M = -.009, SD = .23) than happy faces (M = -.1, SD = -3), *t(*26) = 3.46, p = .002. A significant main effect of intensity was also found*, F(*1.9, 50) = 3.875, p = .029, η_p^2 = .130, post hoc t-tests revealing that corrugator had greater activations for low intensity expressions (M = -.007, SD = .23) than high intensity expressions (M = -.05, SD = 23).

Interactions time *x* emotion*, F(*1.9, 50) = .669, p = .513, η_p^2 = .025, time *x* intensity*, F(*3.2, 85) = 1.888, p = .132, η2 = .068, emotion *x* intensity*, F(*1.3, 34) = 1.05, p = .332, η_p^2 = .039, and time *x* emotion *x* intensity*, F(*4, 107) = 1.214, p = .309, η_p^2 = .045 were not significant, see Figures 4.18, 4.19 and 4.20.

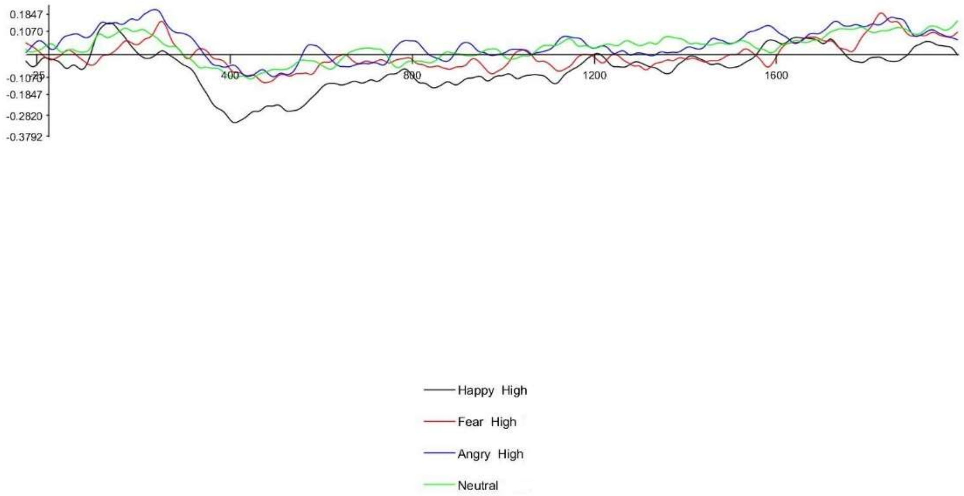


Figure 4.18. Corrugator activity during correct recognition of high intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

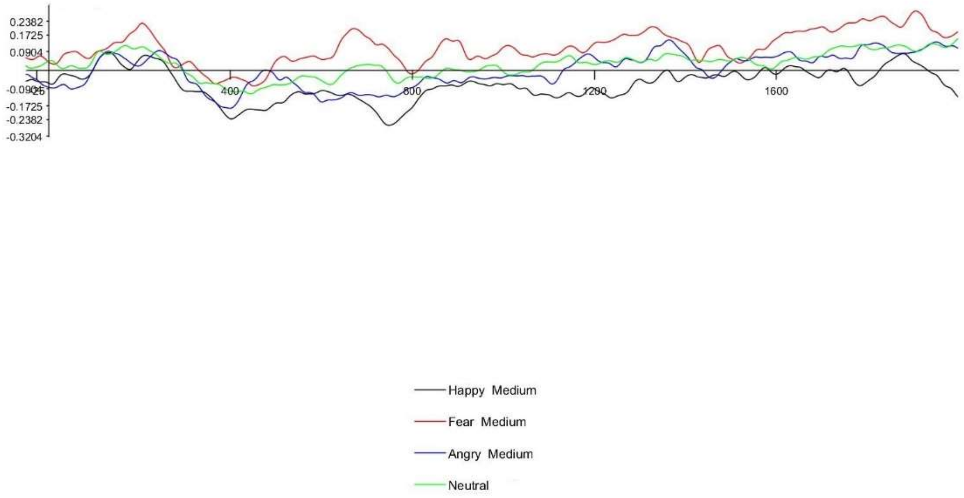


Figure 4.19. Corrugator activity during correct recognition of medium intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

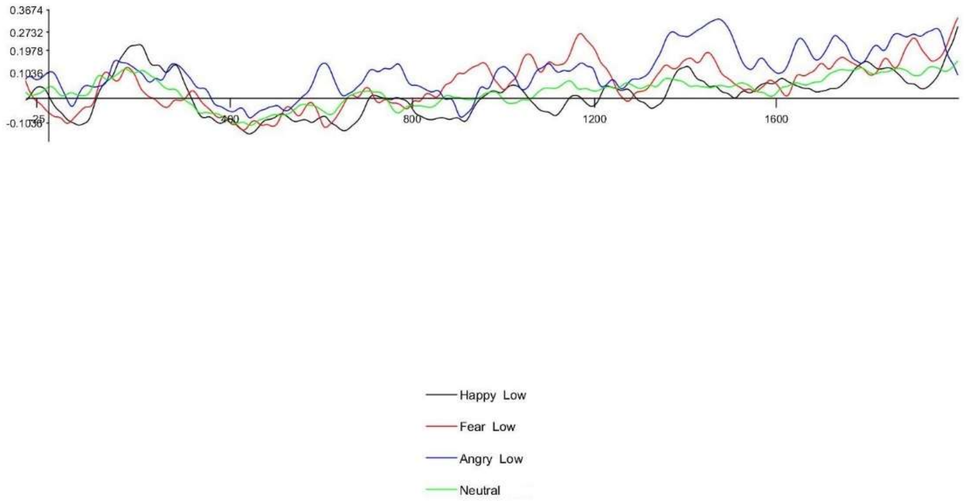


Figure 4.20. Corrugator activity during correct recognition of low intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

4.3.4.3.2 Zygomaticus major

One way ANOVAs did not show main effect of emotion on zygomaticus activity means during exposure to low intensity face expressions, $F(2.2, 5.5) = 2$, $p = .109$, $\eta_p^2 = .562$; medium intensity face expressions, $F(2.5, 63) = 1.4$, $p = .252$, $\eta_p^2 = .053$ and high intensity face expressions, $F(1.6, 540) = 2.3$, $p = .118$, $\eta_p^2 = .086$.

Comparison between intensities

The 2 way ANOVA showed a marginal main effect of emotion, $F(1.4, 36.4) = 3$, $p = .064$, $\eta_p^2 = .108$. Paired samples t-tests exploring this main effect showed a stronger EMG reaction during recognition of happy faces (M = -.005, SD = .03) as compared to EMG reaction during recognition of angry faces (M = -.016, SD = .05; $t(25) = 2.16$, $p = .040$), see Figure 4.21.

No intensity effect, $F(1.4, 38.1) = 1.8$, $p = .178$, η2 = .067 or emotion *x* intensity interaction, $F(1.8, 48.8) = 1.5$, $p = .209$, $\eta_p^2 = .058$ was shown.

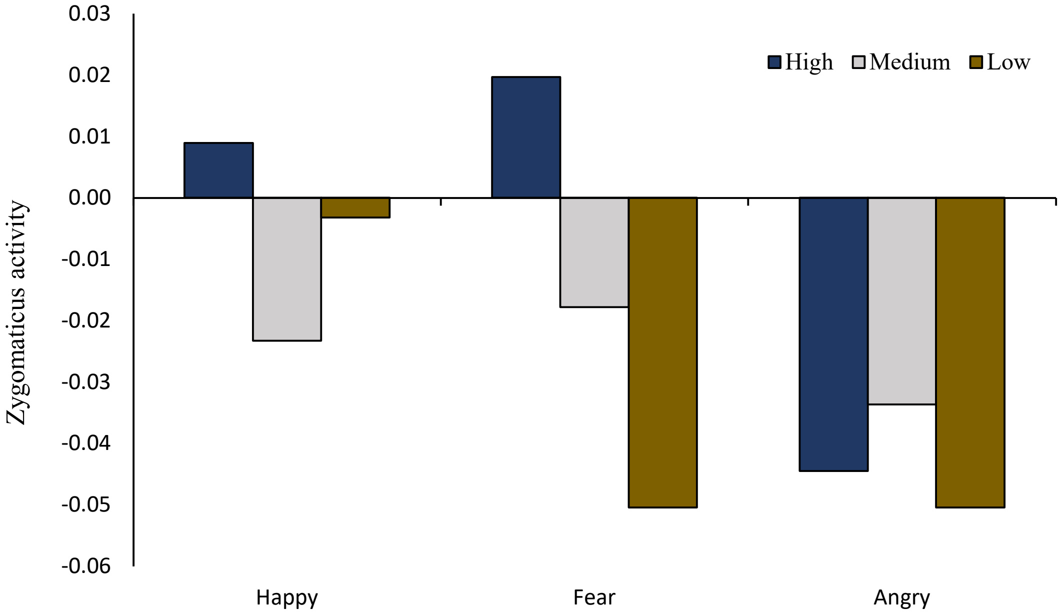


Figure 4.21. Zygomaticus activity during recognition of low, medium and high intensity expressions for all emotions.

Mimicry time course

We analysed the time-course of mimicry by performing two 4-way repeated measures ANOVA with emotion (angry, happy); intensity (3: low, medium, high); time (4: early, mid-early, mid-late, late). As expected, results showed a marginal effect of emotion, *F(*1, 26) = 4.119, p = .053, η_p^2 = .137 with the zygomaticus showing greater activity during happy faces (M = -.002, SD = .03) than angry faces (M = -.03, SD = .07; *t(*26) = 2, p = .053), see Figures 4.22, 4.23 and 4.24.

Main effect of time, *F(*2, 54) = 1.328, p = .271, η_p^2 = .049 and of intensity, *F(*1.6, 43) = .063, p = .911, η_p^2 = .002 were not significant. The interactions time *x* emotion, *F(*1.3, 42) = .795, p = .435, η_p^2 = .030, time *x* intensity, *F(*4, 107) = 1.123, p = .350, η_p^2 = .040, emotion *x* intensity, *F(*1.8, 47) = 1.475, p = .239, η_p^2 = .054, and time *x* emotion *x* intensity, *F(*3, 78) = 1.622, p = .191, η_p^2 = .059 were also not significant.

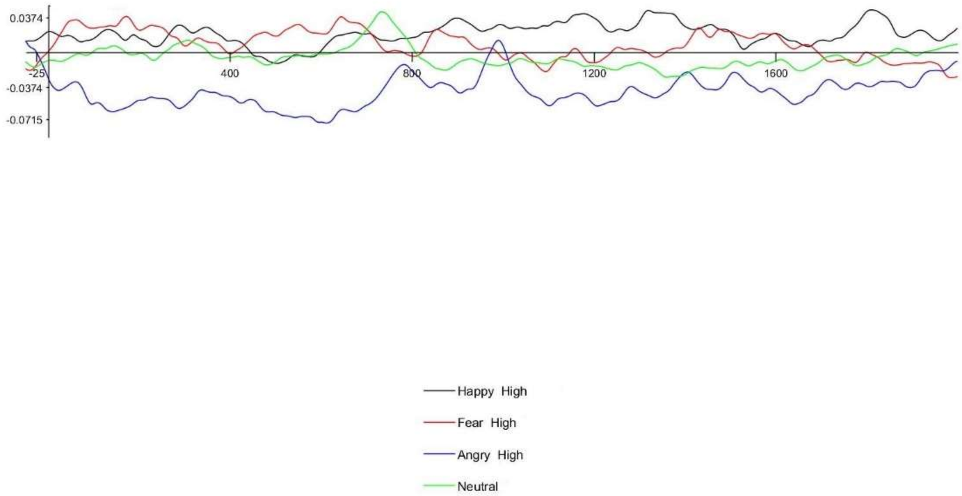


Figure 4.22. Zygomaticus activity during correct recognition of high intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

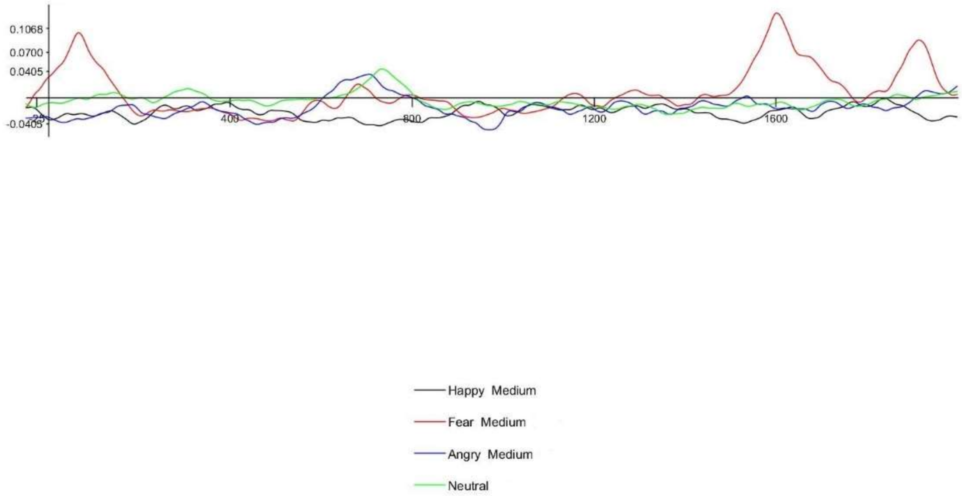


Figure 4.23. Zygomaticus activity during correct recognition of medium intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

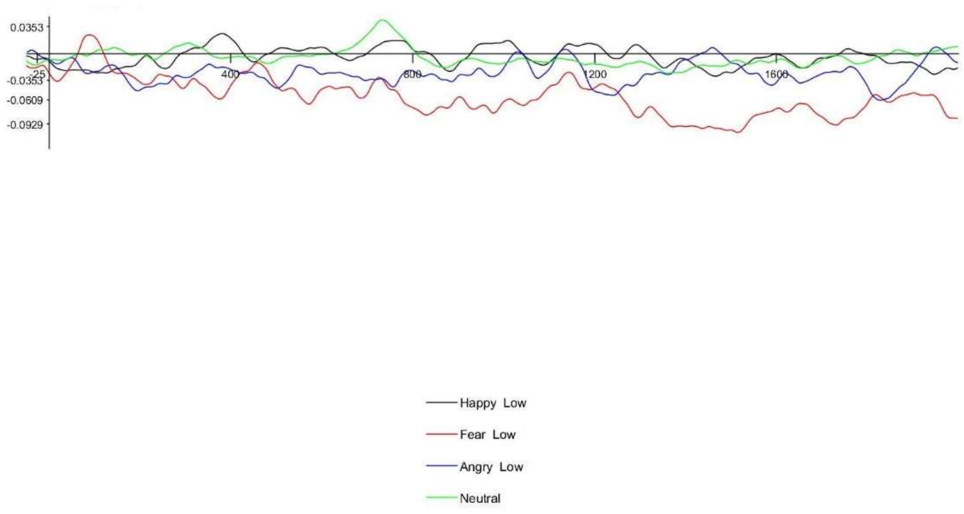


Figure 4.24. Zygomaticus activity during correct recognition of low intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

4.3.4.4 Correlations between EEG activation and behavioural performance

We then performed a non-parametric Spearman rank-order correlation between EPN and N400 activations' means and accuracy and RTs of correct responses. For these analyses, data from 24 participants were used (17 females, age mean = 23.91, age SD = 8.45). Fourteen participants were removed from the behavioural datasets and three participants have been removed for the EEG datasets in order to have a unique matching dataset. Only significant correlations are reported below.

4.3.4.4.1 EPN - behavioural correlations

Accuracy

Weaker right EPN waves were only found to be associated with higher discrimination accuracy of high intensity happy faces (rs (23) = .563, *p* = .005).

Reaction times

No correlation was significant.

4.3.4.4.2 N400 - behavioural correlations

Accuracy

Correlations between N400 activations with response accuracy showed significant results only on the left hemisphere N400 waves. In particular, higher discrimination accuracy of low intensity happy faces was found to be significantly associated with stronger left N400 (rs (23) = -.468, *p* = .024). While, higher discrimination accuracy of low intensity angry faces was found to be significantly associated with less negative left N400 (rs (23) = .570, *p* = .004).

Reaction times

Correlations between N400 activations means with reaction times showed significant results only on the right N400 waves. In particular, slower correct discrimination of medium intensity fearful faces was found to be significantly associated with stronger N400 waves (rs (23) = -.514, *p* = .012). Similarly, slower correct discrimination of high intensity fearful faces was found to be marginally significantly associated with stronger N400 waves (rs (23) = -.389, *p* = .066).

Greater N400 waves were found to be significantly associated with slower correct discrimination of both high intensity angry faces (rs (23) = -.482, *p* = .020) and medium intensity angry faces rs (23) = -.448, *p* = .032).

4.3.4.5 Correlations between EMG activation and behavioural performance

We then performed a non-parametric Spearman rank-order correlation between zygomaticus and corrugator activations' means of each time window and accuracy and RTs of correct responses. As above, data from 24 participants were used for this analysis (females = 18, age mean = 23.75, age SD = 8), with 14 participants removed from the behavioural datasets and three participants removed for the EEG datasets in order to have a matching dataset.

4.3.4.5.1 Corrugator - behavioural correlations

Accuracy

200-400

Correlations between corrugator activations at 200-400 ms and accuracy means showed that greater early corrugator activity faces was marginally associated with correct discrimination of high intensity angry (rs (24) = .370, *p* = .076).

400-600

No correlation was significant

600-800

No correlation was significant

800-1000

Correlations between corrugator activations means with accuracy means showed higher corrugator activation from 800 to 1000 ms after SO associated with higher discrimination accuracy of low (rs (24) = -.498, *p* = .013) and high intensity angry faces (rs (24) = -.489, *p* = .015.

Reaction times

200-400

Correlations between early (200-400 ms after SO) corrugator activations means with RTs means showed that greater corrugator activity marginally associated with slower correct discrimination of low intensity fearful faces (rs (24) = .394, *p* = .057);

400-600

No correlation was significant.

600-800

No correlation was significant.

800-1000

Correlations between corrugator activations means with RTs means showed greater corrugator reactions occurring from 800 to 1000 ms after SO during the discrimination associated with faster correct discrimination of medium intensity fearful faces (rs (24) = -.491, *p* = .015).

4.3.4.5.2 Zygomaticus - behavioural correlations

The same analyses on the zygomaticus muscle did not show any relevant significant result.

4.3.4.6 Correlations between EEG and EMG activity

We then ran a non-parametric Spearman rank-order correlation between each ERP component and zygomaticus and corrugator activations' means. For this analysis 26 participants have been used (females = 17, age mean = 23.91, SD = 8.45). One participant has been removed from the EMG datasets in order to have a unique matching dataset.

4.3.4.6.1 EPN - EMG correlations

200-400 ms

The correlation between corrugator activations means with right EPN activations showed stronger early corrugator activity (200-400 ms after SO) marginally associated with weaker left EPN waves during correct discrimination of medium intensity angry faces (rs

(26) = .354, *p* = .076) but with stronger left EPN waves during correct discrimination of low intensity angry faces (rs (26) = -.376, *p* = .058).

400-600 ms

The correlation between corrugator activations means with right EPN activations during perception of angry faces showed stronger EPN waves associated with stronger corrugator activation from 400 to 600 ms after SO (rs (26) = -.390, *p* = .049) during correct discrimination of medium intensity angry faces.

Regarding correlations between the corrugator activity means during perception of fearful faces, the analysis showed weaker mid early corrugator activity (400-600 ms after SO) marginally associated with stronger left EPN waves during correct discrimination of low intensity fearful faces (rs (26) = .359, *p* = .071).

600-800 ms

The correlation between corrugator activations means with right EPN activations during perception of fearful faces showed weaker late corrugator activity (600-800 ms after SO) marginally associated with stronger EPN waves during correct discrimination of low intensity fearful faces (rs (26) = .367, *p* = .065)

800-1000 ms

No correlation was significant.

4.3.4.6.2 N400 – EMG correlations

200-400 ms

Analysis on physiological data recorded during discrimination of high intensity angry faces showed stronger right N400 waves associated with greater early mimicry (rs (26) = -.451, *p* = .021).

Moreover, less negative left N400 was marginally associated with increased early corrugator activity during discrimination of high intensity fearful faces (rs (26) = .365, *p* = .067).

400-600 ms

Whereas, less negative left N400 was associated with higher mid early corrugator activity during discrimination of medium (rs (26) = .560, *p* = .003) and low (rs (26) = .411, *p* = .037) intensity angry faces.

600-800 ms

This correlation also showed weaker left N400 associated with greater late mimicry reactions during discrimination of medium intensity angry faces (rs (26) = .490, *p* = .011).

Moreover, less negative left N400 was marginally associated with increased late corrugator activity during discrimination of high intensity fearful faces (rs (26) = .455, *p* = .019).

800-1000 ms

Analysis on physiological data recorded during discrimination of high intensity angry faces showed stronger right N400 waves associated with greater very late corrugator activity (rs (26) = .411, *p* = .037). This correlation also showed weaker left N400 associated with very late mimicry reactions during discrimination of medium intensity angry faces (rs (26) = .615, *p* = .001).

Moreover, less negative left N400 was marginally associated with increased very late corrugator activity during discrimination of high intensity fearful faces (rs (26) = .408, *p* = .038).

The analysis also showed higher right N400 was marginally associated with increased very late zygomaticus activity during discrimination of high intensity happy faces (rs (26) = -.354, *p* = .076).

4.3.5 Discussion

The present study was an ERP and EMG study that aimed at investigating occurrence and timing of cognitive-central internal recognition and the occurrence and timing of peripheral simulation related to recognition of face expressions. The study featured low-, medium- and high-intensity (fully expressive) facial expressions. The task was a valence detection task of happy, angry or fearful facial expressions presented rapidly (100 ms). Accuracy and reaction times were recorded. EEG activity was recorded together with facial EMG activity of the *corrugator supercilii* and the *zygomaticus major*, while participants performed a valence detection task. EPN and N400 ERPs components were identified and analysed as the most sensitive to internal cognitive simulation during facial expression recognition, according to the literature (Davis et al., 2017; Mavratzakis et al., 2016).

The results of this study confirmed that fully expressive faces are detected more easily, with accuracy decreasing from high to low intensity expressions across all emotions (happiness, anger and fear). Similarly, our study showed that participants detected high intensity faces quicker than medium and low intensity faces with RT means decreasing correspondingly from high intensity expressions to low intensity expressions. These results are in line with previous studies that found that more subtle face expressions challenge more the recognition process (Hess & Fischer, 2013).

Moreover, our study revealed that participants were more able to detect happy faces compared to angry and fearful faces across all intensities. Therefore, overall positive valence of face expressions has been detected more easily than negative valence face expressions. This is also a common result in the emotion recognition literature, at least for high-intensity fully expressive faces (Adolphs, 2002; Calvo & Beltrán, 2013; Calvo & Nummenmaa, 2008; Leppänen et al., 2007). Despite counterintuitive if we think at the adaptive value of quickly recognising threat in the environment (such as an angry or fearful face), happy faces are often recognised more accurately in facial expression recognition task and this is usually interpreted in terms of priority of processing signs of social affiliation or approval.

Moreover, happy faces are usually easier to recognize not only because the smile is a unique perceptual feature easy to recognise, but also because there is only one positive face to recognise in most studies and instead, when it comes to negative faces, participants have to distinguish between different but sometimes perceptually similar facial displays (e.g. Calvo & Beltrán, 2013). Our results confirm that such superiority of recognition of happy faces is not only more common in fully emotional faces, but it also occurs in case of more subtle displays.

Consistently with previous findings (e.g. Olofsson et al., 2008; Schupp et al., 2004), our EEG results revealed that EPN component showed greater activity for both fearful and happy faces compared to angry faces, but only when expressions were at a medium intensity.

Interestingly, EPN waves were not modulated by emotion when expressions were very ambiguous or very obvious (low and high intensity).

However, an interaction emotion by intensity showed that EPN was sensitive to intensity levels uniquely for fearful faces. Indeed, EPN waves were the strongest for medium intensity fearful faces, followed by high intensity fearful faces and low intensity fearful faces. It is interesting to see once again here that EPN seems to be more responsive to medium-intensity facial expressions.

EMG activity analysis showed that the corrugator supercilii, the muscle responsible for frowning and therefore linked to negative facial expressions, activated more for medium intensity fearful and angry faces. Moreover, time course inspection revealed that corrugator activity was greater during 200 to 400 ms after SO. Whereas, results regarding the zygomaticus major, the muscle involved in pulling the lip corners up for smiling, showed that across all intensities the zygomaticus activated more for happy faces than angry faces. However, intensity of facial expressions did not modulate zygomaticus reactions, both in general and in relation to specific emotions. Results above suggests that mimicry was detected on both muscles.

As mentioned above, behavioural data suggested that participants were more able to recognise happy faces compared to angry and fearful faces across all intensities. As shown above, the zygomaticus activated more for happy faces. We could speculate that these results suggest that the zygomaticus activation for happy faces led to successful recognition supposedly because of an ongoing internal simulation. Another, more conservative way, to interpret this result is that we failed in recording zygomaticus mimicry at all. The lack of any modulation of time on zygomaticus activity and the only marginal effect of emotion might suggest that in our participants the zygomaticus activation was not strong enough to make a significant difference. When looking at correlations between zygomaticus activity and performance, we also did not find any suggestion that participants were more accurate or faster the more they activated the zygomaticus major. More research is needed to determine whether we failed to see significant zygomaticus activity because of technical issues, or whether zygomaticus activity really does not have any bearing on behavioural performance during valence discrimination of facial expressions.

On the other hand, the corrugator activated more for medium intensity fearful and angry faces. Importantly, corrugator mid early activity (400-600 ms after SO) has been found positively correlated with EPN waves during correct detection of medium intensity angry faces. It is worth noticing that EPN showed greater activity when expressions were presented with medium intensity, but across emotions (fearful, happy, angry) the smaller increase was during angry faces. These results suggest that corrugator activation has occupied a critical role in the recognition of medium intensity angry faces, aiding the recognition and holding a supportive-complementary role with EPN. We hypothesize that EPN waves were found decreased due to a supportive peripheral action from the corrugator activity representing an ongoing internal simulation. The analysis of the temporal distribution of EPN (255 ms to 300 ms after SO) and corrugator higher activation allows us to assume that the corrugator activity was greater due an impoverishment of the cognitive central support and not *vice versa*. We argue that the corrugator higher activity from 400 ms after medium intensity angry faces onset represented an embodied processing of anger in the attempt to carry out a successful discrimination.

Regarding N400 component, we found an effect of intensity regardless of the emotional expression, with stronger N400 for low-intensity facial expressions, followed by medium-intensity facial expressions, compared to high-intensity expressions. N400 for all high intensity emotional face expressions were also significantly lower (less negative) than for neutral faces. These results suggest that N400 was stronger when the stimuli are more difficult to recognise (more ambiguous). This finding is in line with previous literature reporting and describing N400 as sensitive to processes that extract meaning from stimuli (Barrett & Rugg, 1989; Willems et al., 2008). Typically N400 greater activity is observed in case of perceptive oddity and peculiarity compared to perceptive and semantically intelligible stimuli across sensory domains (see Federmeier & Laszlo, 2009 for a review).

Correlation analyses also showed that when participants were faster at detecting high intensity angry and fearful faces, as well as when they were more accurate at discriminating the negative valence of low-intensity angry expressions, they had a smaller N400, further confirming what discussed above and suggesting, moreover, that accuracy and RTs in those cases were not driven by a larger N400, but were likely linked to simulative processes instead.

Moreover, during correct recognition of high intensity angry faces, greater N400 was found related with greater early (200-400 ms after SO) but less very late (800-1000 ms after SO) corrugator activity. Additionally, during recognition of high intensity fearful faces, less negative N400 has been found associated with increased early, late and very late corrugator activity. As to the recognition of medium intensity face expressions, correlation analyses showed that faster recognition of medium intensity angry and fearful faces related to less N400.

Similarly, during correct recognition of medium intensity angry faces greater N400 was found related less late (600-800 ms after SO) and very late (800-1000 ms after SO) corrugator activity.

As to the recognition of low intensity face expressions, correlation analyses showed that stronger N400 was related to more accurate recognition of low intensity happy faces.

Additionally, during correct recognition of medium and low intensity angry faces, greater N400 related less mid early (400-600 ms after SO) corrugator activity, which, by the way, coincides with N400's time window. Furthermore, early corrugator activation has been found positively related to slower correct discrimination of low intensity fearful faces. And faster accurate recognition of medium intensity fearful faces was related to greater very late corrugator activity (800-1000 ms).

Thus, correlations between N400 activity and muscle activation showed that the N400 amplitude was in most cases negatively correlated with corrugator activity: when participants activated the corrugator more, the N400 was smaller. This was true for different emotions/intensities and across different time windows. It is interesting to note that even in the 200-400 ms time window we found a negative correlation between corrugator activity during observation of high-intensity fearful expressions and N400 activity, although N400 in our study was isolated between 400-530 ms. We might speculate that, for high-intensity fearful expressions, when participants mimicked the expressions early they needed to activate less semantic processing afterwards. However, in the 200-400 ms time window we also found the corrugator activity to be positively correlated with N400 amplitude in the case of high intensity angry facial expressions.

All these results taken together are in line with findings reported by Davis and colleagues who found that greater N400 was associated with greater semantic retrieval demands (Davis et al., 2017). In other words, N400 seems to represent greater difficulty if the task requires to detect and distinguish semantically an emotion among a few alternatives. In this way, the more ambiguous the face the larger the N400, representing increased task demand. N400 activity trend seems to be particularly sensitive to corrugator activity under the same conditions. The above results in fact suggest that corrugator activation increase concurrently with the task demand, if the case (i.e. for low and medium intensity faces). We argue that such increase does not represent mimicry if present during clear cut face expressions.

If we discuss the above N400 observations in respect to the timeline of corrugator activity we can summarize as follows: regarding negative valence facial expressions, observing corrugator activity from 200-400 ms after SO, greater activity was found associated with greater N400 waves during correct recognition of high intensity angry and fearful faces and slower correct detection of low intensity fearful faces. However, greater early corrugator activity was found associated with less negative N400 waves during correct detection of high intensity fearful faces. In this line, greater corrugator mid early activity (from 400-600 ms after SO) was found associated with less negative N400 waves during correct detection of medium and low intensity angry and fearful faces. Similarly, greater corrugator activity from 600-800 ms after SO was associated with less negative N400 waves during correct detection of high intensity fearful faces. Additionally, corrugator very late activity (800-1000 ms after SO) increase was positively correlated with less negative N400 waves during correct detection of high intensity angry faces and high intensity fearful faces. It is also worth mentioning that corrugator very late activity increase was found associated with more accurate recognition of high intensity angry faces.

Regarding positive valence face expressions, greater N400 waves were associated with greater very late (800-1000 ms after SO) zygomaticus activity during correct recognition of high intensity happy faces. Findings on N400 also showed that greater N400 was associated with correct recognition of low and high intensity happy faces together with greater very late (800-1000 ms after SO) zygomaticus activity.

We interpret the above results arguing that corrugator, and to a lesser extent the zygomaticus, increased activity favours recognition through a sensorimotor simulation that eases semantic retrieval. Corrugator and zygomaticus activity are in fact more present when N400 is decreased. However, we hypothesize that zygomaticus and corrugator higher activity represented mimicry reactions (supporting an internal simulation) only in the case of ambiguity of the emotion displayed (i.e. low and medium intensity expressions). EMG congruent reactions to high intensity expressions would hardly be serving an internal simulation due to the easiness of the task (Niedenthal et al., 2010). However, we can only formulate such an argument only considering rapidly presented high intensity facial expression during a valence detection task.

The above findings seem to confirm that N400 is involved in the representation of affective semantic retrieval (David 2017). It is shown that N400 activity represents a complementary cognitive-peripheral process where mimicry responds selectively in respect to N400 activity. In particular, corrugator activity before N400 leads to successful recognition, but corrugator activity during or after N400 does not. This might be due to a complementary relationship between N400 activity and corrugator activity for which recognition occurs if N400 brain regions are active and corrugator activity shuts down.

4.4 Study 5: Time course of central neurocognitive processing and EMG reactions during categorisation of facial expressions. A simultaneous EEG and facial EMG study.

4.4.1 Introduction

In the previous studies we measured both EPN and N400 EEG components and facial EMG reactions (from corrugator and zygomatic) of individuals doing a task of valence detection of happy, angry or fearful facial expressions presented rapidly (100 ms). The task was aimed at investigating occurrence and timing of cognitive-central internal recognition and the occurrence and timing of peripheral simulation related to recognition of face expressions. The study featured low-, medium- and high-intensity (fully expressive) facial expressions.

In line with previous studies that found that more subtle face expressions challenge more the recognition process (Hess & Fischer, 2013) our results confirmed that fully expressive faces are detected more easily and quicker. Facial mimicry was detected as the corrugator activated more for medium intensity fearful and angry faces between 200 and 400 ms after faces onset and the zygomaticus activated more for happy faces. EPN component showed greater activity for both fearful and happy faces at a medium intensity and showed to be sensitive to intensity levels uniquely for fearful faces. whereas, N400 amplitude was in most cases negatively correlated with corrugator activity: when participants activated the corrugator more, the N400 was smaller. This was true for different emotions/intensities and across different time windows. In particular, corrugator activity before N400 leads to successful recognition, but corrugator activity during or after N400 does not.

The above findings led us to hypothesise that N400 might be involved in the representation of affective semantic retrieval (Davis et al., 2017), whereby N400 activity represents a complementary cognitive-peripheral process where mimicry responds selectively in respect to N400 activity.

The present study, using similar methods and procedure of the previous study, was designed to observe mid late cognitive emotional processing as well as facial mimicry reactions during an explicit emotion categorisation task. Specifically, in this study we observe the ERP components N400 and EPN as representative of an ongoing semantic-linguistic retrieval and the attempt to categorize a particular facial configuration. Furthermore, the present study observes if the modulation of the intensity of the emotion shown in the face during a task of categorization of facial expressions influences N400 and EPN as well as EMG emotion congruent reactions. This study aims at observing weather, if present, the variation of either ERP component across conditions, modulates facial reactions as they did during a task of valence detection of rapidly presented facial expressions. Similarly to the previous study, this study features four different types of face expression, such as happiness, anger, fear and neutral. The study is therefore primarily focused on weather emotion intensity modulation interacts with the ability to discriminate discrete emotions. N400 and EPN components activity were recorded in order to observe whether the modulation of the difficulty of the task (given by the variation of facial expressions' ambiguity) impacts the cognitive emotional processing as represented by the retrieval of a semantic label.

4.4.2 Aims and hypotheses

We expect to replicate the previous study's findings that facial muscles are activated during observation of correspondent facial expressions. We also hypothesise that higher intensity levels of emotion expressed will be associated with facial expression recognition accuracy and RTs. We expect a modulation of EPN and N400 amplitudes related to mimicry occurrence (i.e. before, during or after ERPs onset). We are, however, unable to make full predictions based on the previous study because of the different duration of stimuli presentation (100 ms in the previous study and 2500 ms in the present study) and because of the different nature of recognition task (valence detection in the previous and specific expressions discrimination in the present study).

4.4.3 Methods

4.4.3.1 Participants

Forty-three healthy adults (27 females; mean age = 24.3, age SD = 7.9) participated to this study. 41 of these were the same as in Study 4. Recruitment, exclusion criteria and compensation were the same.

All participants gave an informed consent to participate to the present study. The study was approved by the ethical committee of the School of Psychology at the University of Kent.

4.4.3.2 Materials and procedure

Stimuli, overall procedure and EEG/EMG electrodes placement and data filtering were the same as in Study 4. The only difference was in the type of task participants undertook, which was an explicit emotion categorisation task. Each trial started with a 500 ms fixation cross, followed by a picture of a facial expression (either happy, angry, fearful or neutral) presented for 2500 ms, followed by a blank screen (500 ms), after which participants were prompted to perform an explicit categorization (4 alternative forced choice task: happiness, fear, anger, neutral). The question ‘Which emotion did the face display?’ appeared on the screen and the participant was invited to respond using the buttons Z, X, N and M for ‘happy’, ‘neutral’, ‘angry’, ‘fear’. They had 3 seconds to answer, after which the computer no longer recorded answers. An adjustable blank screen appeared if the 3000 ms were not used up, filling the remaining time (i.e. 2000 ms if all 3000 ms were spent). The ‘Blink’ screen then appeared for 250 ms followed by a 500 ms fixation cross (see Figure 4.25). The appearance of faces was randomized and the response hand counterbalanced. The order of the buttons was counterbalanced across participants with ‘angry’ and ‘fear’ (negative valence) buttons always on one side of the keyboard and ‘happy’ and ‘neutral’ (positive and no valence) buttons on the other to facilitate memorization. During each trial, the response screen had again displayed the four labels indicating the buttons-emotion correspondence. However, participants were asked to do their best to memorize the keys rather than reading them on the screen to minimize eyes movement artefacts. Participants were instructed to use only those keys to give their response as the program did not store any answer given through different keys. Participants could press the keys to give their answer once they saw the question and the labels on the screen. Participants were instructed to use both hands' index and middle fingers. Participants were encouraged to remain with their fingers in the instructed position throughout the experiment. Participants were told that some facial expressions could be difficult to detect. In these cases, they were invited to guess. Participants were invited to try their best to be as fast and as accurate as they could when they were prompt to give their answer.

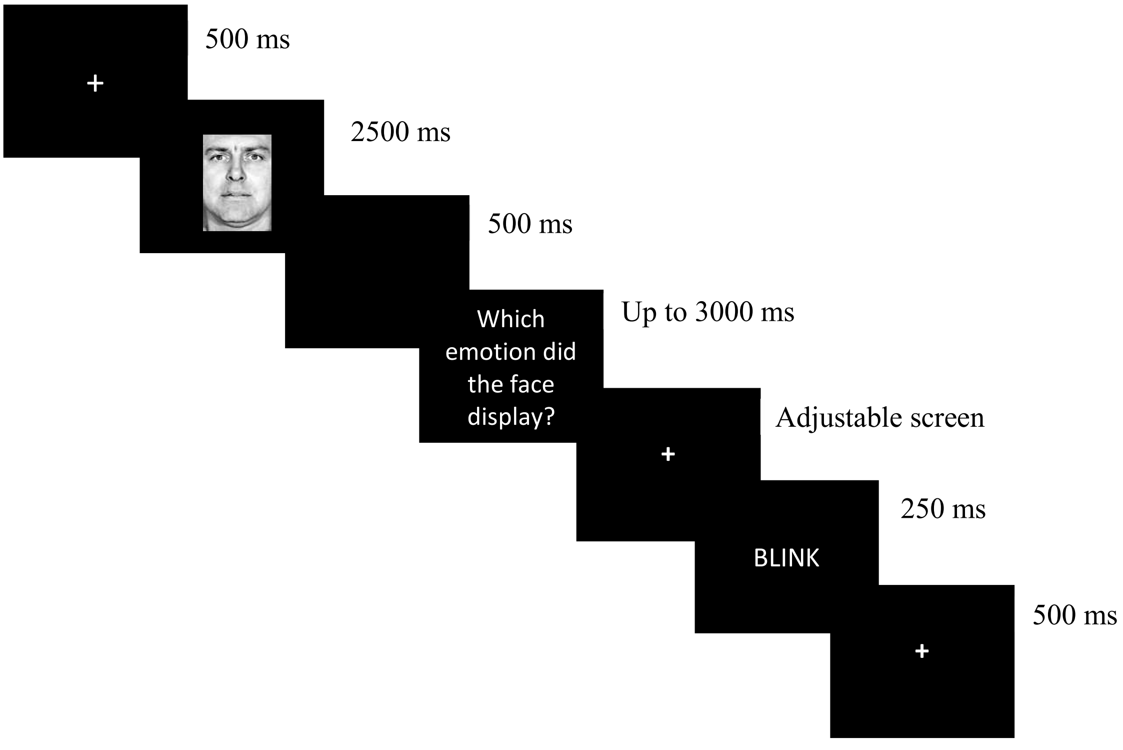


Figure 4.25. Timeline of a trial. Images and text not to scale.

4.4.3.3 Preprocessing of EEG data

We carried out EEG data pre-processing using EEGLAB (Delorme and Makeig, 2004), a MATLAB toolbox (MATLAB R2017A). All EEG channels have been re-referenced to mastoids so that their signal was subtracted from each EEG channel. We then applied a high-pass filter on the data with a 0.2 Hz FIR filter (middle edge cut off at 0.1Hz). The signal has then been epoched with a 500 ms baseline and a 2500 ms epoch. All subjects' datasets have then been visually inspected and we manually rejected trials with excessive noise provoked by muscle artifacts, cardiovascular signal or electrode impedance, and trials with severe drifts (N of trials removed from all datasets = 229). Then ICA (independent component analysis) has been performed on all channels. ICA decomposes data to create a collection of components. More specifically, from each channel a component is filtered out that represents the signal that has been most temporally independent. A second visual inspection then allowed us to identify and reject ICA components most likely to represent muscle artifact (eyes blinks or saccadic movements) or other type of artifact (N of ICA components removed from all datasets = 68). A Basic FIR low pass filter of 40 Hz has then been manually applied to all datasets. Next 20. Next, we carried out a last visual inspection to verify that all the excessively noisy segments were removed after noise correction (N of trials removed from all datasets = 77). Baseline correction was then performed with a 200 ms baseline. To exclude epochs with remaining artifacts, epochs whose activity was -100 +100 microvolt threshold have been rejected (13.7%). To calculate ERPs we then split the epoch files into condition files. We then manually computed the averaged ERPs for each subject. Fifteen participants have been excluded due to an online low pass filter problem (subjects 1-

15). Two participants have been excluded due to excessive behavioural missing responses (subjects 33-34). The following analysis have therefore been conducted on 27 participants (20 females, mean age = 29, age SD = 8.4).

4.4.3.4 Preprocessing of EMG data

The two EMG channels have first been separated from the EEG channels. A notch filter of 50Hz was then applied to the data. Data have then been filtered with a 20 Hz FIR filter cutoff. The signal has then been rectified and resampled to 30 Hz. Epochs have then been extracted in bins that range from -500 from stimulus onset and 2500 ms from stimulus onset. All epochs have then been baseline corrected with a baseline of 500 ms. Artifacts have then been removed rejecting epochs showing extreme amplitudes. We then split the epoch files into condition files. We then manually computed both channels EMG waveform for each subject with ERPLAB.

4.4.3.5 Visual inspection

Visual inspection allowed us to identify components and their time windows. Visual inspection was carried out on ERP's grand averages of activity during successful recognition. All conditions were inspected. Clusters, electrodes and time windows of interest for both components have been based on both literature and data. In this way, we used time windows reported on relevant literature as a guideline for our visual inspection (Achaibou et al., 2007; Calvo et al., 2013; Davis et al., 2017; Dong et al., 2010; Spape' et al., 2017; Hayasaka et al., 2016; Pollux et al, 2016; Mavratzakis et al., 2016). Clusters observed were the temporal-occipital cluster (left: T7, P7, O1, right: T8, P8, O2) and a parietal cluster (left: P7, P3, right:

P4, P8). For N400, we analysed both clusters of scalp sites in order to observe the component peaking in different regions. EPN was only observed in the temporal-occipital cluster.

For EPN we observed EEG activity form about 200 to about 350 ms after stimulus onset (SO). Visual inspection proved that all cluster's electrodes showed mor or less the component peaking with and allowed us to identify possible hemisphere effects (e.g. T7 showing weaker EPN than T8). In particular, EPN in T7 was most pronounced from 290-336 ms, while EPN peaking time window shifted to 270 to 311 ms in T8. Regarding P7, EPN peaked from 235 to 330 ms after SO, but for P8 it was mostly present from 222 to 350 ms. Finally, EPN was also neatly visible in O1 especially from 250 to 320 ms after SO and in O2 from 280 to 320 ms after SO. We then calculated EPN observed onset and offset means (onset: 246, offset: 330 ms) and rounded them up (onset: 245, offset: 330 ms).

For N400, we observed EEG activity form about 350 up to 500 ms after SO. Visual inspection showed that the component peaked more or less under all temporal- occipital cluster electrodes. In particular, N400 appeared stronger from 370 to 475 ms after SO in T7, and from 246 to 463 ms after SO in T8. N400 observed in P7 peaked mostly from 393 ms to 465 ms after SO and from 350 to 460 ms after SO in P8. N400 seem also to differentiate across conditions in O1 where it peaked the most form 350- 460 ms after SO and in O2 where it peaked the most from 350 ms to 480 ms after SO. We then calculated EPN observed onset and offset means (onset: 343, offset: 467 ms) and rounded them up (onset: 345, offset: 465 ms). Visual inspection of N400 in the parietal cluster revealed a peak only under P3 and P4 from 400 to 500 ms after SO. We then calculated the average of N400 observed onset and offset means of both clusters (temporal-occipital cluster onset mean: 345, offset: 465 ms; parietal cluster onset mean: 400, offset mean: 500 ms) and rounded them up (onset: 385, offset: 485 ms). Given the observations above, we extracted P7, P8, O1, O2, T7, T8 activity means from 245 to 330 ms after SO for EPN data analysis and from 385 to 485 ms after SO for N400 data analysis. We also extracted P3 and P4 activity means from 385 to 485 ms after SO for N400 data analysis. Clusters means have then been calculated on Excel before analysing data using SPSS software (version 24.0).

4.4.3.6 Data analysis

4.4.3.6.1 EEG

Separate 2-way repeated measures ANOVAs with hemisphere (left, right) and emotion (happy, angry, fearful, neutral) as factors were conducted on EPN activity means to compare each component activations during low, medium and high-intensity emotional conditions against neutral.

Separate 3-way repeated measures ANOVAs with cluster (temporal-occipital, parietal) hemisphere (left, right) and emotion (happy, angry, fearful, neutral) as factors were conducted on N400 activity means to compare activations during low, medium and high-intensity emotional conditions against neutral.

Furthermore, a 3-way ANOVA with hemisphere (left, right), emotion (happy, angry, fearful) and intensity (low, medium, high) was conducted to compare EPN activations between intensities.

A 4-way ANOVA with cluster (temporal-occipital, parietal) hemisphere (left, right), emotion (happy, angry, fearful) and intensity (low, medium, high) was conducted to compare N400 activations between intensities. All p values given in are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020).

4.4.3.6.2 EMG

Visual inspection allowed us to identify what were the time windows that mostly reveal a difference between conditions. We then extracted 4 time windows: a very early time window going from 200 to 400 ms after stimulus onset (SO), an early time window going from 400 to 600 ms after SO, a late time window going from 600 to 800 ms after SO and a very late time window going from 800 to 1000 ms after SO.

We analysed zygomaticus and corrugator activity means from 200 to 1000 ms after SO for each intensity (low, medium, high) with two one-way ANOVA having 'emotion' (happy, angry, fearful, neutral) as factor.

We then ran a 2-way repeated measures ANOVA with 'emotion' (happy, angry, fearful) and intensity (low, medium, high) as factors on each muscle's activity means of the same time window (200 to 1000 ms after SO).

Then, the activity time course of each muscle was inspected. Time course inspection was performed only for happy and angry emotions to analyse mimicry responses on the zygomaticus and corrugator. We ran two 3-way repeated measures ANOVA with emotion (angry, happy); intensity (3: low, medium, high); time (4: early, mid-early, mid-late, late) on corrugator and zygomaticus activity separately. All p values given are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020).

4.4.3.6.3 Behavioural

Two 2-way repeated measures ANOVAs Emotion (happy, fearful, angry) x Intensity (high, med, low) on accuracy and reaction times have been performed with Greenhouse–

Geisser correction and subsequent Bonferroni adjustment (alpha level, po.05) for multiple comparisons.

4.4.3.6.4 Combined

We then performed a non-parametric Spearman rank-order correlation between EPN and N400 activations' means and accuracy and RTs of correct responses.

Two non-parametric Spearman rank-order correlation between zygomaticus and corrugator activations' means of each time window and accuracy and RTs of correct responses have also been conducted.

Finally, we ran a non-parametric Spearman rank-order correlation between each ERP component and zygomaticus and corrugator activations' means. All p values given are not corrected for multiple comparisons (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016; Kaminska et al., 2020). Similarly, to what has been said for the previous study's analyses, no other study has exhaustively analysed the relationship between EPN and N400 and EMG activity increase and accuracy and RTs during a valence detection of fast presented happy, angry and fearful facial expressions.

These analyses will also explore both positive and negative correlations during strictly relevant conditions (e.g. corrugator activity during angry and fearful expressions conditions, zygomatic activity during happy expressions conditions).

4.4.4 Results

4.4.4.1 Behavioural

Six subjects were excluded because their accuracy level was lower than 80% and we therefore performed our analysis on 37 subjects (females = 24, mean age = 23.32, SD = 5.92).

We first conducted 2-way repeated measures ANOVAs with emotion (happy, fearful, angry), and intensity (high, med, low) as within-subject factors on accuracy and reaction times.

<u>4.4.4.1.1 Accuracy</u>

This analysis revealed a main effect of emotion, $F(1, 36) = 10.02$, $p < .001$, $\eta_p^2 = .223$. Paired samples t-tests exploring this main effect showed that participants were more accurate at explicitly categorising happy faces (M = .708, SD = .118) compared to angry faces (M = .621, SD = .109; t (36) = -3.505, $p = .001$) and fearful faces (M = .617, SD = .101; t (36) = -3.993, $p < .001$). Neutral faces (M = .775, SD = .18) were recognised more than angry faces, t (36) = 3.567, $p = .001$, and more than fearful faces, t (36) = -3.826, $p < .001$, see Figure 4.26.

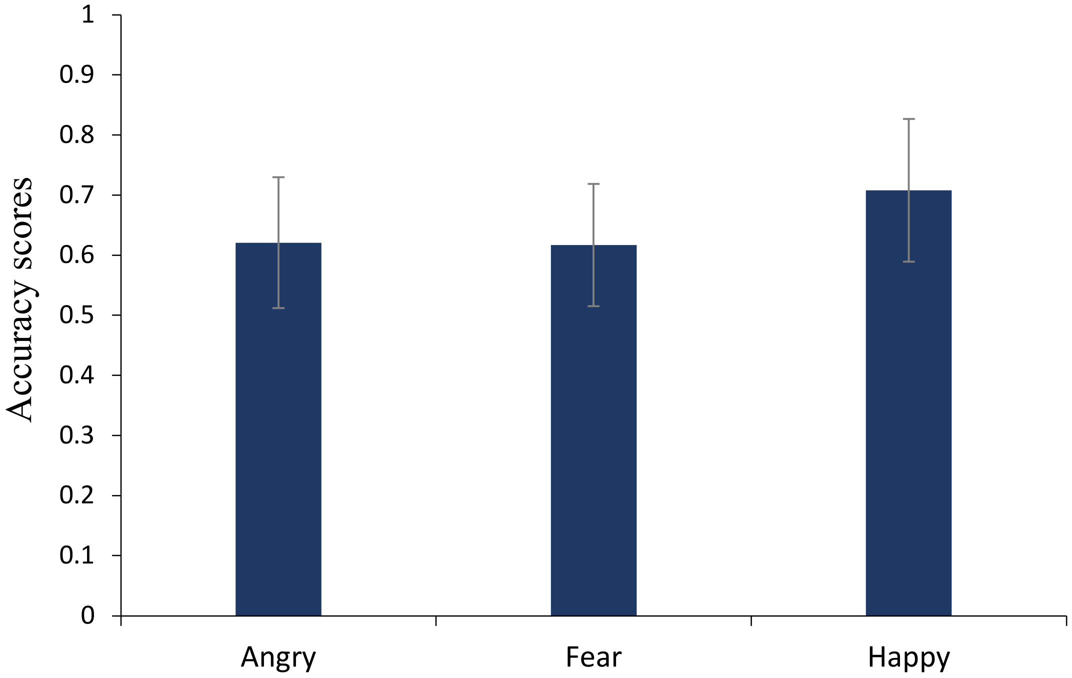


Figure 4.26. Accuracy scores' means of the three emotions.

The analysis also showed a main effect of intensity, *F(*1, 36) = 582.15, p < .001, η_p^2 = .943. As predicted, paired-samples t-tests showed that participants were more able to recognise high-intensity facial expressions (M = .887, SD = .045) than medium-intensity facial expressions (M = .739, SD = .093; t (36) = -3.993, p < .001) and low-intensity facial expressions (M = .319, SD = .133; t (36) = 27.039, p < .001); and in turn they recognized more accurately medium-intensity (M = .740, SD = .093) than low-intensity facial expressions (M = .319, SD = .133; t (36) = 23.375, p < .001), see Figure 4.27.

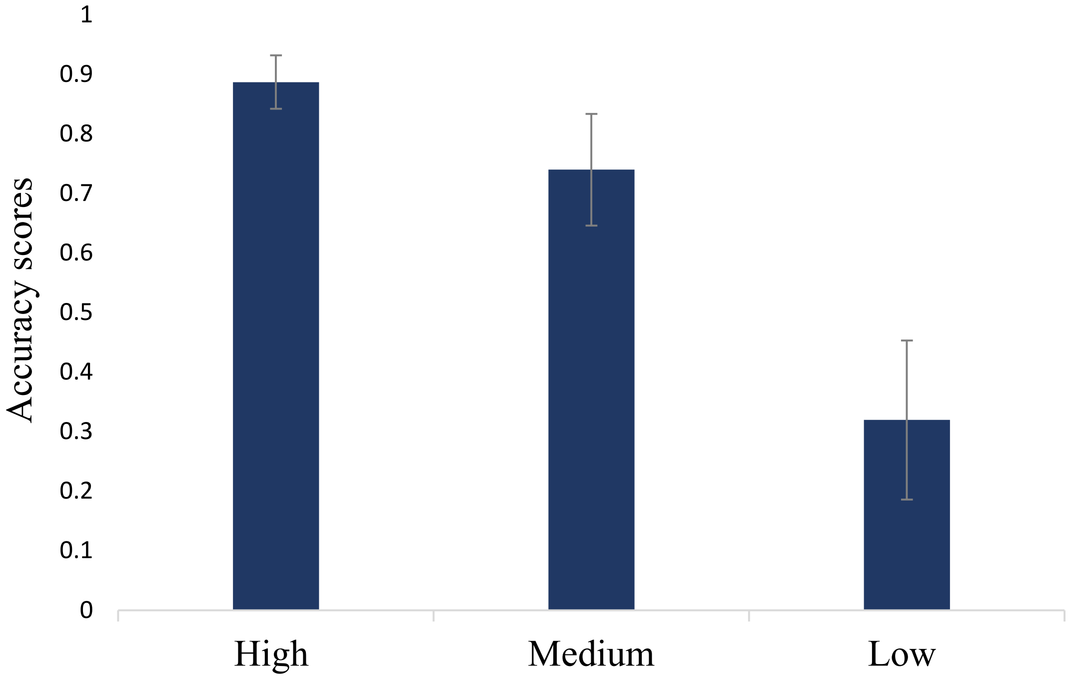


Figure 4.27. Accuracy scores' means of the three intensities.

The interaction between emotion and intensity was marginally significant, *F(*3,3) = 2.58, p = .057, η_p^2 = .069. Across high-intensity expressions, participants recognized happy faces (M = .946, SD = .06) better than angry faces (M = .87, SD = .083; t (36) = 4.4, p < .001) and fearful faces (M = .844, SD = .086; t (36) = 6.1, p < .001). Similarly, across medium-intensity faces participants recognize better happy faces (M = .814, SD = .15) than angry faces (M = .71, SD = .136; t (36) = 3.2, p = .003) and fearful faces (M = .69, SD = .12; t (36) = 4, p

< .001). Across low-intensity faces, participant recognized happy faces (M = .357, SD = .195) more than angry faces (M = .286, SD = .15; *t* (36) = 2, *p* = .052). High-intensity happy faces were recognized better then medium (M = .814, SD = .15; *t* (36) = 7, *p* < .001) and low-intensity happy faces (*t* (36) = 19, *p* < .001), with medium-intensity happy faces being recognized better than low-intensity happy faces (M = .357, SD = .195; *t* (36) = 16, *p* < .001). Similarly, high-intensity angry faces were recognized better then medium, *t* (36) = 11.49, *p* < .001, and low-intensity angry faces, *t* (36) = 23.4, *p* < .001, with medium-intensity angry faces (M = .71, SD = .136) being recognized better than low-intensity angry faces (M = .286, SD = .15; *t* (36) = 19.4, *p* < .001). Finally, high-intensity fearful faces were recognized better then medium, *t* (36) = 9.1, *p* < .001, and low-intensity fearful faces *t* (36) = 19, *p* < .001, with medium-intensity fearful faces (M = .69, SD = .12) being recognized better than low-intensity fearful faces (M = .315, SD = .162; *t* (36) = 17.3, *p* < .001), see Figure 4.28.

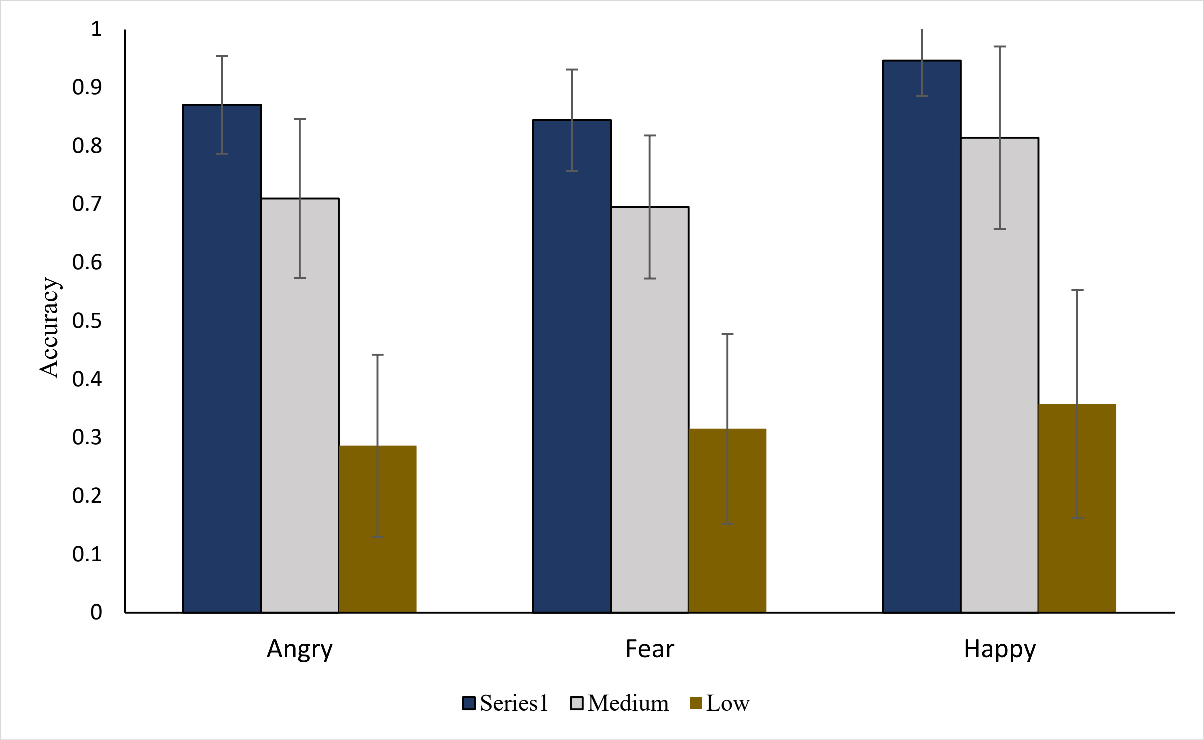


Figure 4.28. Accuracy scores of recognition of low, medium and high intensity expressions for all emotions.

4.4.4.1.2 Reaction times

The same ANOVA performed on reaction times revealed main effect of intensity, $F(1, 36) = 12.154$, $p < .001$, $\eta_p^2 = .258$. Post hoc paired samples t-tests showed that participants recognized high-intensity facial expressions (M = .469, SD = .154) faster than low-intensity facial expressions (M = .522, SD = .186; t (36) = -4.339, $p < .001$). Similarly, they recognized medium-intensity facial expressions (M = .482, SD = .154) quicker than low-intensity facial expressions (M = .522, SD = .186; t (36) = -2.836, $p = .007$), see Figure 4.29.

The main effect of emotion was not significant, $F(1.4,1.4) = 1.25$, $p = .292$, $\eta_p^2 = .035$ as well as the emotion × intensity interaction, $F(3,3) = .825$, $p = .511$, $\eta_p^2 = .023$.

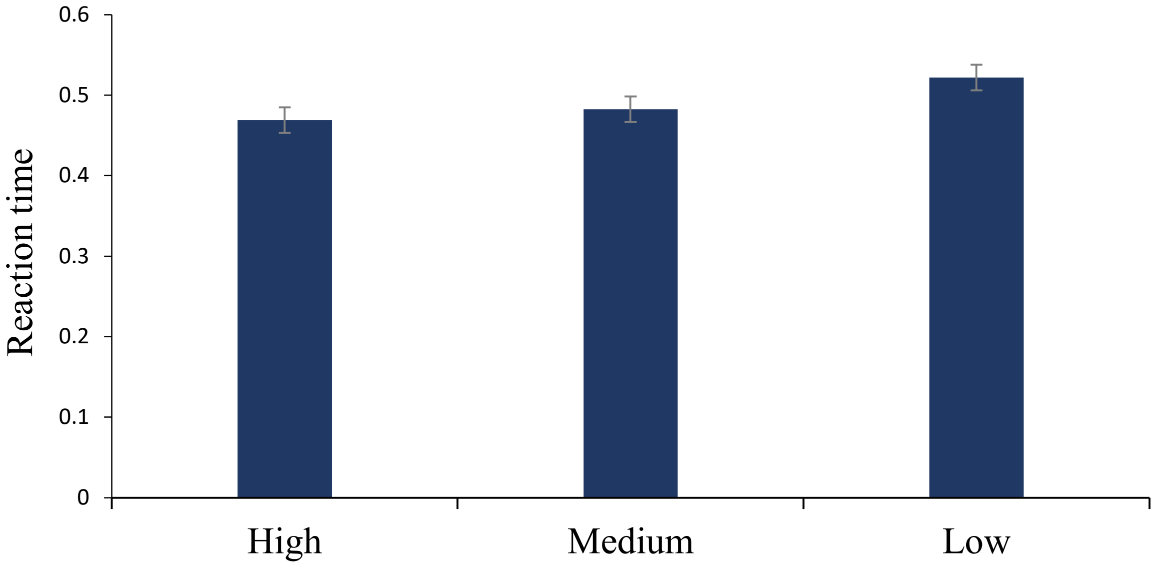


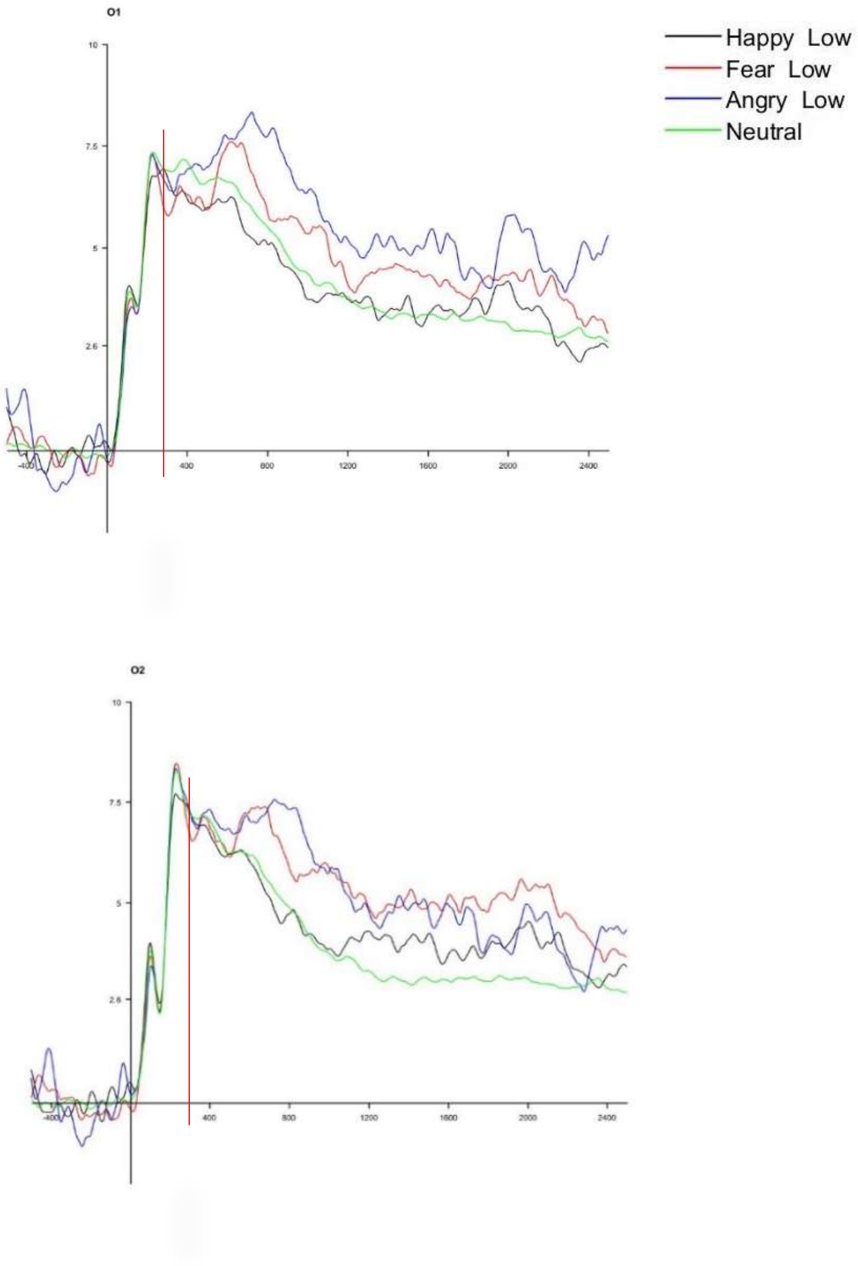
Figure 4.29. Reaction times means of the three intensities.

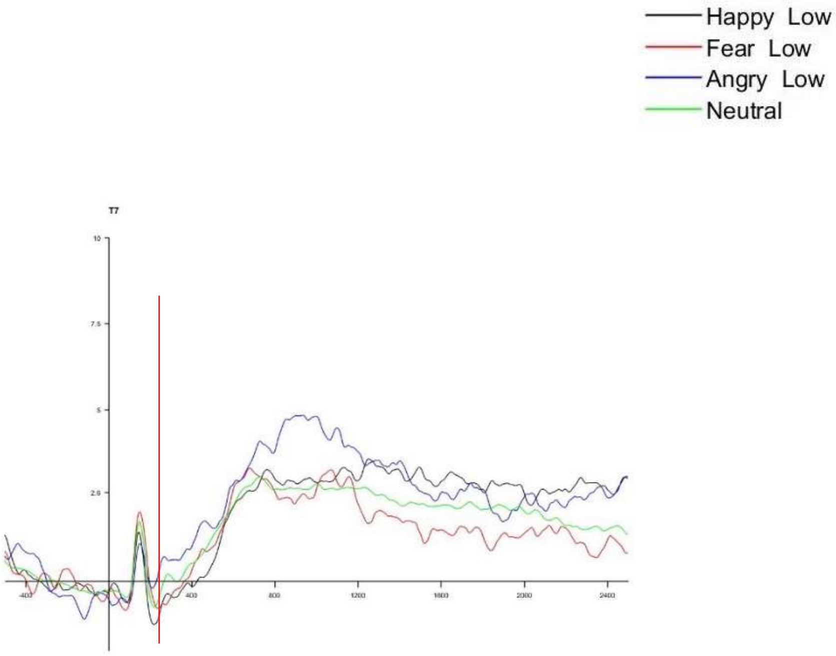
4.4.4.2 EEG

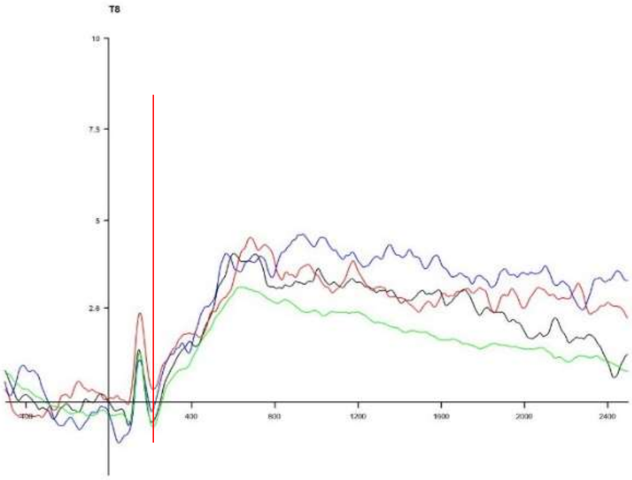
4.4.4.2.1 EPN

Low-intensity vs Neutral

The ANOVA on EPN activity during low-intensity faces did not show a significant effect of hemisphere: $F(1, 26) = 2.527$, $p = .124$, $\eta_p^2 = .089$ or emotion: $F(2.4, 63.7) = .562$, $p = .642$, $\eta_p^2 = .021$. The interaction between hemisphere and emotion was also not significant, $F(2.2, 58.3) = 1.036$, $p = .368$, $\eta_p^2 = .038$, see Figure 4.30.




Happy Low
Fear Low
Angry Low
Neutral
T7
10
7.5
5
2.5
-400
400
800
1200
1600
2000
2400


T8
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7.5
5
2.5
-400
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800
1200
1600
2000
2400

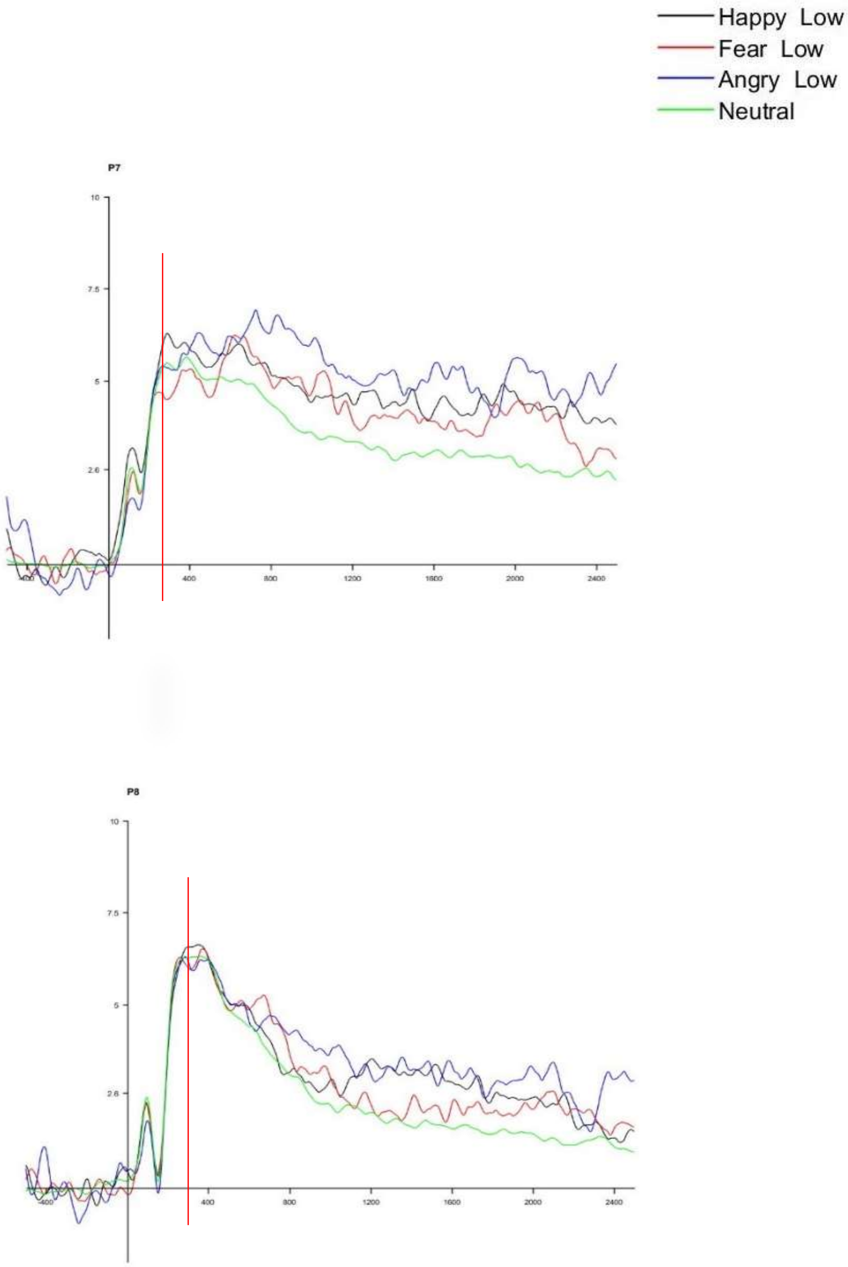
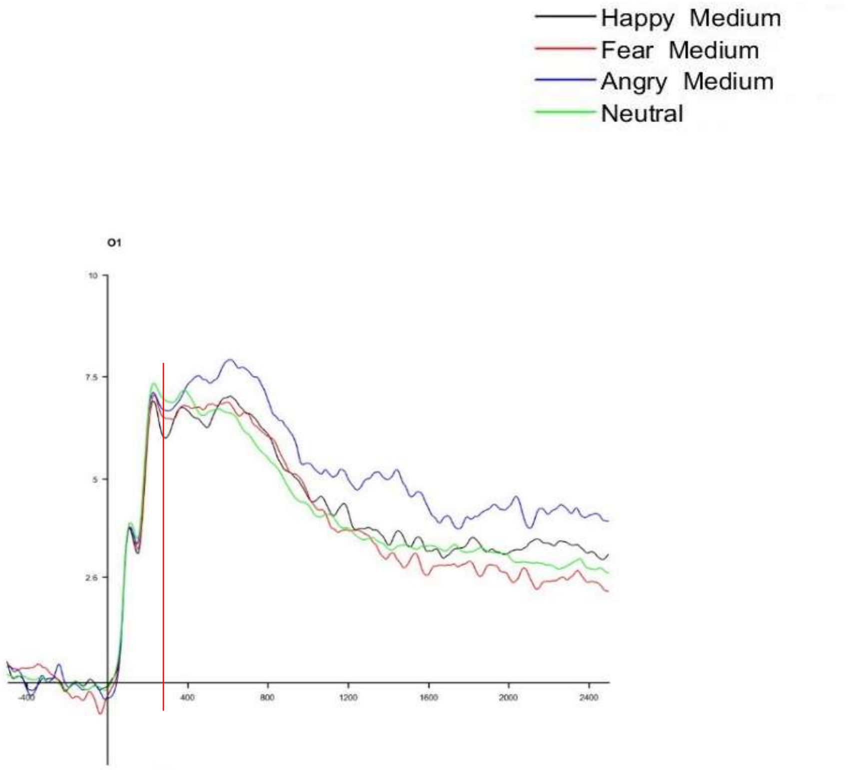
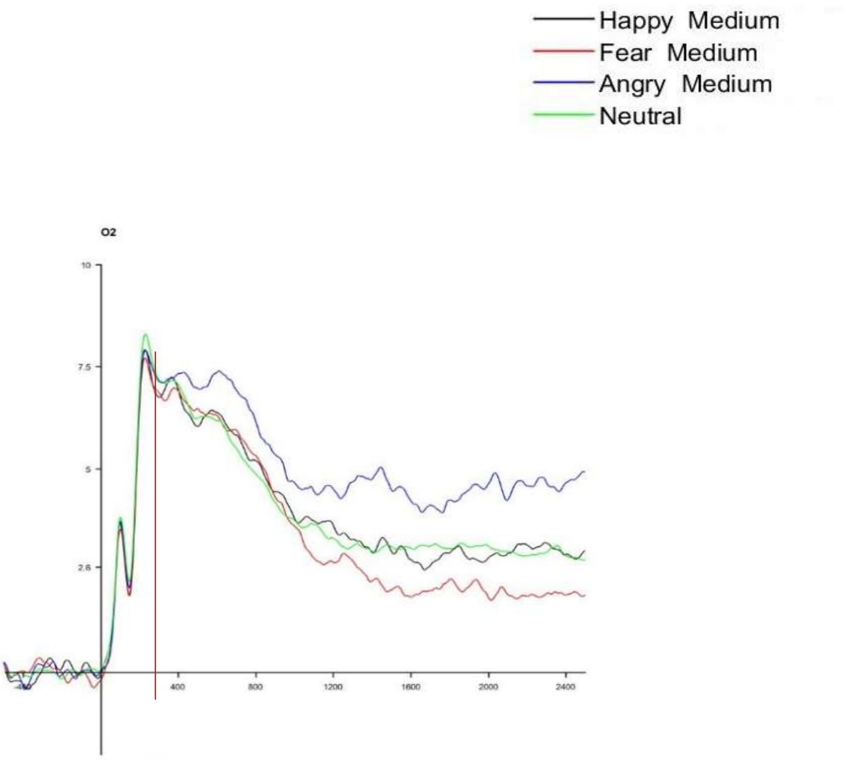


Figure 4.30. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P7/P8) representative electrodes during correct recognition of low intensity emotions and neutral expressions. EPN (245 ms to 330 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Medium-intensity vs Neutral

The ANOVA on EPN activity during medium-intensity faces did not show a significant main effect of hemisphere, *F*(1, 26) = 2.841, p = .104, η_p^2 = .099 or emotion, *F*(2.1, 56.3) = 1.394, p = .257, η_p^2 = .051. The interaction hemisphere x emotion was also not significant, *F*(2.3, 61.8) = .644, p = .555, η_p^2 = .024, see Figure 4.31.




Happy Medium
Fear Medium
Angry Medium
Neutral
O2
10
7.5
5
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-400
400
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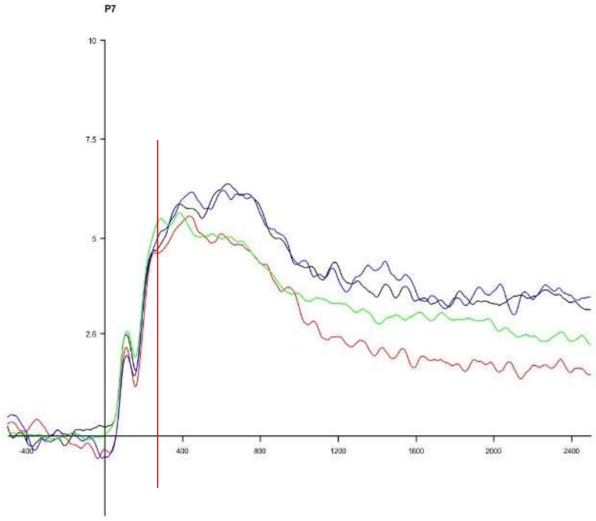
1200
1600
2000
2400


P7
10
7.5
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-400
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1200
1600
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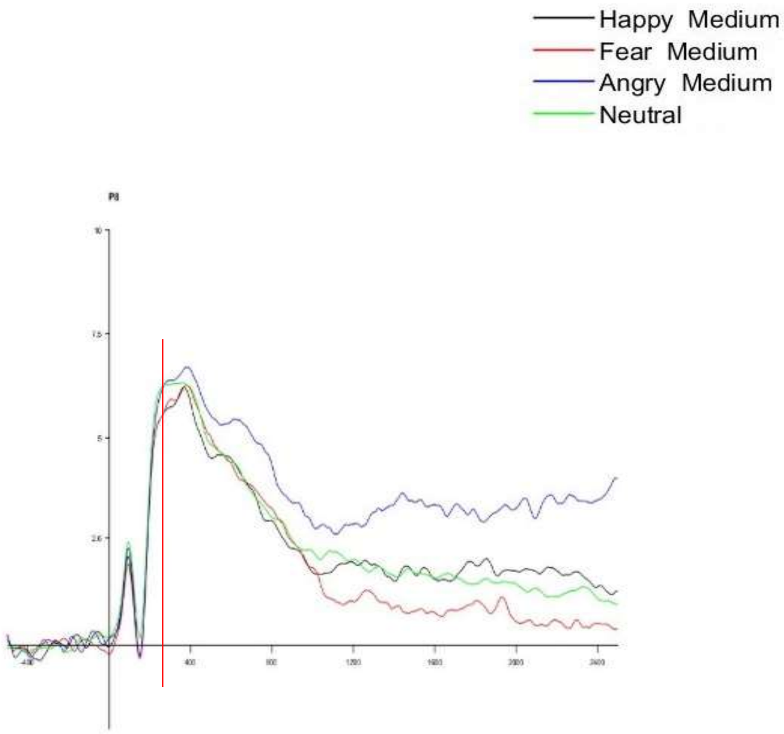
2400


Happy Medium
Fear Medium
Angry Medium
Neutral
P8
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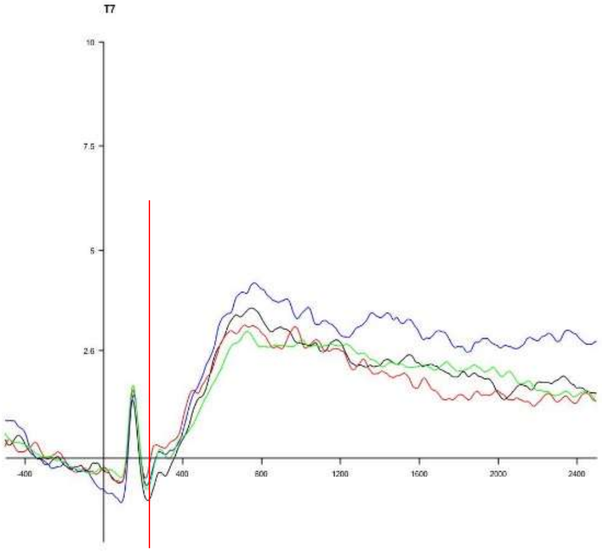
T7
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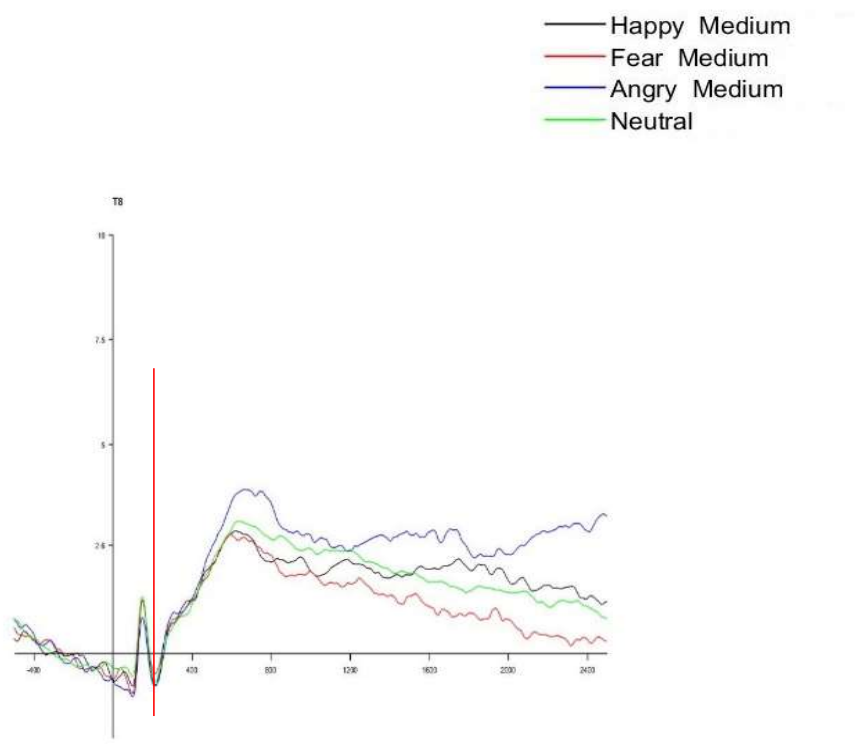
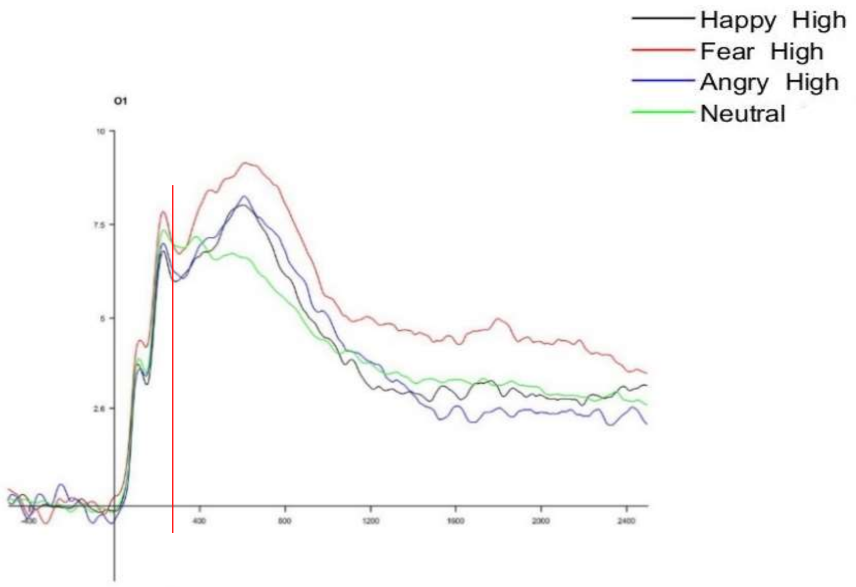


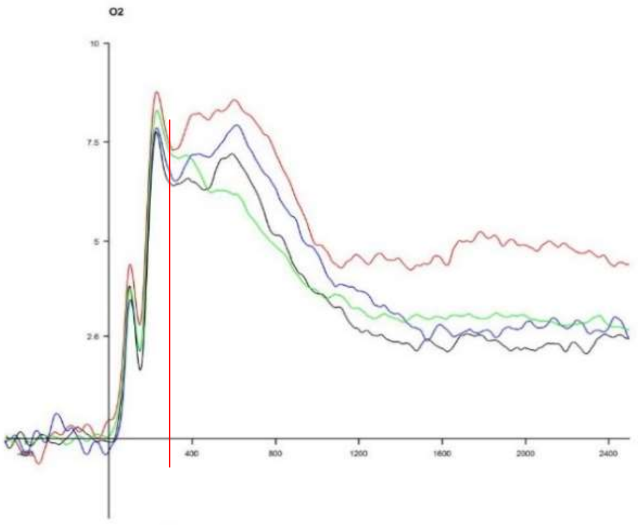
Figure 4.31. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P7/P8) representative electrodes during correct recognition of medium intensity emotions and neutral expressions. EPN (245 ms to 330 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

High-intensity vs Neutral

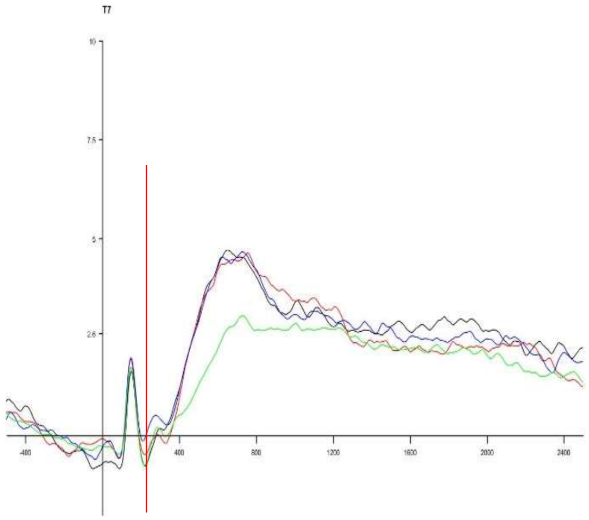
The ANOVA on EPN activity during high-intensity faces only showed a marginal main effect of hemisphere *F(*1, 26) = 3.363, p = .078, η_p^2 = .115). Paired samples t-tests exploring this main effect showed that EPN component during exposure to high-intensity faces was stronger in the right hemisphere (M = 4.693, SD = 2.61) as compared to the left hemisphere (M = 4.039, SD = 2.27; *t* (26) = -1.834), p = .078, see Figure 4.32.

The ANOVA did not reveal a significant effect of emotion, *F(*1, 26) = .694, p = .514, η_p^2 = .026 or interaction hemisphere x intensity, *F(*2.7, 70.2) = .501, p = .664, η_p^2 = .019.






Happy High
Fear High
Angry High
Neutral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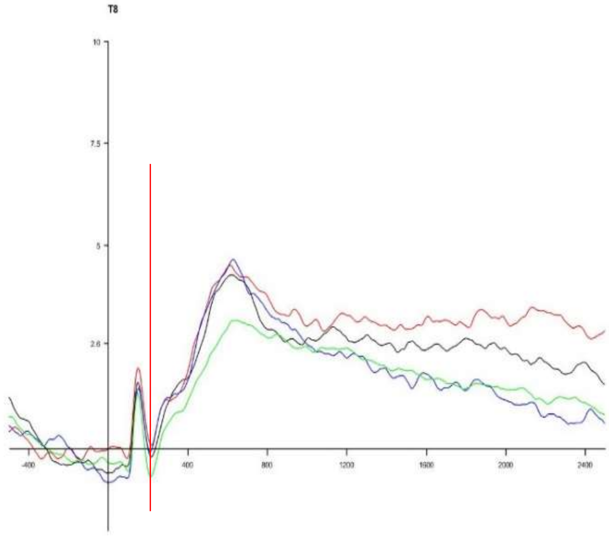
T8
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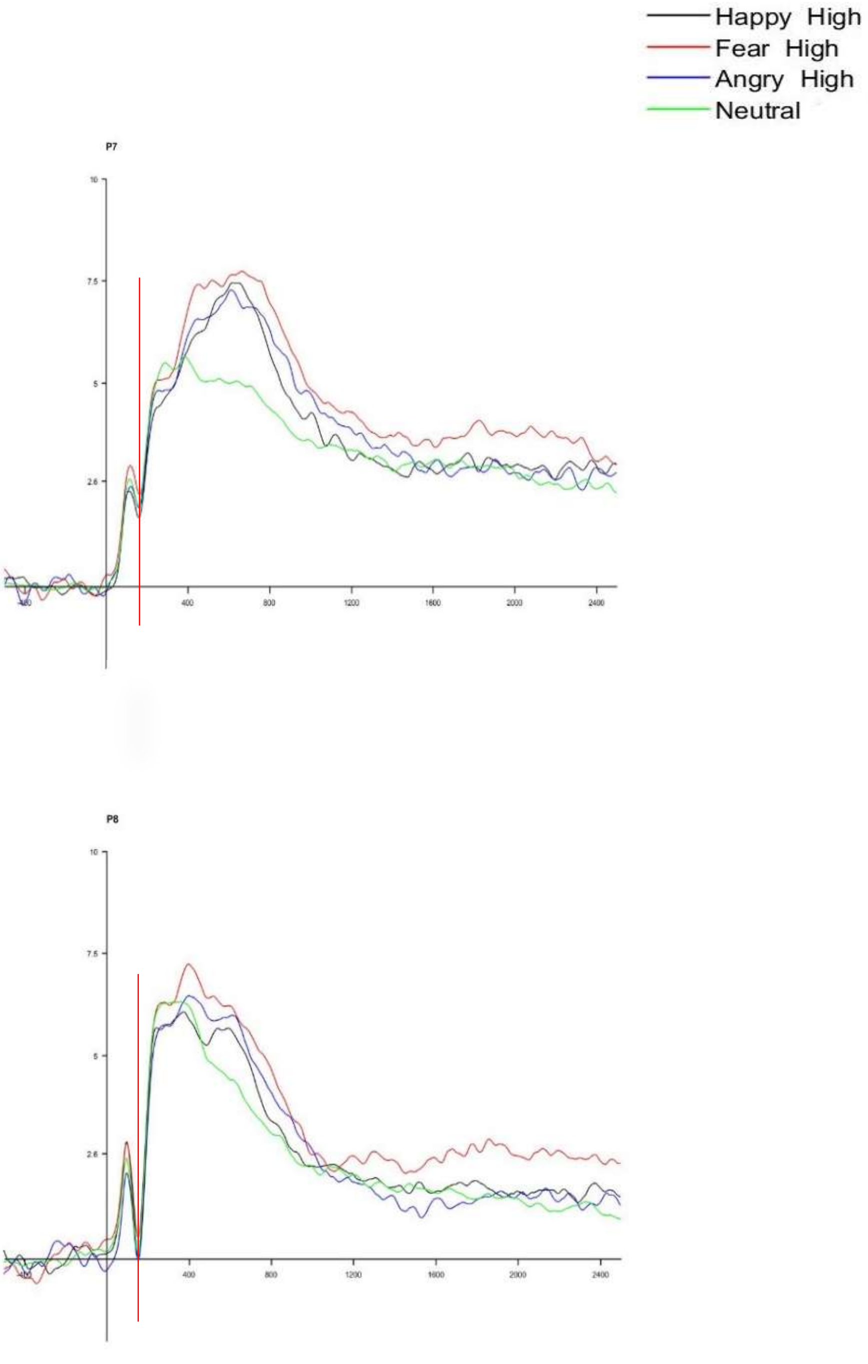


Figure 4.32. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P7/P8) representative electrodes during correct recognition of high intensity emotions and neutral expressions. EPN (245 ms to 330 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Comparisons between intensities

We then performed a 3-way repeated measures ANOVA with hemisphere (2: left, right), emotion (3: happy, fearful, angry), and intensity (3: low, medium, high) as factors on all components to explore main effects of intensity and interactions with it. We did not consider neutral faces in this analysis.

This analysis showed a marginal main effect of hemisphere, *F(*1, 26) = 3.336, p = .079, η_p^2 = .114), exploratory paired samples t-tests showed a stronger right EPN (M = 4.712, SD = 2.77) during exposure to facial expressions as compared to left EPN (M = 4.039, SD = 2.29; *t* (26) = -1.826, p = .079). See figure 4.33 for isovoltage maps of the difference between the three intesities conditions for anger, fear and happiness. However, this ANOVA did not show any main effect of emotion, *F(*1.9, 58.8) = 1.274, p = .288, η_p^2 = .047) or intensity, *F(*1.5,39.2) = .303, p = .740, η_p^2 = .012). No interactions were significant, hemisphere x emotion: *F(*1.9, 49.8) = .125, p = .822, η_p^2 = .005), emotion x intensity: *F(*2.9, 75.9) = .577, p = .628, η_p^2 = .022), hemisphere x emotion x intensity: *F(*2.7, 72.6) = 1.134, p = .339, η_p^2 = .042).

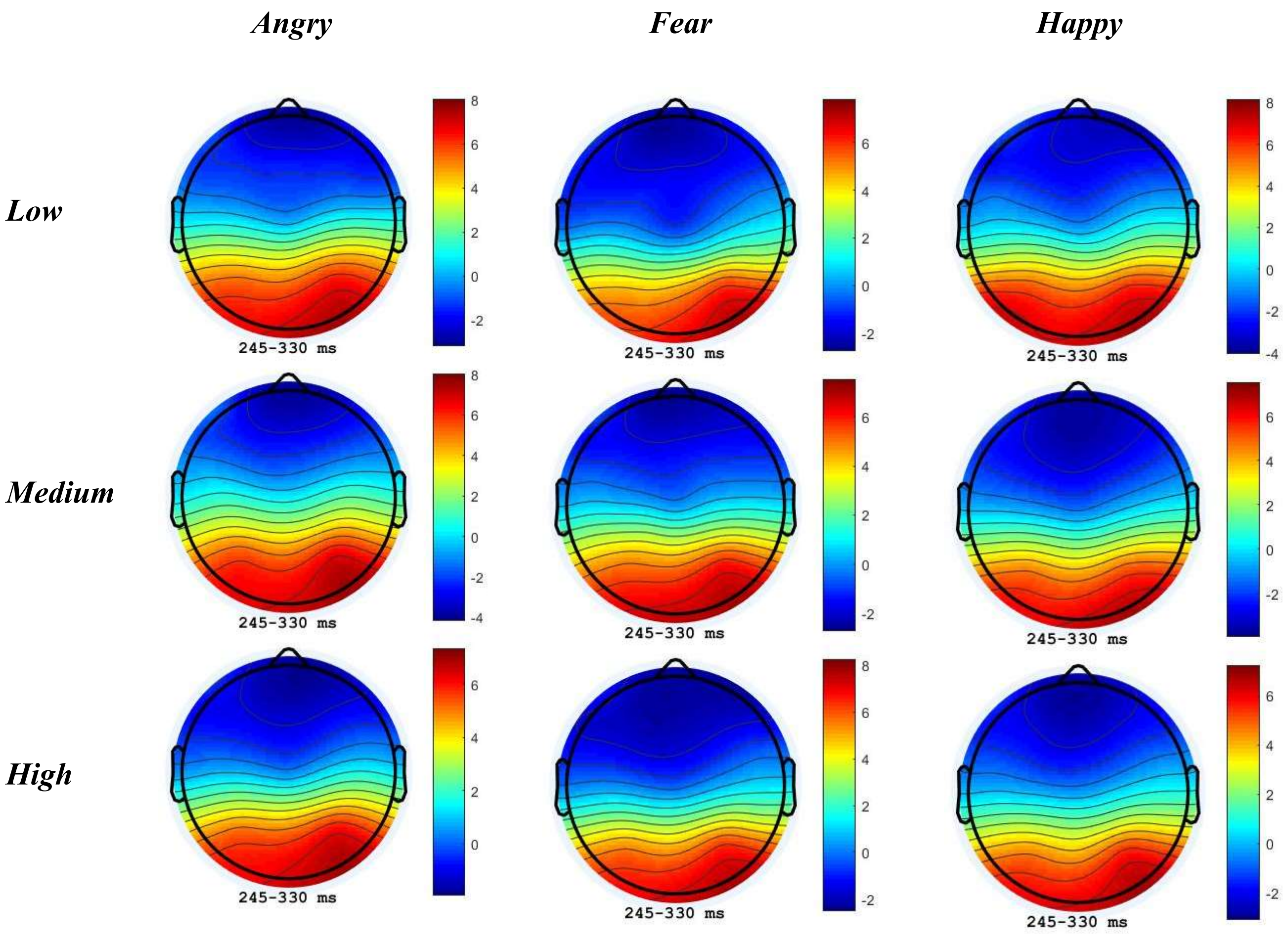
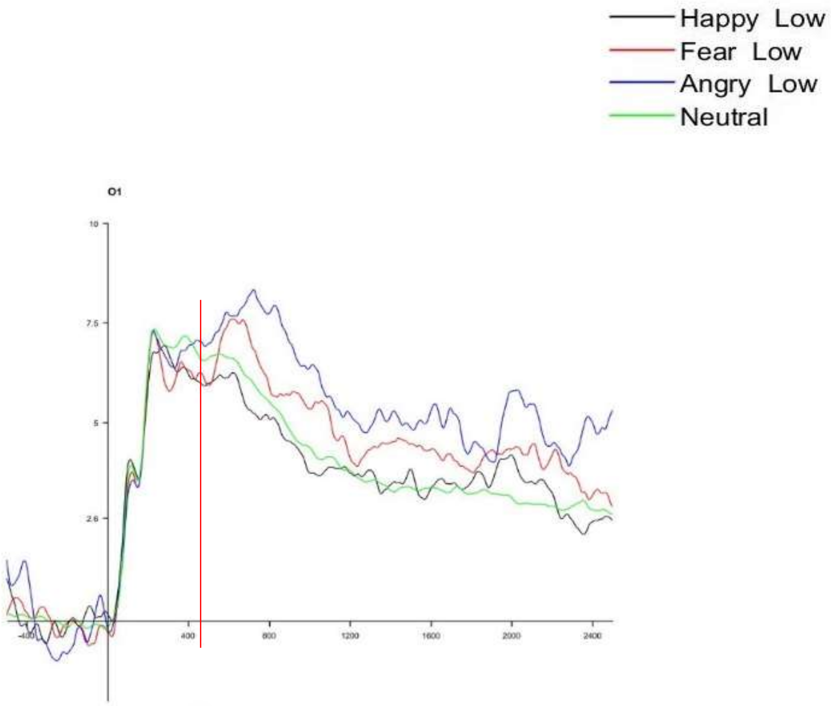


Figure 4.33. Topographic representations of the difference in mean amplitude across the scalp between the three intensities (low, medium and high) during EPN interval (245-330 ms after faces onset) during correct recognition of emotions (anger, fear and happiness). Results showed stronger right EPN.

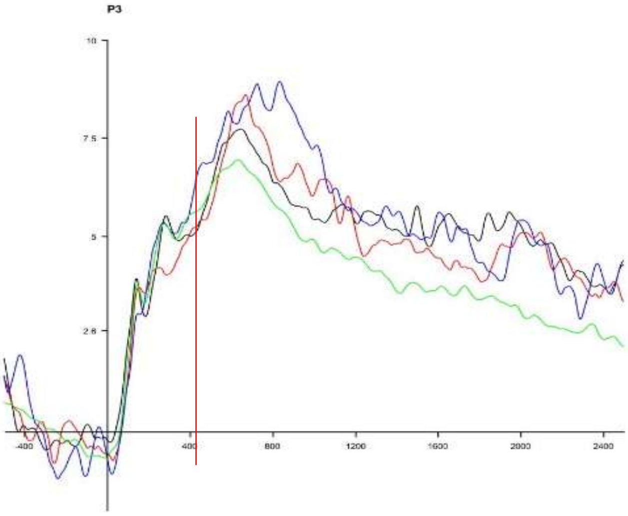
<u>4.4.4.2.2 N400</u>

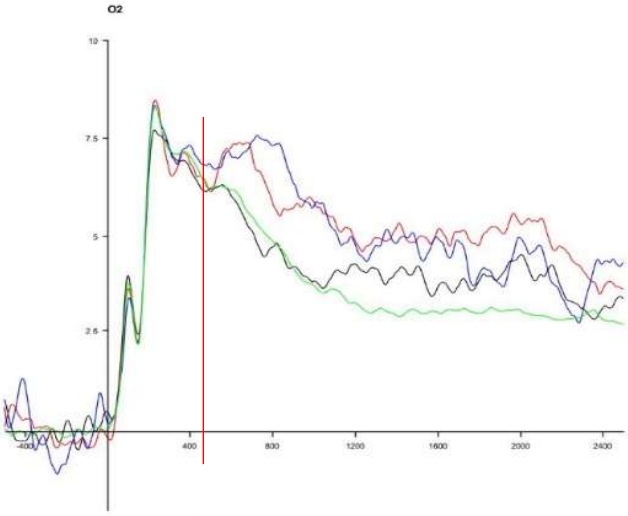
Low-intensity vs Neutral

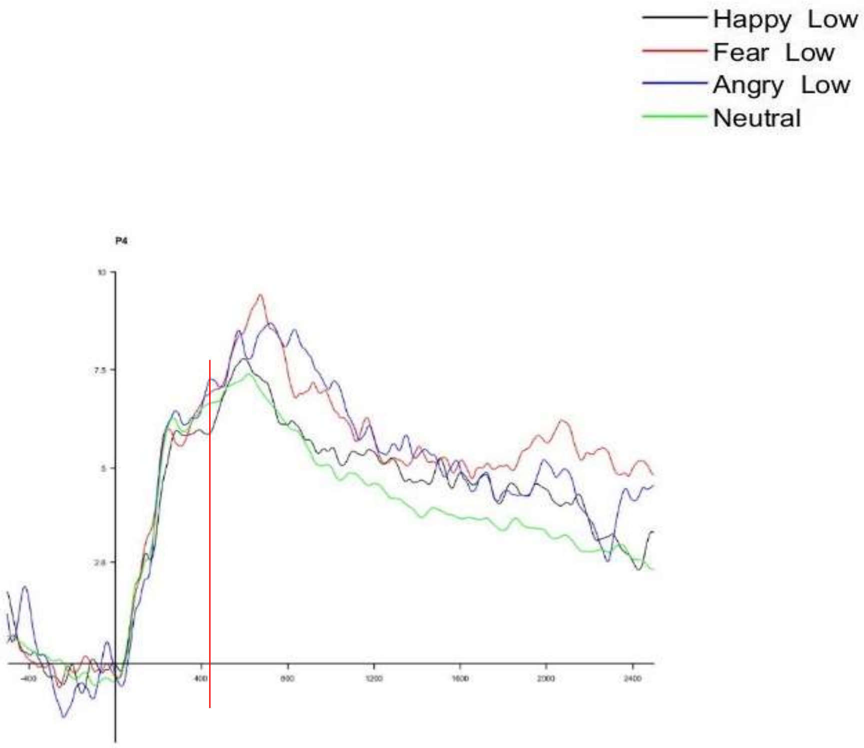
The ANOVA on N400 activation during exposure to low-intensity emotional facial expressions and neutral faces showed a main effect of cluster, $F(1, 26) = 19.590$, $p < .001$, η_p^2 = .430). Here again, post hoc t-tests revealed that N400 waves in the temporal-occipital cluster were larger (M = 4.58, SD = 2.56) as compared to N400 waves in the parietal cluster (M = 6.34, SD = 3.77; t (26) = -4.426, p < .001). The ANOVA did not show significant main effect of emotion, $F($2.4, 63.3) = .856, p = .449, η_p^2 = .032, of hemisphere $F($1, 26) = 3.4, p = .076, η_p^2 = .116, or interactions: cluster x hemisphere $F($1, 26) = 2.681, p = .114, η_p^2 = .093; cluster x emotion $F($1.9, 52.3) = .406, p = .672, η_p^2 = .015; hemisphere x emotion $F($1.9, 50.1) = .710, p = .492, η_p^2 = .027; cluster x hemisphere x emotion $F($2, 53.2) = .807, p = .454, η_p^2 = .030, see Figure 4.34.



— Happy Low
— Fear Low
— Angry Low
— Neutral







Happy Low
Fear Low
Angry Low
Neutral
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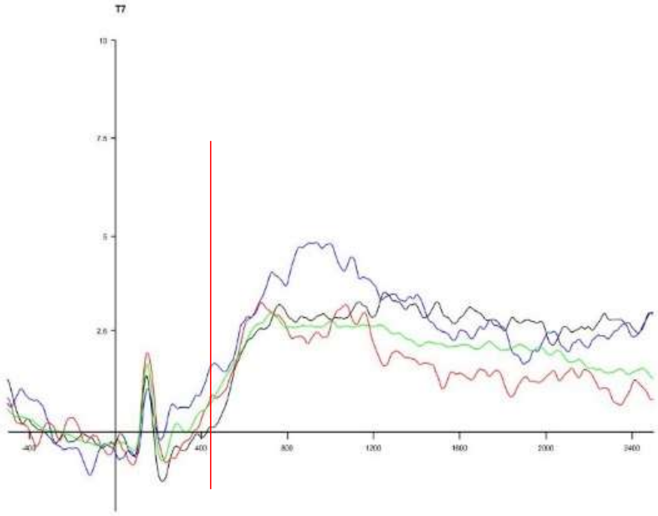

T7
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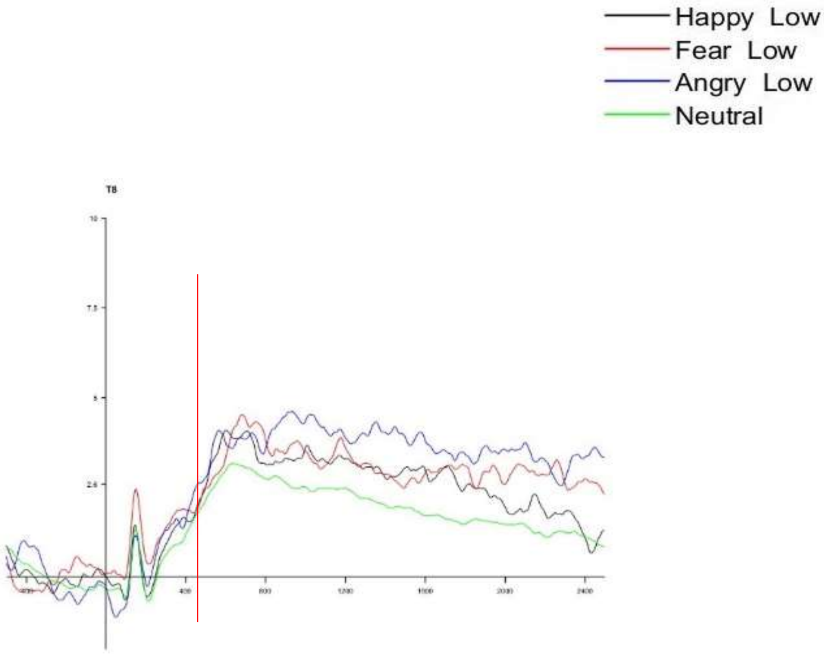
Happy Low
Fear Low
Angry Low
Neutral
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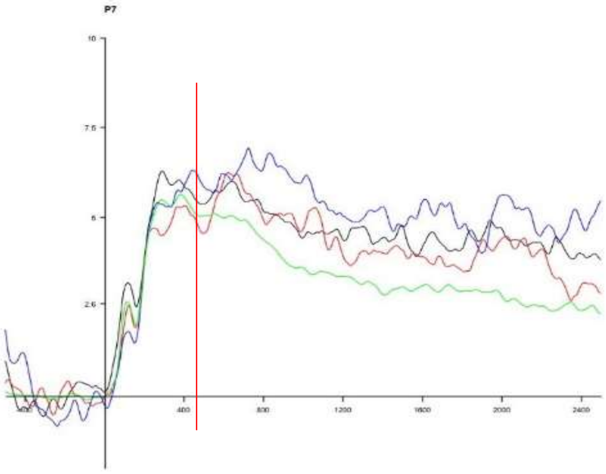
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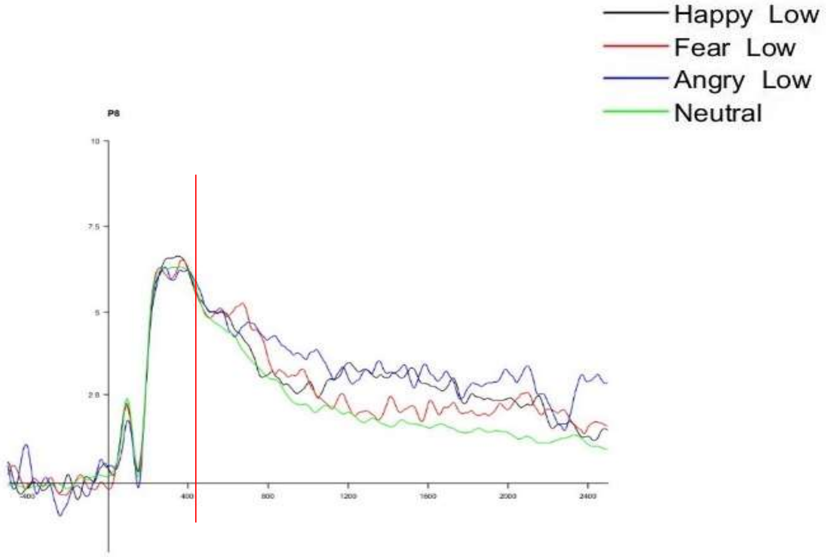


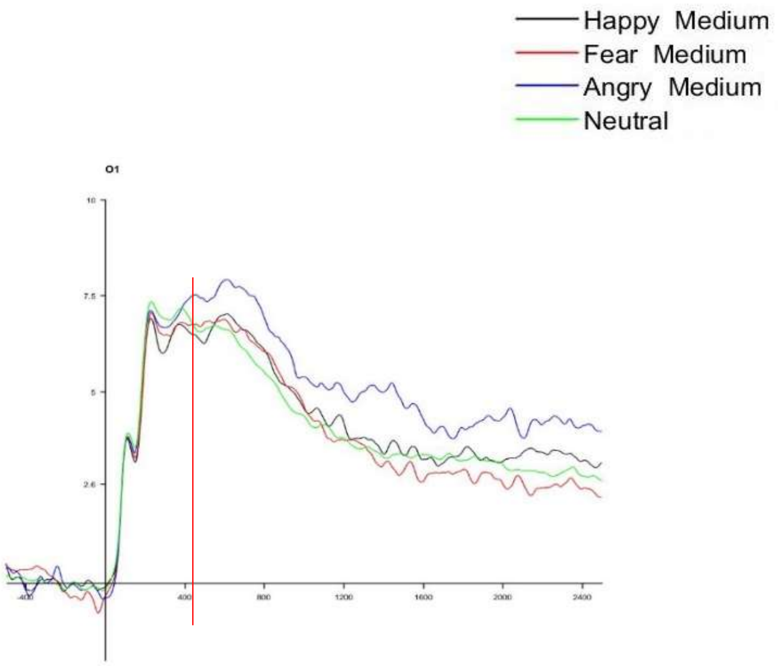
Figure 4.34. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P3/P4/P7/P8) representative electrodes during correct recognition of low intensity emotions and neutral expressions. N400 (385 to 485 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Medium-intensity vs Neutral

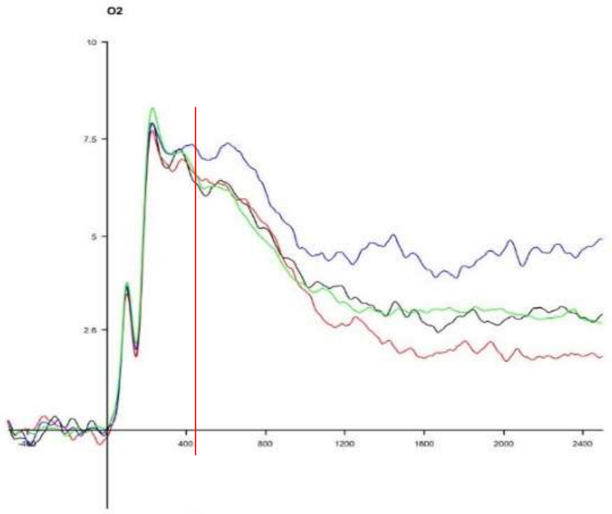
Similarly, the ANOVA on N400 activity during exposure to medium-intensity emotional and neutral facial expressions showed a main effect of cluster, *F(*1, 26) = 27.975, $p < .001$, $\eta_p^2 = .518$) with temporal-occipital N400 being larger (M = 4.75, SD = 2.45) than parietal N400 (M = 6.86, SD = 3.55), *t* (26) = -5.289, $p < .001$. This analysis also showed a marginal main effect of hemisphere, *F(*1, 26) = 3.532, $p = .071$, $\eta_p^2 = .120$) with left N400 being larger (M = 5.99, SD = 3.33) than right N400 (M = 5.62, SD = 2.67); and a marginal main effect of emotion, *F(*2.4, 63.1) = 2.637, $p = .069$, $\eta_p^2 = .092$) with N400 peaks during medium-intensity happy faces being larger (M = 5.30, SD = 2.86) than during medium-intensity fearful faces (M = 6.01, SD = 3.28; *t* (26) = -1.879, $p = .071$), and angry faces (M =

6.35, SD = 3.67; *t* (26) = -2.454, $p = .021$). N400 waves during exposure to medium-intensity angry faces were more reduced than waves during neutral faces (M = 5.56, SD = 2.66; *t* (26) = 2.088, $p = .047$).

An interaction cluster x emotion, $F(2.56, 66.6) = 4.890$, $p = .006$, $\eta_p^2 = .158$) was also showed. Explorative paired samples t-tests showed a stronger parietal component activation during medium-intensity happy faces (M = 6.13, SD = 3.41) as compared to N400 activity during medium-intensity fearful faces (M = 7.18, SD = 4.07), *t* (26) = -2.240, $p = .034$ and angry faces (M = 7.57, SD = 4.453; *t* (26) = -2.794, $p = .010$). Moreover, activations during medium-intensity angry faces were even weaker that activations during neutral faces exposure (M = 6.55, SD = 3.366; *t* (26) = 1.540, $p = .028$). The interaction cluster x hemisphere was not significant $F(1,26) = 1$, $p = .324$, $\eta_p^2 = .037$, as well as the interaction hemisphere x emotion $F(1,26) = .667$, $p = .575$, $\eta_p^2 = .025$ and the interaction $F(2.5, 66) = .536$, $p = .659$, $\eta_p^2 = .020$, see Figure 4.35.




Happy Medium
Fear Medium
Angry Medium
Neutral


O2
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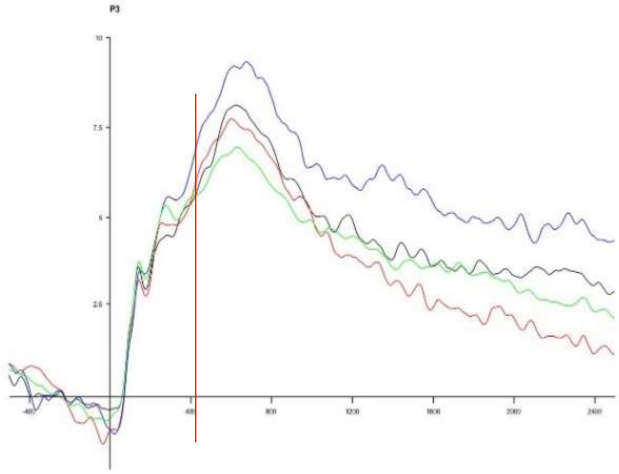
P3
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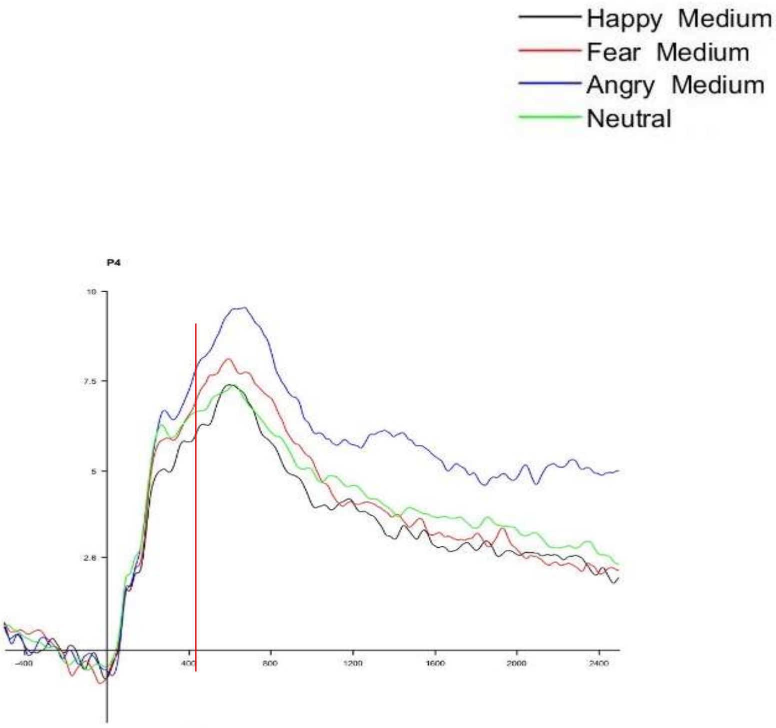
Happy Medium
Fear Medium
Angry Medium
Neutral
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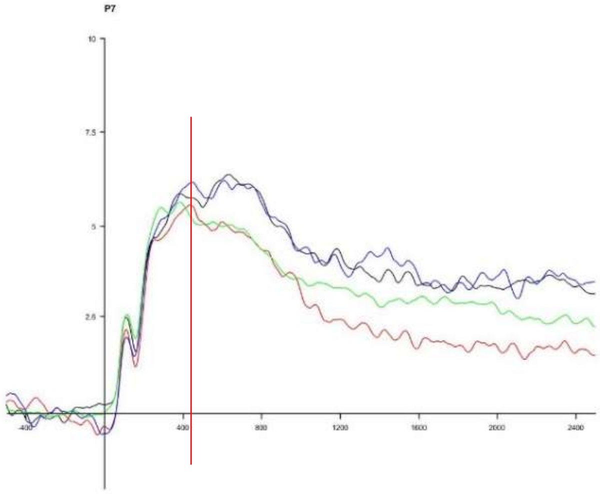
P7
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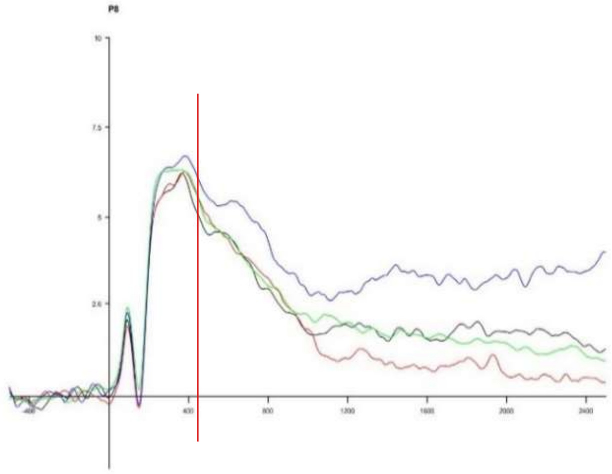
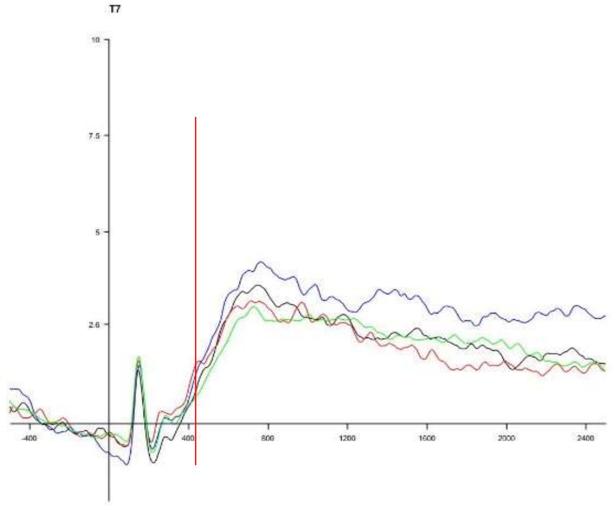
— Happy Medium
— Fear Medium
— Angry Medium
— Neutral





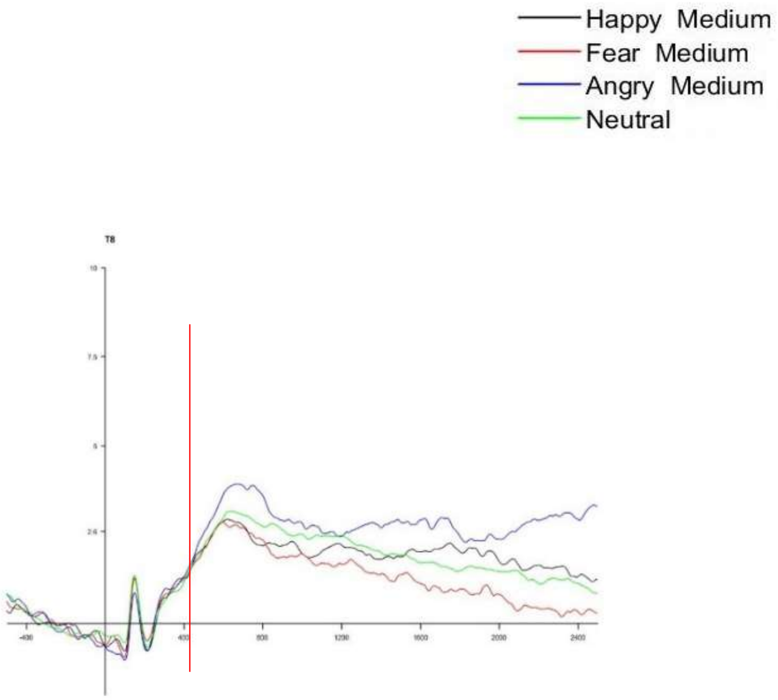


Figure 4.35. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P7/P8) representative electrodes during correct recognition of medium intensity emotions and neutral expressions. N400 (385 to 485 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

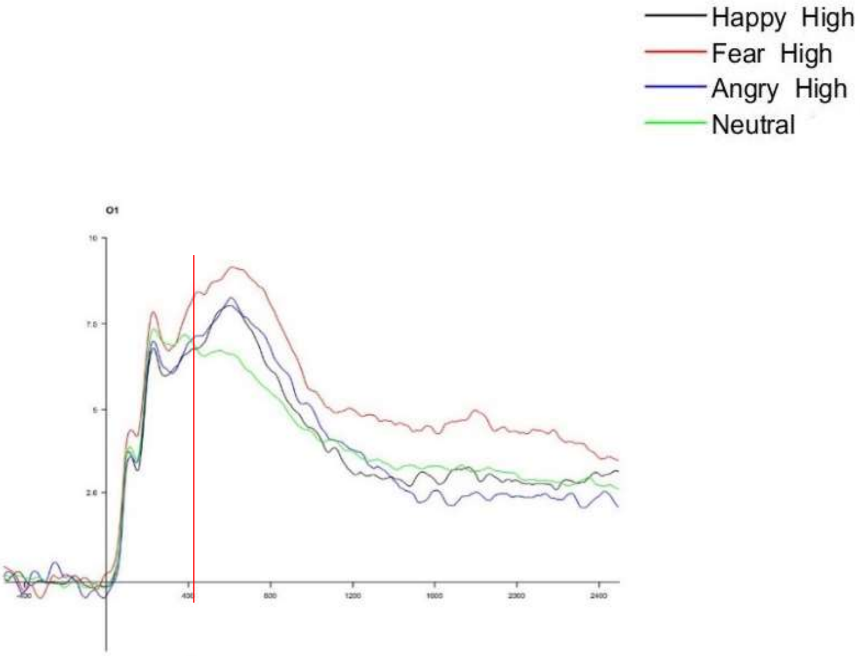
High-intensity vs Neutral

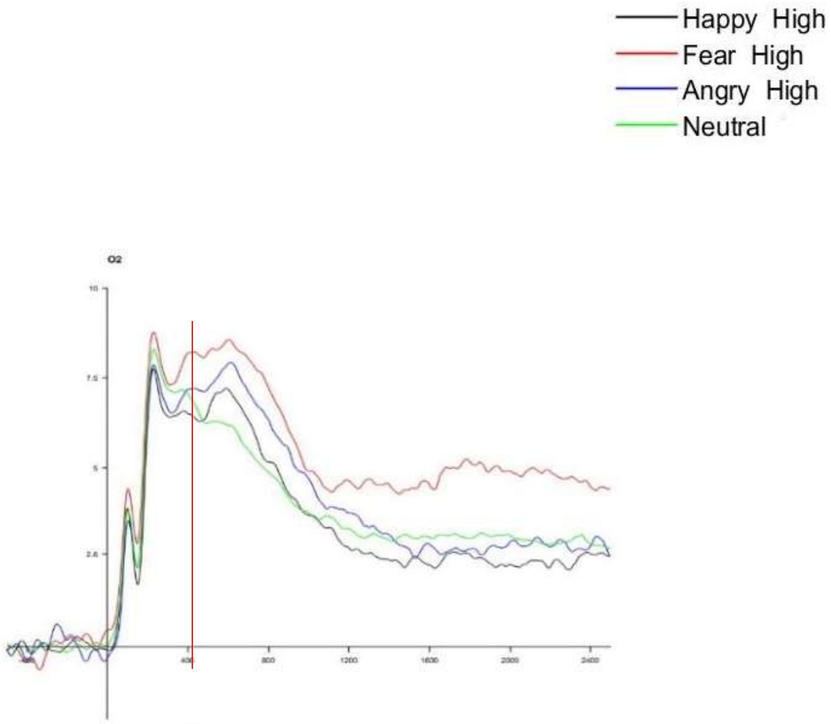
ANOVA on N400 activations during the exposure to high-intensity emotional and neutral facial expressions showed a main effect of emotion, *F(*2.921, 75.941) = 3.926, *p* = .012, η_p^2 = .131) that revealed that N400 waves during the exposure to high-intensity fearful faces were less negative (M = 6.94, SD = 3.57) as compared to N400 waves during exposure to neutral faces (M = 5.56, SD = 2.66; *t* (26) = 3.367, *p* = .002). Similarly, N400 component was less negative during the exposure to high-intensity angry faces (M = 6.55, SD = 3.21) as compared to N400 activity during the perception of neutral faces, *t* (26) = 2.471, *p* = .020.

A main effect of cluster was also found, *F(*1, 26) = 33.545, $p < .001$, $\eta_p^2 = .563$. Paired samples t-tests showed that temporal-occipital N400 peaks were more negative and therefore larger (M = 5.14, SD = 2.31) than parietal N400 peaks (M = 7.38, SD = 3.41; *t* (26) = -5.792, $p < .001$).

The ANOVA also showed a main effect of hemisphere, *F(*1, 26) = 4.351, $p = .047$, $\eta_p^2 = .143$). Paired samples t-tests exploring this result did not show a significant effect between left and right hemispheres.

The ANOVA did not show any interaction: cluster x hemisphere, *F(*1,26) = .668, $p = .421$, $\eta_p^2 = .025$; cluster x emotion, *F(*2.6, 69.6) = 1.405, $p = .250$, η2 = .051; hemisphere x emotion *F(*2.3, 59.9) = .730, $p = .504$, $\eta_p^2 = .027$; cluster x hemisphere x emotion *F(*2.6, 67.7) = 1.798, $p = .163$, $\eta_p^2 = .065$, see Figure 4.36.




Happy High
Fear High
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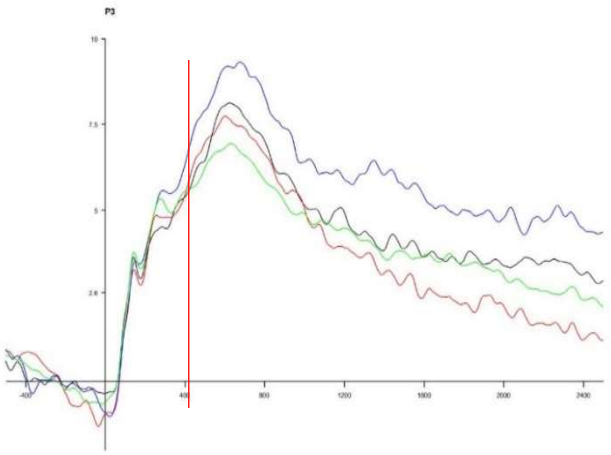
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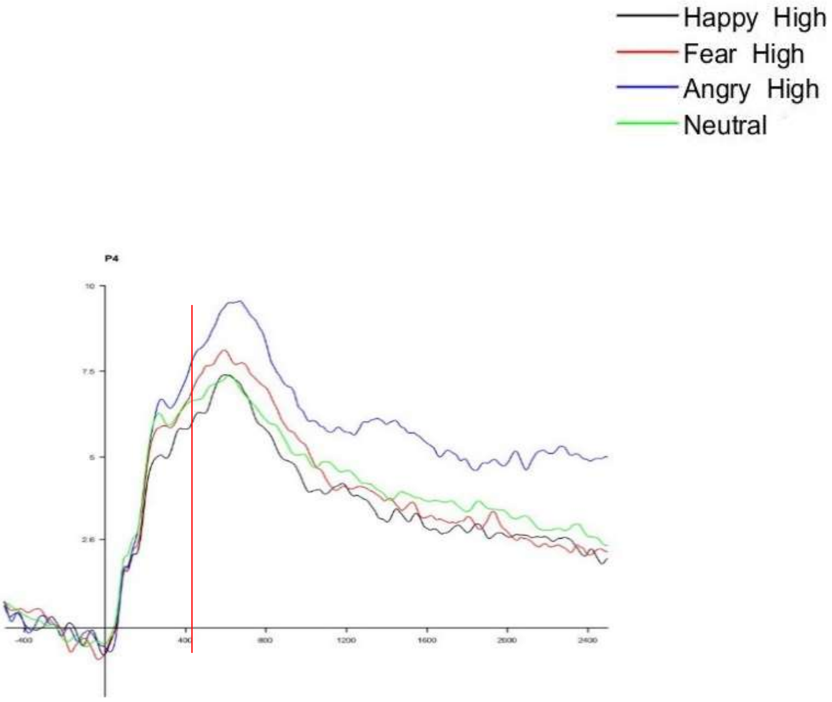
Happy High
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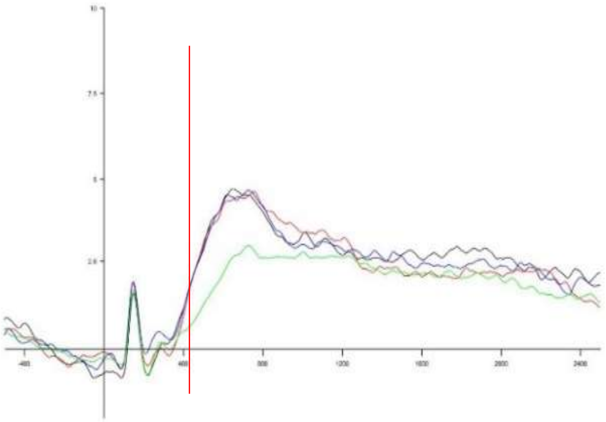
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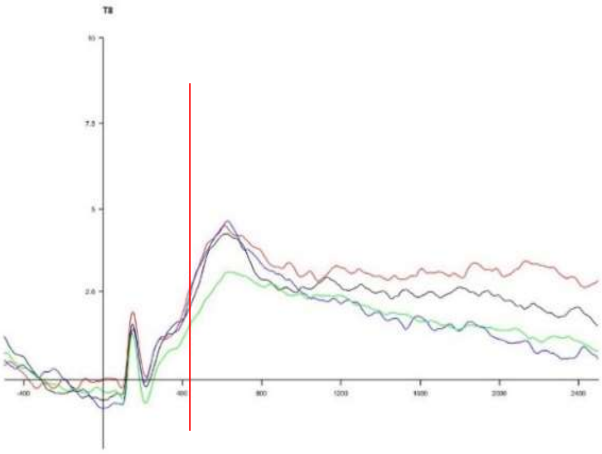
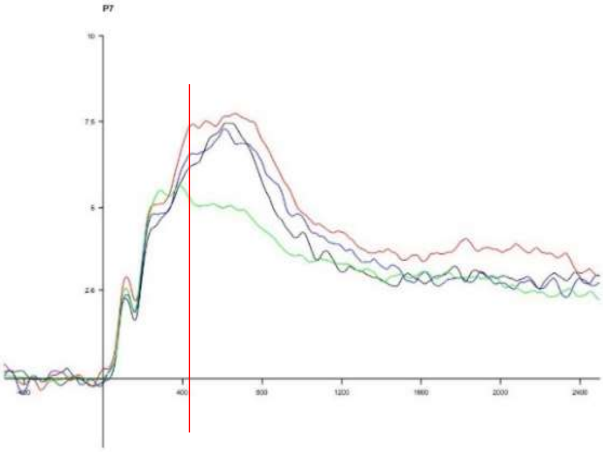
— Happy High
— Fear High
— Angry High
— Neutral





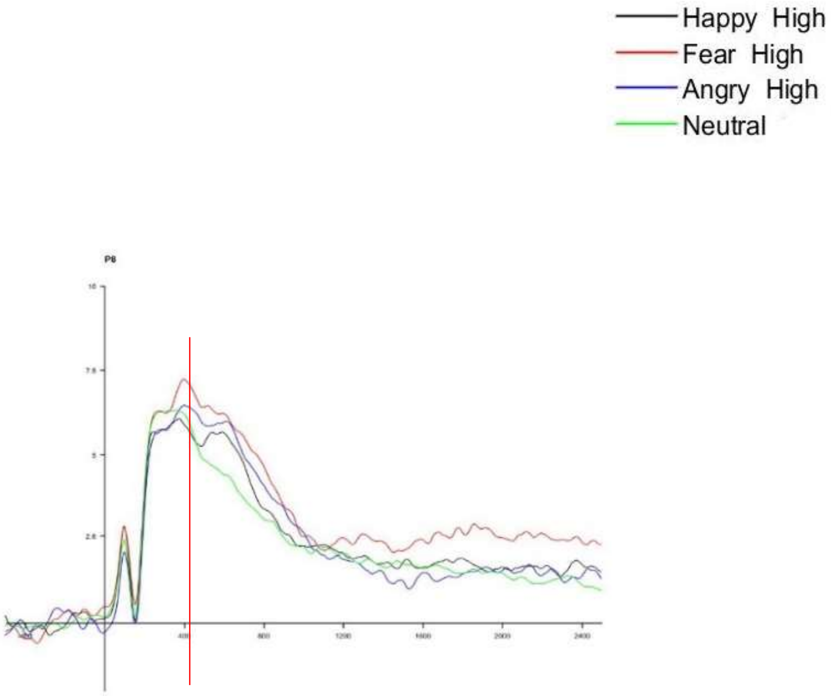


Figure 4.37. ERP waves (Y-axes display microvolts and X-axes milliseconds). ERPs elicited at occipital (O1/O2), temporal (T7/78) and parietal (P7/P8) representative electrodes during correct recognition of high intensity emotions and neutral expressions. N400 (385 to 485 ms after face onset) mean peak time of specific electrodes is indicated by the vertical red bar.

Comparisons between intensities

We then performed a 4 way repeated measures ANOVA with cluster (temporal-occipital, parietal), hemisphere (left, right), emotion (happy, fearful, angry), and intensity (low, medium, high) as factors on N400 activity means to explore main effects of intensity and interactions with it. Given the separate ANOVAs on single intensities, in case of significant interactions with the factor intensity I will only report here comparisons between intensity levels (e.g. low-high). This ANOVA showed a main effect of cluster, *F(*1, 26) = 27.094, p < .001, η_p^2 = .510). as predictable from previous analysis, post hoc t-tests showed a stronger temporal-occipital N400 (M = 4.82, SD = 2.39) as compared to parietal N400 (M = 6.16, SD = 3.06), *t* (26) = -5.202, p < .001; a marginally significant effect of hemisphere was also revealed, *F(*1, 26) = 3.648, p = .067, η_p^2 =.123) with stronger left N400 activations (M = 5.69, SD = 2.77) than right (M = 6.109 , SD = 3.326). A marginally significant effect of emotion, *F(*1.992, 51.782) = 3.118, p = .053, η_p^2 = .107) was also showed, explorative t-tests showed that N400 during exposure to angry faces, regardless of intensity, (M = 6.30, SD = 3.60) was significantly smaller than after happy (M = 5.42, SD = 2.80) and neutral faces (M = 5.56, SD = 2.66). The ANOVA also showed a main effect of intensity, *F(*1.518, 39.472) = 8.567, p = .002, η_p^2 = .248. Post hoc t-tests revealed stronger N400 activations during exposure to low- (M = 5.46, SD = 3.05) and medium-intensity facial expressions (M = 5.8, SD = 2.87) as compared to high-intensity facial expressions (M = 6.26, SD = 2.73; t (26) = 3.043, p = .005). An interaction cluster x intensity, *F(*1.711, 44.491) = 6.181, p = .006, η_p^2 = .192) was also found. Explorative paired samples t-tests revealed a larger temporo-occipital N400 during exposure to low-intensity facial expressions (M = 4.58, SD = 2.56) as compared to high- (M = 5.14, SD = 2.31; t (26) = 3.031, p = .005), and medium-intensity facial expressions (M = 4.75, SD = 2.45) t (26) = -3.064, p = .005. Moreover, there was a larger parietal N400 during low- (M = 6.34, SD = 3.77) as compared to medium- (M = 6.86, SD = 3.55; t (26) = -2.269, p = .032) and high-intensity facial expressions (M = 7.38, SD = 3.41; t (26) = 3.394, p = .002). Activations of the parietal N400 component during the exposure to medium-intensity facial expressions (M = 6.86, SD = 3.55) was also stronger than activations during high-intensity facial expressions (M = 7.38, SD = 3.41; t (26) = -2.807, p = .009), see figure 4.37 for isovoltage maps of the difference between the three intesities conditions for anger, fear and happiness.

The interaction cluster x hemisphere F(1,26) = 1.190, p = .285, η_p^2 = .044 was not significant as well as the interaction cluster x emotion, F(1.6, 43.8) = 2.15, p = .135, η2 = .077, hemisphere x emotion, F(1.9, 49.5) = .475, p = .616, η_p^2 = .018, cluster x hemisphere x emotion, F(1.9, 51.5) = .287, p = .750, η_p^2 = .011, hemisphere x intensity, F(1.3, 35.1) = .067, p = .863, η_p^2 = .003, cluster x hemisphere x intensity, F(1.4,37.7) = 2.695, p = .095, η_p^2 = .094, emotion x intensity, F(3.1, 81.9) = .574, p = .642, η_p^2 = .022, cluster x emotion x intensity F(2.5, 65.3) = .481, p = .663, η_p^2 = .018, hemisphere x emotion x intensity F(2.6, 66.9) = 1, p = .378, η_p^2 = .038, cluster x hemisphere x emotion x intensity F(2.6, 69.2) = 1, p = .362, η_p^2 = .040.

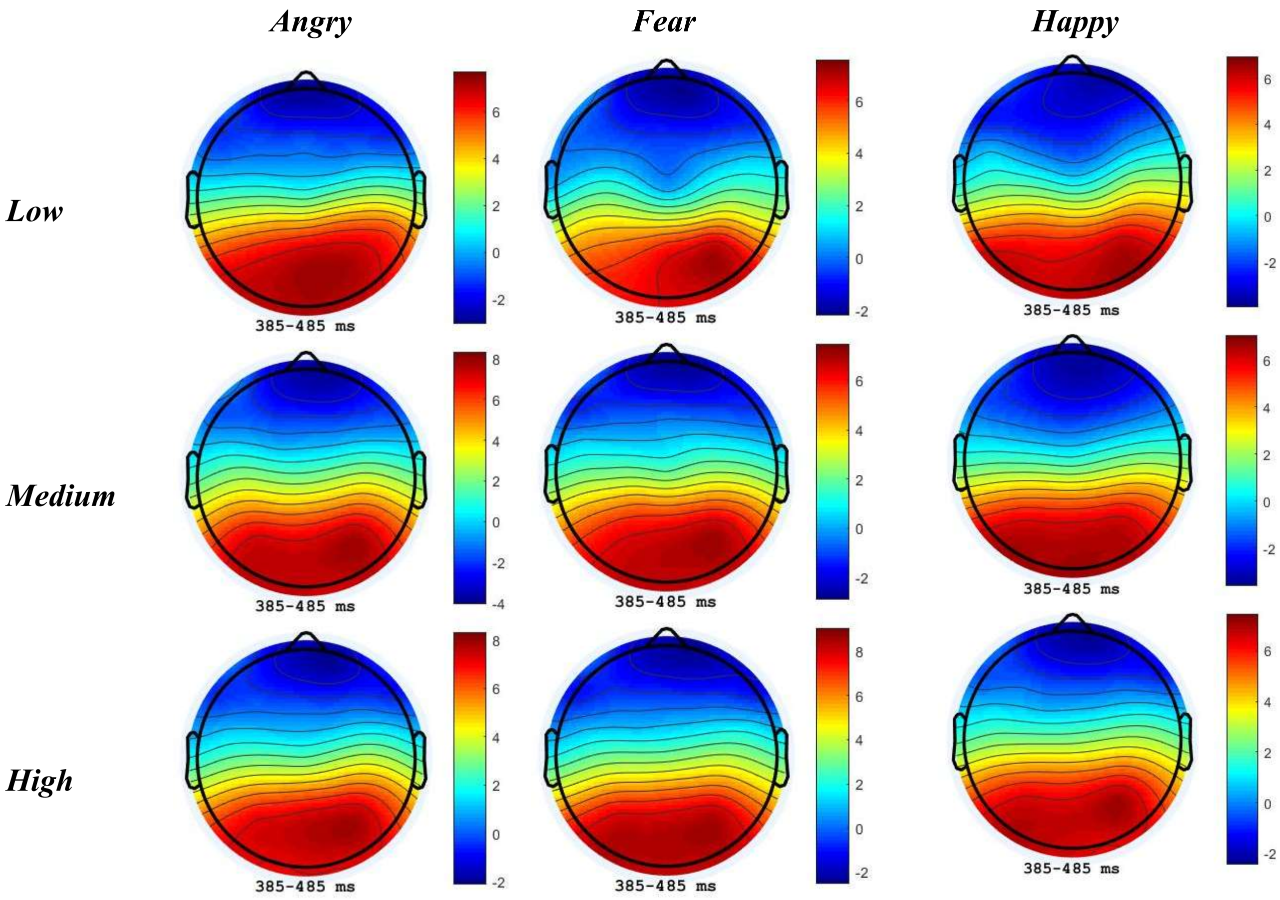


Figure 4.38. Topographic representations of the difference in mean amplitude across the scalp between the three intensities (low, medium and high) during N400 interval (385-485 ms after faces onset) during correct recognition of emotions (anger, fear and happiness). N400 was smaller (less negative) during exposure to angry faces than after happy and it was stronger (more negative) during exposure to low- and medium-intensity facial expressions as compared to high-intensity facial expressions. Results also showed larger temporo-occipital N400 during exposure to low-intensity facial expressions as compared to high-, and medium-intensity facial expressions. Moreover, there was a larger parietal N400 during low- as compared to medium- and high-intensity facial expressions. Activations of the parietal N400 component during the exposure to medium-intensity facial expressions was also stronger than activations during high-intensity facial expressions.

4.4.4.3 EMG

4.4.4.3.1 Corrugator

The one-way ANOVA did not show a main effect of emotion on corrugator activity during exposure to high, *F(*1.5, 38.8) = 1.824, *p* = .181, η_p^2 = .068; medium, *F(*1.5, 38.8) = .558, *p* = .489, η_p^2 = .022; or low-intensity facial expressions, *F(*1, 26.9) = 1.269, *p* = .274, η_p^2 = .048.

Similarly, the 2-way repeated measures ANOVA did not show an intensity effect, *F(*1.9, 49.3) = 2, *p* = .166, η_p^2 = .075, or emotion effect *F(*2.9, 27.4) = 2.64, *p* = .082, η_p^2 = .096. The interaction emotion x intensity was also not significant, *F(*5.9, 210) = .7, *p* = .422, η_p^2 = .027, see Figure 4.38.

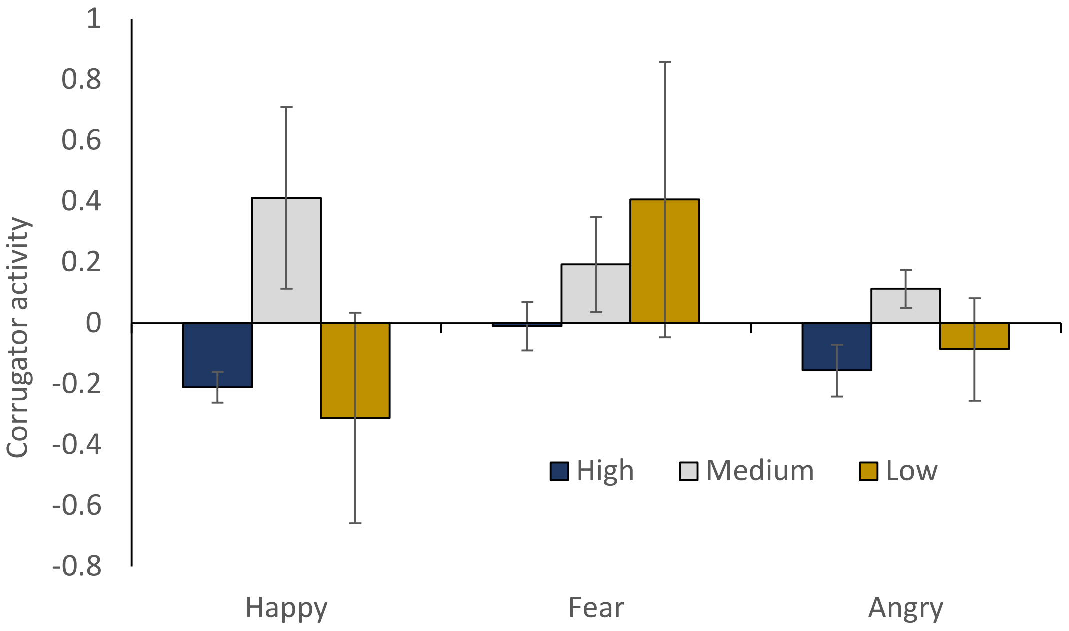


Figure 4.39. Corrugator activity during recognition of low, medium and high intensity expressions for all emotions.

Mimicry time course

Time course analysis did not reveal any significant effects or interactions: time, *F(*1.4, 36) = 1.29, p = .278, η_p^2 = .049; emotion, *F(*1, 25) = 1.24, p = .275, η_p^2 = .047; intensity, *F(*1, 25.5) = .863, p = .364, η_p^2 = .033; time x emotion, *F(*1.1, 28.9) = .323, p = .607, η_p^2 = .013; time x intensity, *F(*1, 26.6) = 1, p = .330, η_p^2 = .039; emotion x intensity, *F(*1.1, 28.3) = 1, p = .315, η_p^2 = .042; *F(*1.3, 34.6) = .764, p = .429, η_p^2 = .030, see Figures 4.39, 4.40 and 4.41.

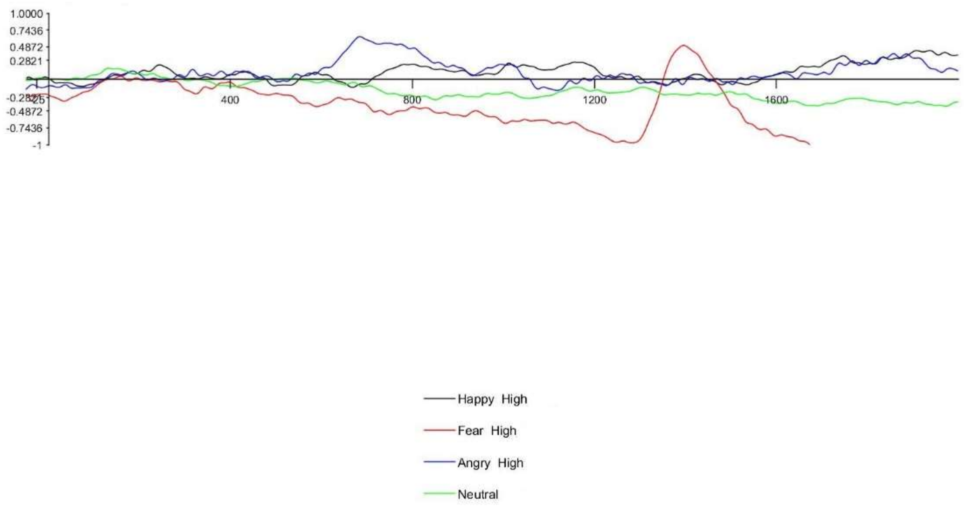


Figure 4.40. Corrugator activity during correct recognition of high intensity emotions and neutral expressions (Y-axes display microvolts and X-axes milliseconds).

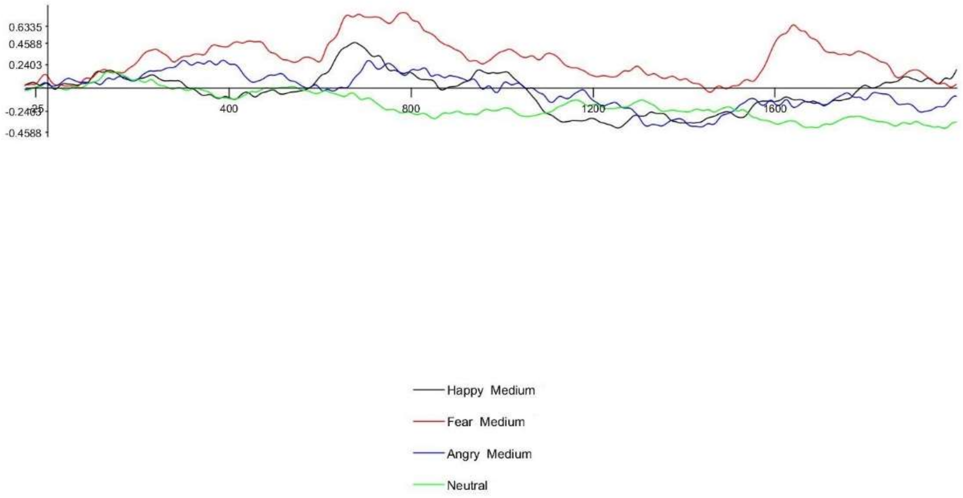


Figure 4.41. Corrugator activity during correct recognition of medium intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

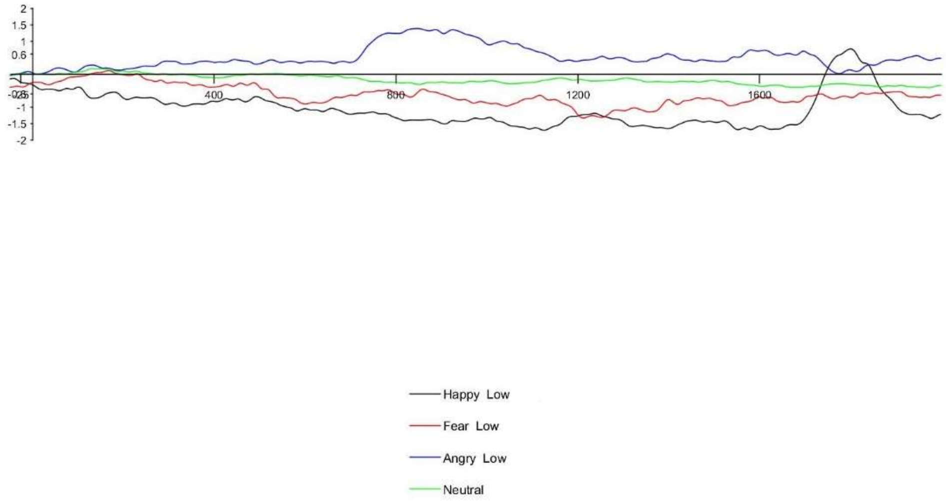


Figure 4.42. Corrugator activity during correct recognition of low intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

4.4.4.3.2 Zygomaticus

The one-way ANOVA did not show main effect of emotion has been found on zygomaticus activity means during exposure to all intensity facial expressions, high: $F(1.5, 38.8) = .851$, $p = .373$, $\eta_p^2 = .033$; medium: $F(1.3, 34.7) = 1$, $p = .331$, $\eta_p^2 = .041$; low: $F(2.1, 53.2) = .650$, $p = .536$, $\eta_p^2 = .025$. The 2-way repeated measures ANOVA did not show an intensity effect, $F(1, 27) = .395$, $p = .551$, $\eta_p^2 = .016$, or emotion effect, $F(1.2, 32) = 1.1$, $p = .312$, $\eta_p^2 = .043$, see Figure 4.42. The interaction emotion x intensity was also not significant, $F(2.2, 56) = .453$, $p = .660$, $\eta_p^2 = .018$.

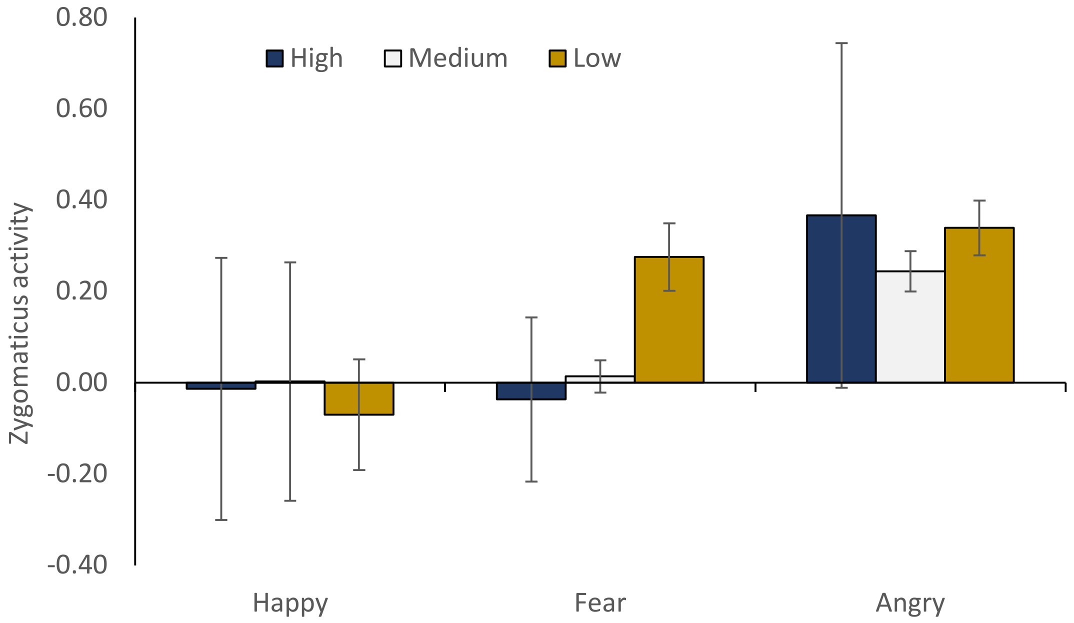


Figure 4.43. Zygomaticus activity during recognition of low, medium and high intensity expressions for all emotions.

Mimicry time course

Time course analysis did not reveal any significant effects or interactions: time, *F(*1.3, 32.4) = .453, p = .716, η_p^2 = .018; emotion, *F(*1, 25) = .112, p = .741, η_p^2 = .004; intensity, *F(*1.9, 48) = 2.4, p = .095, η_p^2 = .090; time x emotion, *F(*1.3, 34) = .231, p = .710, η_p^2 = .009; time x intensity, *F(*2, 50) = 2.6, p = .081, η_p^2 = .095; emotion x intensity, *F(*1.5, 39) = 1, p = .350, η_p^2 = .040; *F(*1.5, 39) = .528, p = .554, η_p^2 = .021; see Figures 4.43, 4.44 and 4.45.

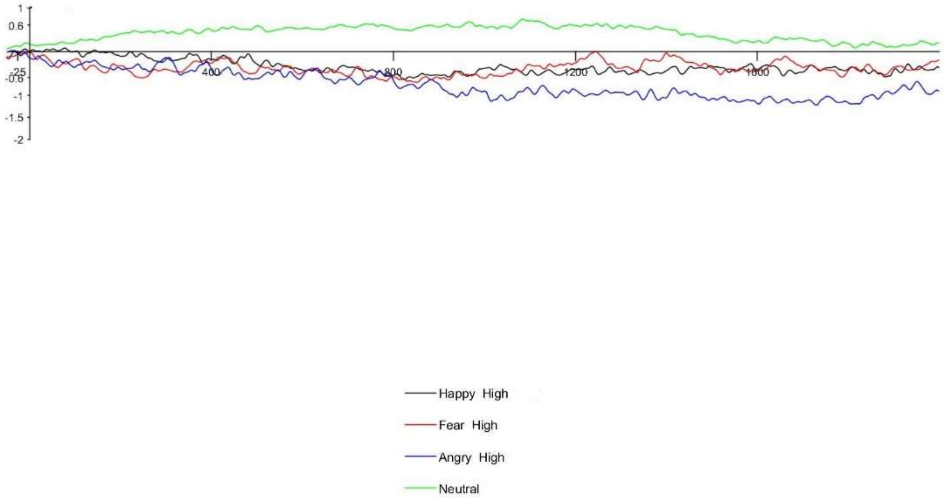


Figure 4.44. Zygomaticus activity during correct recognition of high intensity emotions and neutral expressions (*Y-axes display microvolts and X-axes milliseconds*).

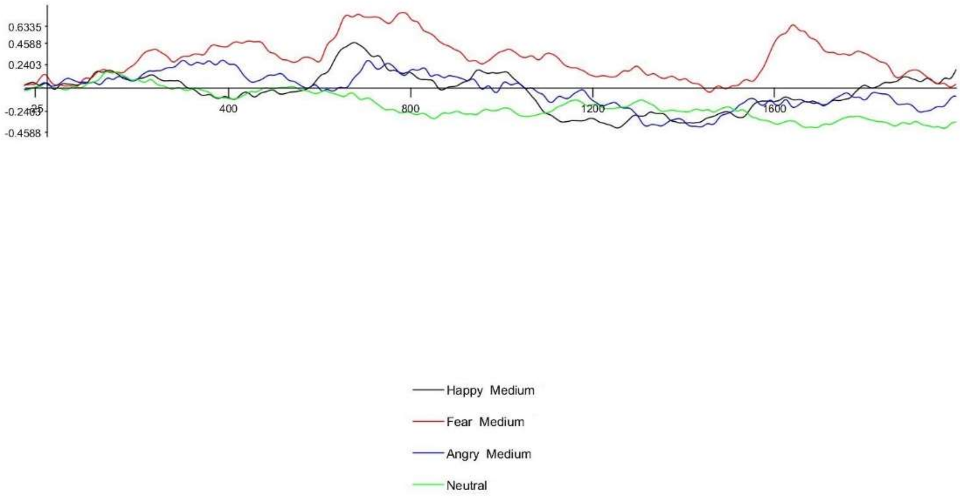


Figure 4.45. Zygomaticus activity during correct recognition of medium intensity emotions and neutral expressions (Y-axes display microvolts and X-axes milliseconds).

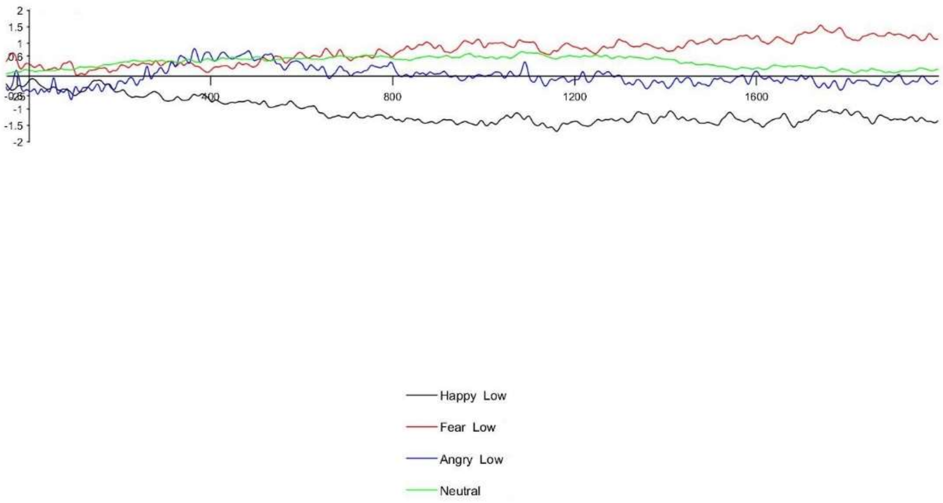


Figure 4.46. Zygomatic activity during correct recognition of low intensity emotions and neutral expressions (Y-axes display microvolts and X-axes milliseconds).

4.4.4.4 Correlations between EEG activation and behavioural performance

For this analysis 23 participants were used (18 females, age mean = 22.26, age SD = 4). Fourteen participants were removed from the behavioural datasets and four participants were removed for the EEG datasets in order to have a unique matching dataset. We performed a non-parametric Spearman rank-order correlations between each ERP component and accuracy and RTs.

4.4.4.4.1 EPN

Accuracy

No relevant correlation was significant.

Reaction times

Analysis between EPN activity mean and behavioural results showed that stronger left EPN waves were significantly associated with slower correct discrimination of medium-intensity happy faces (rs (23) = -.436, *p* = .038).

4.4.4.4.2 N400

Accuracy

Correlations between N400 activity means in both clusters and behavioural results showed that higher discrimination accuracy of low-intensity happy faces was significantly associated with stronger right N400 waves (rs (23) = -.445, *p* = .033). On the other hand, higher discrimination accuracy of high-intensity angry faces has been found to be significantly associated with weaker right N400 waves (rs (23) = .554, *p* = .006).

Correlations between each cluster means and behavioural results showed that higher discrimination accuracy of high-intensity angry faces was significantly associated with weaker N400 waves in the right temporal occipital cluster (rs (23) = -.426, *p* = .043) and in the right parietal cluster (rs (23) = -.556, *p* = .006). Moreover, higher discrimination accuracy of medium-intensity angry faces has been found to be significantly associated with weaker N400 waves of the right parietal cluster (rs (23) = -.437, *p* = .037).

Reaction times

No relevant correlation was significant.

4.4.4.5 Correlations between EEG and EMG activity

We then ran a non-parametric Spearman rank-order correlation between each ERP component and zygomaticus and corrugator activations' means. For this analysis 26 participants have been used (females = 20, age mean = 23.84, SD = 8.28). One participant has been removed from the EMG datasets in order to have a unique matching dataset.

4.4.4.5.1 EPN - EMG correlations

200-400 ms

The correlation between zygomaticus activations means with right EPN activations showed weaker left EPN waves associated with stronger early zygomaticus activity (200-400 ms after SO, rs (26) = .419, *p* = .033) during correct discrimination of medium intensity happy faces.

400-600 ms

The correlation between zygomaticus activations means with right EPN activations showed weaker left EPN waves associated with stronger mid late zygomaticus activity, rs (26) = .462, *p* = .018 during correct discrimination of medium intensity happy faces.

Weaker left EPN was also associated with stronger mid late corrugator activity during correct discrimination of low intensity fearful faces (rs (26) = .424, *p* = .031).

600-800 ms

Weaker left EPN was also associated with stronger late corrugator activity during correct discrimination of medium intensity fearful faces (rs (26) = .404, *p* = .040) and high intensity angry faces (rs (26) = .406, *p* = .039).

800-1000 ms

No significant correlations were found.

4.4.4.5.2 N400

200-400 ms

No significant correlations were found on this time window.

400-600 ms

Analysis on physiological data recorded during discrimination of high intensity angry faces showed weaker left temporal-occipital N400 waves associated with greater mid late corrugator activity (rs (26) = .420, *p* = .033).

600-800 ms

This correlation also showed weaker left temporal-occipital N400 associated with greater late corrugator activity during discrimination of high intensity angry faces (rs (26) = .477, *p* = .014).

800-1000 ms

Analysis on physiological data recorded during discrimination of medium intensity fearful faces showed weaker left temporal occipital N400 waves marginally associated with greater very late corrugator activity (rs (26) = .386, *p* = .051).

4.4.5 Discussion

This study intended to examine the psychological and neural mechanisms underlying the process of explicit facial expression recognition. Through a combined EEG/EMG experiment we aimed at investigating whether different intensities of emotional facial expressions (low, medium and high) affect the cognitive (central) and embodied (peripheral) processing of facial expression recognition measured with effects on EPN and N400 ERP components and with effects on facial mimicry (detected with EMG amplitudes). Recognition ability was measured with accuracy and RTs of responses.

Analysis of behavioural data showed that participants were more accurate at explicitly categorising happy faces compared to angry and fearful faces. Moreover, analysis of accuracy and reaction times showed that participants recognized low intensities facial expressions slower and less accurately than respectively medium- and high-intensity expressions.

Our EEG results showed larger N400 waves respectively for low and medium-intensity emotional facial expressions as compared to high-intensity emotional facial expressions. Across all intensities, N400 was greater for happy faces, with significantly more negative waves as compared to those elicited by angry faces. When emotions were expressed at the highest intensity, N400 was greater for neutral faces than fearful and angry faces. Results also showed greater N400 for medium-intensity happy faces as compared to fearful faces and angry faces, but N400 during happy faces was not significantly greater than that for neutral faces. Whereas, N400 waves did not differ across emotions when they have been expressed at the lowest intensity. In line with findings of Davis (Davis et al., 2017), N400 was found more negative for more demanding semantic retrieval conditions, namely with low and medium-intensity facial expressions presented among a few alternatives. In fact, the main effect of expression intensity found in our behavioural results revealed that our participants were faster and more able to recognize high-intensity facial expressions than medium- and low-intensity facial expressions. This finding, together with the fact that participants recognised low-intensity facial expressions slower than medium- and high-intensity facial expressions, strongly suggests that the recognition task became more demanding as the emotional intensity decreased. Additionally, correlation analyses showed that higher discrimination accuracy of low-intensity happy faces was significantly associated with stronger right N400 waves and, on the other hand, higher discrimination accuracy of high-intensity angry faces was found to be significantly associated with weaker right N400 waves. Explicitly classifying emotions in high-intensity facial expressions proved to be a less demanding semantic task than respectively medium and low-intensity facial expressions. We argue that conditions with high-intensity expressions elicited a less negative N400 as a measure of less cognitive effort to carry out a semantic retrieval. We hypothesise that neutral faces on the other hand, elicited a greater N400 representing the cognitive effort to detect a given emotion with a more attentional and time-consuming processing (Davis et al., 2017; Federmeier & Laszlo, 2009; Kutas & Federmeier, 2011). Behavioural data inform that neutral faces have been recognized better than angry and fearful faces, but participants did not take more time to discriminate emotional expressions. Being 'neutral' one of the four option of the emotion discrimination task and being low intensity emotional expressions only expressing the 20% of emotional content in a fully expressive display, we argue that low intensity and neutral expressions conditions act as mutual distractors during the task.

These results taken together suggest that N400 waves characterised the activation of areas dedicated to semantic distinction of emotional facial configuration among distracting alternatives. Our results are in line with the hypothesis that N400 is sensitive to the augmented demand of an emotion recognition task due to a more difficult and more time-consuming semantic retrieval. Davis and colleagues argued that N400 waves represent the integration of perceptive element with mnemonic and linguistic element to form a judgement in regards to a facial expression (e.g. 'this person is happy') (Davis et al., 2017).

Our findings also reveal that N400 was greater for medium intensity happy faces. Previous research shows that threatening stimuli are likely to be processed before socially beneficial stimuli (e.g. from 170 to about 250 ms after face onset). In this way, the priority given to threat processing produces a late discrimination of positive valence stimuli, multiple times observed in mid late components (such as N2 peaking approximately at 230 ms after face onset, Calvo & Beltrán, 2013). These findings gave rise to the hypothesis that threat, rather than social approval is prioritized automatically, as reward stimuli became salient only after safety is acknowledged (Williams et al., 2006).

The present study correlation analysis revealed a negative correlation between EPN activity (peaking from 245 ms to 330 ms after SO) and early and mid late zygomaticus activity during correct discrimination of medium intensity happy faces. However, similar results have been observed also for negative valence stimuli as greater EPN waves were associated with less intense mid late (400-600 ms after SO) corrugator activity during correct discrimination of low intensity fearful faces and late (600-800 ms after SO) corrugator activity during medium intensity fearful faces as well as high intensity angry faces. These results suggest that, although not significant, a cognitive processing of both valences faces might have taken place.

In line with this, many studies inform that early affective analysis (i.e. from about 170 ms up to about 350 ms after SO) does not always provide a refined discrimination of emotions (required in a recognition task), so presumably what determined the discrimination superiority of happy faces on N400 in our study was due to happy faces perceptual uniqueness (Adolphs, 2002; Calvo & Beltrán, 2013; Calvo & Nummenmaa, 2008; Leppänen et al., 2007).

Our study confirms a stronger temporal occipital N400 above parietal N400 (J. D. Davis et al., 2017; Hayasaka & Miyachi, 2016). Indeed, converging evidence indicates that N400 reflects the activation of groups of neurones located in the superior and middle temporal gyrus, the temporal-parietal junction (e.g. Tse et al., 2007). The present study results are also in line with studies that highlight N400’s critical role in both hemispheres (Kutas & Federmeier, 2000). Interestingly, our results regarded both left and right N400.

Specifically, ANOVAs revealed stronger left N400 across intensities, however all significant correlations regarded right N400. Literature on this matter proposes similar evidence. Studies that have recorded N400 activity in both hemispheres found salient activity on both hemispheres with a slight less significative activity on the right.

Regarding EPN, analyses did not show a significant modulation of EPN component across emotions and intensities. Calvo et al. proposed that EPN is modulated by expression intensity, so that higher intensity makes the encoding easier. However, our task did not elicit an EPN sensitive to different intensities. We interpret the lack of significant modulation of EPN activity across conditions as an inhibition of the emotional arousal that usually characterize EPN amplitudes. We hypothesize that our task demanded a specific discrimination of facial postures that have not characterized the majority of studies that investigated EPN. We argue that at this stage there is not still a specific detection of intrinsic affective aspects of facial configurations as demanded in our task.

The recognition task used in the present study did not elicit significant congruent facial reactions to stimuli. Indeed, both the corrugator and the zygomaticus did not activate differently across emotions or intensities. This result might be interpreted as a lack of peripheral simulative response indicating the missed attendance of mimicked simulation. However, the complete lack of congruent facial EMG reactions suggest that a muscular impedance on the corrugator provoked by excessive focussing has diminished the facial muscle availability (Seibt et al., 2015). A variety of reasons might have determined that. We are determined to dismiss the hypothesis of excessive cognitive load caused by the task. Conditions that involved the presentation of high-intensity expressions would have in fact facilitated congruent EMG reactions (unlike mimicry) regardless of the task proposed. However, correlational analysis showed weaker N400 waves associated with greater mid late and late corrugator activity during exposure to high intensity angry faces, which strongly suggests that congruent facial reactions did take place.

Although, the experimenters have taken care of participants' comfort before and during the task performance and a natural behaviour has been encouraged. Electrodes placed on the scalp and on the face might have caused excessively poor mobility of head and neck compromising participants' facial muscle availability.

It is, however, worth noticing that, consistently with the previous study results, correlations found between EPN activity and facial reactions seems to have held a complementary relationship with congruent facial activations. However, correlations regard different time windows of EMG activations suggesting that EPN activity can also produce delayed inhibition of congruent facial reactions.

4.5 General discussion

The first study presented in this chapter (Study 4) investigated whether different intensities of emotional facial expressions (low, medium, high) affected the cognitive (central) and embodied (peripheral) processing of emotional valence. The task was a valence detection task of happy, angry or fearful facial expressions presented rapidly (100 ms). The ERP components N400 and EPN were recorded and analysed, together with corrugator and zygomaticus muscles activity as expression of facial mimicry of respectively angry (and fear, on a smaller scale) and happy faces. Valence detection ability was also measured with accuracy and RTs responses.

In line with our expectations, this study revealed that the ambiguity of facial expressions challenges the process underlying recognition and increases its reaction times.

The study also revealed that the positive valence of happy facial expressions was detected more easily than the negative valence of fearful and angry facial expressions.

These results, together with the fact that the zygomaticus activated more for happy faces across all intensities, suggest that mimicry was detected and that was associated with successful recognition even of low- and medium-intensity expressions. We argued that such recognition was supported by an ongoing internal simulation.

Results also revealed stronger corrugator activity for medium-intensity fearful faces and angry faces. Interestingly, EPN showed greater activity when emotions were expressed with medium intensity, but across emotions (fearful, happy, angry) the smaller increase was during angry faces. These findings are in line with a positive correlation found between corrugator mid-early activity (400-600 ms after SO) and EPN waves (250-350 ms after SO) during correct detection of medium-intensity angry faces. In light of these results, we claim that mimicry of the corrugator had a critical role in the recognition of medium-intensity angry faces, aiding the recognition and holding a supportive-complementary role with EPN.

This study revealed also a complementary cognitive-peripheral process where mimicry responds selectively in respect to N400 activity. Indeed, in line with what has been reported by Davis and colleagues (Davis et al., 2017), our study detected greater N400 waves (more negative) associated with greater semantic retrieval demands. In fact, N400 was found larger as expressions’ ambiguity increased, and therefore with increased task demand. These findings further support the hypothesis that sees N400 representing greater difficulty if the task requires to discriminate semantically an emotion among a few distracting alternatives.

The second study investigates whether different intensities of emotional facial expressions (low medium high) affect the cognitive (central) and embodied (peripheral) processing of explicit facial expression categorisation. The study used a very similar set-up as

Study 4, with N400 and EPN measured concurrently with corrugator and zygomaticus activity and behavioural performance. The second study was run to observe the variation of corrugator and zygomaticus activity as well as EPN and N400 activity across conditions during a task of explicit expressions categorisation. Specifically, we wanted to observe whether a task that demanded the recognition of discrete expressions presented for 2500 ms (rather than 100 ms) involved more mentalization and/or simulation processing.

Similarly to the previous study, participants of this study recognized low intensities facial expressions slower and less accurately than respectively medium and high intensities expressions.

This study revealed larger N400 waves for low and medium-intensity emotional facial expressions as compared to high-intensity emotional facial expressions. When emotions have been expressed at the highest intensity, N400 was greater for neutral faces. When emotions have been expressed at a medium-intensity, N400 was greater for happy faces as compared to fearful faces and angry faces. When emotions have been expressed at the lowest intensity, N400 waves did not differ across emotions.

Moreover, analyses revealed higher discrimination accuracy of low-intensity happy faces associated with stronger right N400 waves and, on the other hand, higher discrimination accuracy of high-intensity angry faces associated with weaker right N400 waves. The above results are also in line with the fact that, across all intensities, participants recognized happy faces more and N400 was larger for happy faces.

Findings from both studies are in line with the hypothesis that N400 is sensitive to the augmented demand of an emotion recognition task. N400 was found to be more negative for more demanding semantic retrieval conditions, namely with low and medium-intensity facial expressions presented among a few alternatives. In both studies behavioural results revealed that our participants were more able and faster at recognizing high-intensity facial expressions than medium and low-intensity facial expressions suggesting that the recognition task became more demanding as the face intensity decreased.

We argued that internal simulation occurs especially in case of increased task demand and it develops through a complementary cognitive-peripheral process where mimicry responds selectively in respect to central activity, represented by N400. More specifically we hypothesise that corrugator activity leads to successful recognition before N400 and not during or after N400.

Thesis conclusions

The social circumstances of daily life lead us to engage in activities with other people. These interactions very often involve the coordination of mutual intents, the attempt to avoid misunderstandings and the maintenance of harmonious relationships. To do so, individuals are regularly challenged to understand the intentions and feelings of the people that surround them. In some instances an accurate understanding of the intentions of others might prove demanding, in some others it is straightforward (Gallese, 2005).

Facial expressions relate to people's inner state, and understanding them provides an insight into their feelings and body-mind states. For these reasons, it is generally believed that interactions between individuals aimed at disclosing such inner moods and frames of mind are not only valuable but also represent a basic adaptive function (e.g. Adolphs, 2006).

The ability to recognize facial expressions favours deep and authentic social interaction. In this ability, individuals seem to differ considerably between each other, especially when it comes to understanding complex emotions (Kaminska et al., 2020). Recognizing emotions means not only perceiving them but also attributing a semantic value to them, which has to be universally shared. Thus, a specific facial muscle configuration generally tends to be associated to a semantic label (Calvo & Nummenmaa, 2015). The Theory of Mind hypothesis introduced the notion according to which the ability to read others' minds is a skill people are born with and one that has its basis on an internal supposition that others have a mind which is similar to their own. This theory allows individuals to put themselves into another's shoes, to interpret and observe their behaviour, to understand their intentions and purposes (e.g. Baron-Cohen, 1991). The research stemming from this line of investigations has led both to the development of theories proposing that individuals base their understanding of the world on some implicit knowledge (Churchland, 1991), as well as Simulation theories inspired by the discovery of mirror neurons (Gallese & Goldman, 1998).

Simulation theories of emotion recognition posit that when we attempt to read someone else's mind through their emotional bodily expressions, we activate an automatic internal simulation that intends to reproduce the perceived emotion into our own body, that is, we re-enact the other's emotion into our sensorimotor system (Davis et al., 2017). Simulation theories therefore postulate the presence of a bodily feedback during the recognition process that backs central cognitive operations (Gallese & Goldman, 1998). Recent theorizations have argued that such simulation processes may sometimes supported by a peripheral simulation, known as facial mimicry (Hess & Fischer, 2013; Konvalinka et al., 2011).

There is a substantial amount of research that shows that emotion recognition tasks can elicit a subtle mimicry of the face expression seen (Blom et al., 2020). The automatic nature of this phenomenon suggests that emotion recognition involves the engagement of the sensorimotor system during the reading and semantic retrieval of the emotion occurring during motivated social interactions (e.g. Niedenthal et al., 2005). Daily social interactions in real life see us committed to sympathize with people looking at more subtle and complex expressions than those pictured in research laboratories, and it has been proposed that the necessity of sensorimotor simulation might be more salient as facial expressions become more ambiguous (e.g., Halberstadt et al., 2009; Niedenthal et al., 2001). However, the way facial mimicry helps recognition is still fundamentally unclear. It is not clear, for instance, if mimicry represents a sensorimotor simulation of specific emotions, or whether it is only responsive to affective valence; moreover, it is not clear whether mentalization causes mimicry or *vice versa* (Hess & Fischer, 2014). Additionally, some authors have argued that mimicry only activates when someone is motivated to understand the expressions perceived, and even in this case mimicry might occur only when the emotions or the context are difficult to decode and the mentalization alone is not sufficient (Wood, Rychlowska, et al., 2016).

The first study of this thesis addressed a basic assumption of embodied cognition theories, i.e. that the proprioceptive feedback from the activation of an observers' facial muscles represents a sensorimotor feedback to be integrated with a visual feedback during the observation of facial expressions (Goldman & Sripada, 2005). In our first study we observed whether the ability to perceive their own facial movements and positions (facial proprioception) influenced individuals in their ability to recognize facial expressions, due to a presumed awareness of their own facial mimicry (Goldman & Sripada, 2005). We therefore measured facial proprioception (through the AMEDA method, Frayne et al., 2016a) and facial mimicry (*corrugator supercilii* and *zygomaticus major* were measured with EMG) during a task of recognition of emotional facial expressions. Through this design we aimed, firstly, to examine the relationship between the ability to recognise facial expressions and the ability to perceive one's own facial movements and positions. We also aimed to investigate whether facial proprioception modulates the occurrence and/or intensity of congruent facial EMG reactions to facial expressions during the recognition. Results revealed that during the recognition of emotional facial expressions, greater activation of congruent facial EMG was detected (facial mimicry), especially in the c*orrugator supercilii* expressed as difference from the baseline during exposure to angry faces. Interestingly, such mimicry of the corrugator occurred only for high-proprioception participants, whereas low-proprioception participants showed an activation of the zygomaticus muscle during early processing of angry facial expressions. In the whole sample, independently of proprioception differences, the corrugator was significantly greater during the recognition of angry faces, while results did not show significant congruent EMG activity on the zygomaticus for happy faces. However, participants' recognition ability (accuracy and reaction time) was not modulated by their facial proprioceptive ability. Instead, behavioural results revealed that happy faces were particularly easy to recognize. High accuracy and speed of happy faces recognition suggested that recognition ability was not challenged by the task. On the other hand, angry faces were recognized less accurately and slower by both participants with low and high proprioception levels. The results of this study led us to argue that during the recognition of happy faces participants did not engage in a simulation process, and that the reason for this may have been that the ease of the recognition required by the task meant that facial mimicry was not crucial during the recognition process. Participants might instead have engaged a sensorimotor simulation during the detection of angry faces in order to supplement the recognition process with an additional source of information (Wood et al., 2016). These findings shed light on a possible moderating role of facial proprioception where proprioceptive ability promotes more mimic as proprioceptive feedback can be of better use, rather than mimicry facilitating recognition *through* proprioception.

Studies 2 and 3 investigated another main assumption recently claimed by modern simulation theories according to which the social context strongly determines the occurrence and nature of facial mimicry in response to the observed facial expressions (Wood et al., 2016). Hess and Fisher (2014) suggested that the congruence between the expresser's emotion and the emotional state suggested by the environment modulates the occurrence and nature of mimicry reactions (Hess & Fischer, 2014). We firstly designed a study to investigate the effect of affective contextual information on emotion recognition ability using brief sentences providing information about an event that occurred to the person expressing the emotion. Given the results of the previous study, and to also investigate the hypothesis made by Wood and colleagues' (2016), Study 2 of the thesis featured subtle emotional expressions, so that the perceptual information available was diminished. Indeed, the aim was to observe whether the ambiguity of the facial expression as well as of the knowledge about the situation increased the likelihood and the extent of mimicry reactions. If so, it would provide support to the hypothesis of Wood and colleagues (2016) that the lack of information is likely to promote a sensorimotor simulation.

In Study 2, participants were presented with angry and happy subtle facial expressions, preceded by a brief contextual scenario describing a recent event involving the expresser, and were asked to rate how angry or happy they thought the face was. Facial expressions and scenarios could be congruent (happy expression and scenario, angry expression and scenario), incongruent (happy expression and negative scenario, angry expression and positive scenario) or neutral (happy or angry expressions and neutral scenario). Facial EMG reactions (corrugator and zygomatic) were measured concurrently. The findings of this study revealed that valence-congruent associations led to higher ratings of the facial expressions as compared to valence-incongruent associations. Further, greater zygomaticus activity in response to happy faces and greater corrugator activity in reaction to angry faces were found. Interestingly, whereas corrugator activity for angry faces was found greater when angry faces followed negative and positive scenarios, zygomaticus activity was not differentially affected by the valence of the scenarios and activated more also for angry faces following positive scenarios.

These results clearly are at odds with the classic view according to which mimicry imitates a directly perceived behaviour (Chartrand & Bargh, 1999). In our study, observers also mimicked what they expected or what they thought they knew about the character's state of mind. However, a significant difference between scenario conditions and mimicry activity was not found. When mimicry occurred, it did not interact with face-scenario congruence. In light of this we hypothesized that, rather than mimicry, what we detected was emotional contagion, whereby simulation did not occur. Consequently, this study revealed that even if social context information modulates the way emotions are perceived, this modulation is not moderated by mimicry.

Given these results, a second study was carried out with a similar procedure and methods, which considered ambiguous expressions together with obvious facial expressions. This second study allowed us to better disentangle the modulation operated by both expressions and context ambiguity on facial mimicry and recognition ability. Results revealed that the ambiguity of expressions as well as the incongruency of scenarios disrupted the recognition. Indeed, fully expressed happiness and anger were always more easily recognized compared to ambiguous expressions, even in case of incongruent scenarios. The perception of anger in ambiguous angry expressions was clear only when faces were associated with negative scenarios, suggesting that participants relied much more on the contextual information when angry faces were ambiguous and difficult to decode. An interesting finding of this study was that participants relied on the context also during the recognition of fully expressive happy faces. This suggests that happy faces are easier to be misinterpreted and that the perception of happy faces is more manipulable by context. In this study mimicry-like responses of the corrugator (for angry faces) and zygomaticus (for happy faces) muscles have been shown mainly for fully expressive faces. Interestingly, corrugator activity was detected during the recognition of ambiguous happy faces linked to incongruent (upsetting) scenarios. This finding, together with findings of the previous study, strongly suggests that mimicry is called into question when the affective information provided is not sufficiently clear, namely in front of an ambiguous face and/or during incongruent face-scenario associations.

The last two studies of this thesis were designed to further investigate the relationship between the cognitive-central internal recognition and the peripheral simulation related to recognition of face expressions. Given the results found in Study 3, we decided to consider different intensities of expression to manipulate the ambiguity of the facial displays shown.

Specifically, both study 4 and 5 featured low- (20%), medium- (40%) and high-intensity (60%) facial expressions. The first task was a valence detection task of happy, angry or fearful facial expressions presented rapidly (100 ms), while the second task was a recognition task of the same emotions presented for 2500 ms. For both studies, EEG activity was recorded together with facial EMG activity of the *corrugator supercilii* and the *zygomaticus major*. We focused our analysis on EPN and N400 ERPs components as they have been identified as the most sensitive to internal cognitive simulation during facial expression recognition, according to the literature (Davis et al., 2017; Mavratzakis et al., 2016). Accuracy and reaction times were also recorded.

The results of Study 4 revealed that medium intensity fearful faces have been processed more cognitively by EPN brain areas, and that the recognition was facilitated by greater corrugator activity. The lack of effect of emotion on EPN waves for low and high intensity faces suggested that EPN was not sensitive to very clear and very unclear emotional expressions when shown quickly. Time course inspection revealed that corrugator activity was greater during 200 to 400 ms after face onset, which corresponds to the EPN time window. In line with this, correlation analyses showed that correct discrimination of high intensity angry faces was associated with greater early corrugator activity. This is in line with the fact the corrugator activated more during this time window. Moreover, EPN showed greater waves for medium intensity fearful faces. These results, taken together, strongly suggested that the central cognitive processing of medium intensity fearful faces might be connected with a peripheral simulation expressed through measurable mimicry. Moreover, the lack of an emotion effect for low intensity face expressions is also in line with the results for the EPN component, which were found not to be sensitive to very ambiguous emotional expressions shown rapidly.

Is it interesting that the EPN component also appeared to be particularly sensitive to ambiguous fearful faces (medium intensity) and, as mentioned above, that the corrugator muscle activated significantly more in the EPN time window (200-400 ms after face onset). This might suggest a relationship between central processing as represented by EPN of fearful and angry faces and peripheral reactions to them expressed by a greater activity of the corrugator. This evidence is further confirmed by a positive correlation found between EPN and corrugator activity during correct recognition of medium intensity angry faces. Interestingly, the correlation regarded corrugator activity from 400 to 600 ms after face onset, which follows typical EPN activity (250-350 ms after face onset). Regarding the N400 component, it showed stronger waves for low-intensity facial expressions, followed by medium- and high-intensity facial expressions. Correlation analyses showed smaller N400 waves associated with faster detection of high intensity angry and fearful faces. Smaller N400 have been also been found associated with more accurate discrimination of negative valence of low-intensity angry expressions. Additionally, correlations between N400 activity and corrugator activity showed that the N400 activity was in most cases negatively correlated with the corrugator, in particular, a smaller N400 was in the majority of cases associated with higher corrugator activity. The findings of this study are in line with findings reported by Davis and colleagues, who hypothesized a critical role for the N400 during greater semantic retrieval for an emotion recognition task. This study further confirms that N400 is associated with greater difficulty if the task requires to semantically detect an emotion among a few alternatives.

We speculate that there is a complementary relationship between N400 and corrugator activity. According to this hypothesis, successful semantic retrieval during a demanding emotion recognition task is more likely if the corrugator muscle increases its activity before and not after the N400 time window. However, the present study did not test any other factor that would increase complexity of recognition beside the intensity level of face expressions. Further research is required to account for other factors, such as the incongruence of social context.

Study 5, which was an explicit emotion classification task, did not show a significant modulation of the EPN component across emotions and intensities. However, a negative correlation between EPN activity (peaking from 245 ms to 330 ms after face onset) and early and mid-late zygomaticus activity was detected during correct discrimination of medium intensity happy faces. A negative correlation was also found between EPN and mid-late (400-600 ms after face onset) corrugator activity during correct discrimination of low intensity fearful faces and late (600-800 ms after face onset) corrugator activity during medium intensity fearful faces as well as high intensity angry faces. This result is consistent with the findings of Study 4 as correlations found between EPN activity and facial reactions seems to have held a complementary relationship with congruent facial activations.

As to N400, results showed larger N400 waves for low and medium-intensity emotional facial expressions as compared to high-intensity emotional facial expressions. Moreover, when emotions were expressed at the highest intensity, N400 was greater for neutral faces than fearful and angry faces. Correlation analyses also revealed that stronger N400 was associated with higher discrimination accuracy of low-intensity happy faces and less discrimination accuracy of high-intensity angry faces.

Thus, results of study 4 and 5 taken together suggested that the N400 is sensitive to the ambiguity of facial expressions, with larger N400 associated with increased ambiguity of the face. Both studies further confirm the critical role of this component during the process of emotion recognition when measured considering distracting alternatives. There is a consensus on the assumption that the N400 generally indicates integration of perceptive and semantic elements during the attempt to detect a facial emotion (Davis et al., 2017; Kutas & Federmeier, 2000, 2011). Our results are in line with theories that see the N400 representing the allocation of more cognitive resources to linguistic memory retrieval and binding (Kutas & Federmeier, 2011). According to this view, the N400 would index a specific cognitive process that integrates non-linguistic information with linguistic information. Therefore, the N400 indexes the usage and incorporation of multiple modules of semantic retrieval (Kutas, & Federmeier, 2000). Furthermore, our studies suggest that if the emotion recognition involves the detection of fine intrinsic features of expressions as required by our task, the EPN does not represent the most salient component in terms of cognitive and temporal salience.

Taken together, the results from all five studies shed light on a more complex role of facial mimicry when people try to identify others' emotions through facial expressions. Theory-theory models have hypothesised that the recognition of facial expressions develops from an initial visual acquisition of the configuration of facial muscles. Our results are in line with the hypothesis that sees such visual perception as propaedeutic to a semantic (interpreted) representation of the emotion (Gopnik & Wellman, 1992). Further, and in line with what has been argued by simulation theories, our findings strongly suggest that recognition is related to the engagement of an internal sensorimotor simulation during the detection of facial expressions (Gallese, 2005). Specifically, our findings consistently showed automatic emotion-congruent facial EMG reactions during facial expressions' recognition tasks (Dimberg, 1982, 1990). Our findings showed that facial mimicry is linked with better facial expression recognition (Hyniewska & Sato, 2015; Korb et al., 2010, 2014; Künecke et al., 2014; Lobmaier & Fischer, 2015; Rychlowska et al., 2014). However, our results showed that facial mimicry represents a sensorimotor simulation of specific emotions, rather than being responsive only to affective valence (Kaminska et al., 2020). This is in contrast with what has been hypothesized by Hess and Fischer (2014), who proposed that mimicry is valence-specific and does not represent a sensorimotor simulation of discrete emotions. Our findings also showed augmented reaction on both the corrugator and zygomaticus muscles for respectively angry and happy faces not associated with better recognition, suggesting that mimicry must be carefully disentangled from another phenomenon discovered by Hess and Fisher called ‘emotional contagion’ (Hess & Fischer, 2014). However, Hess and Fisher argued that such emotional contagion occurs only on the corrugator as a reaction to angry faces, as mimicry tends to serve affiliative purposes. In light of our findings, we agree with Hess and Fisher’s view according to which facial mimicry tends to occur when the observer is affectively affiliated to the expresser, and thus when the observer already knows the reasons that caused the expresser’s emotion. However, our results showed that mimicry can occur also in the attempt to understand anger, having acquired information of recent past life events, especially when the expression and/or the context are ambiguous. We therefore discard the hypothesis that sees facial mimicry facilitated only by affiliation feelings. Finally, in line with what has been proposed by Wood and colleagues (Wood et al., 2016), our findings show that facial mimicry is not crucial for the recognition process and it tend to occurs when the expression is particularly difficult to understand. We agree with Wood and colleagues that an internal sensorimotor simulation occurs to supplement the recognition process with an additional source of information (Wood et al., 2016). We argue that facial mimicry holds a moderating role during the recognition of facial expressions whereby the peripheral feedback *might* facilitate the recognition process, but it is not necessary for a successful recognition process. Mimicry seems to be particularly critical when the information provided from the facial display and/or from the context is not sufficient, namely in front of an ambiguous face and/or during incongruent face-scenario associations. Additionally, and perhaps most importantly, mimicry can reflect the interpretation of the perceiver, not necessarily mirroring the facial expression displayed. This might be a step during the formation of a final judgement in a trial-and-error procedure that leads to successful recognition, which would be well aligned with the view that mimicry ‘is not the result of exact copying of what one sees but rather of the inferred meaning and thus the interpretation of an emotional signal’ (Hess & Fischer, 2014). For this reason, further research focussed on the investigation of the role of facial mimicry will need to consider factors that would increase the complexity of recognition, such as the intensity level of face expressions and the incongruence of social context; a strategy to shed light on this matter may also be that of investigating the processes underlying facial expression recognition in more natural settings.

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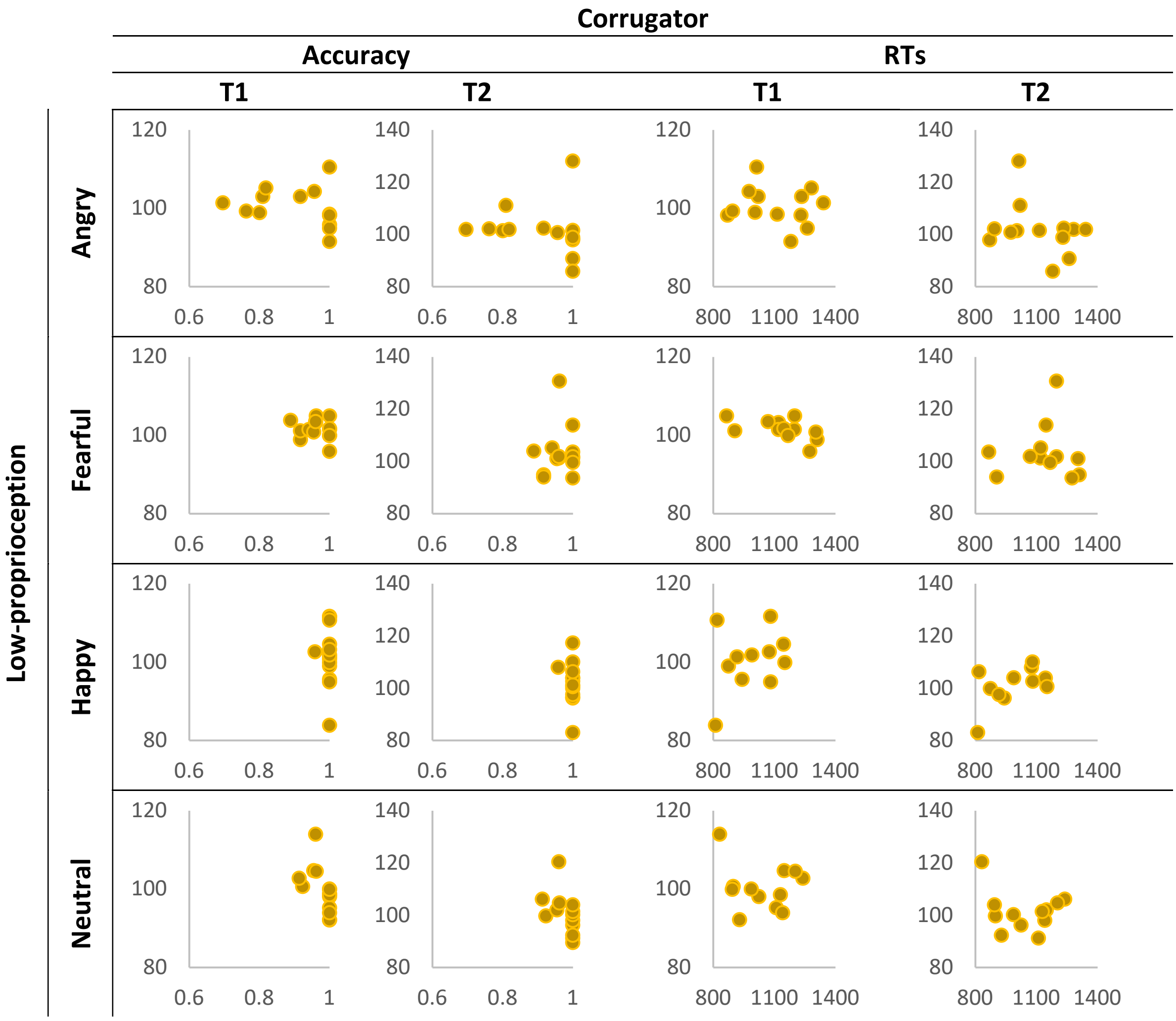
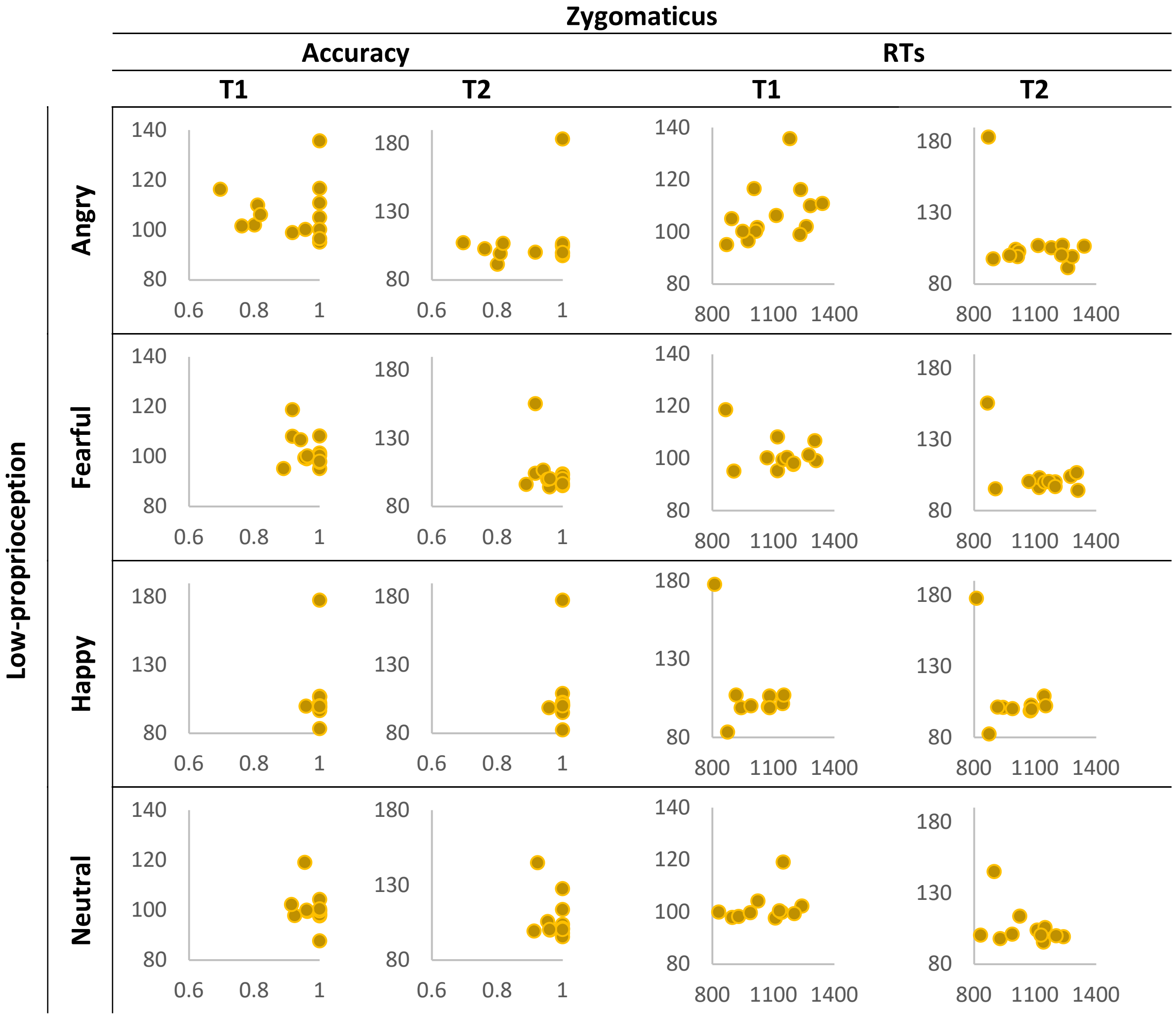
Appendix A

Scatterplots of the relationship between EMG activity and behavioural responses.

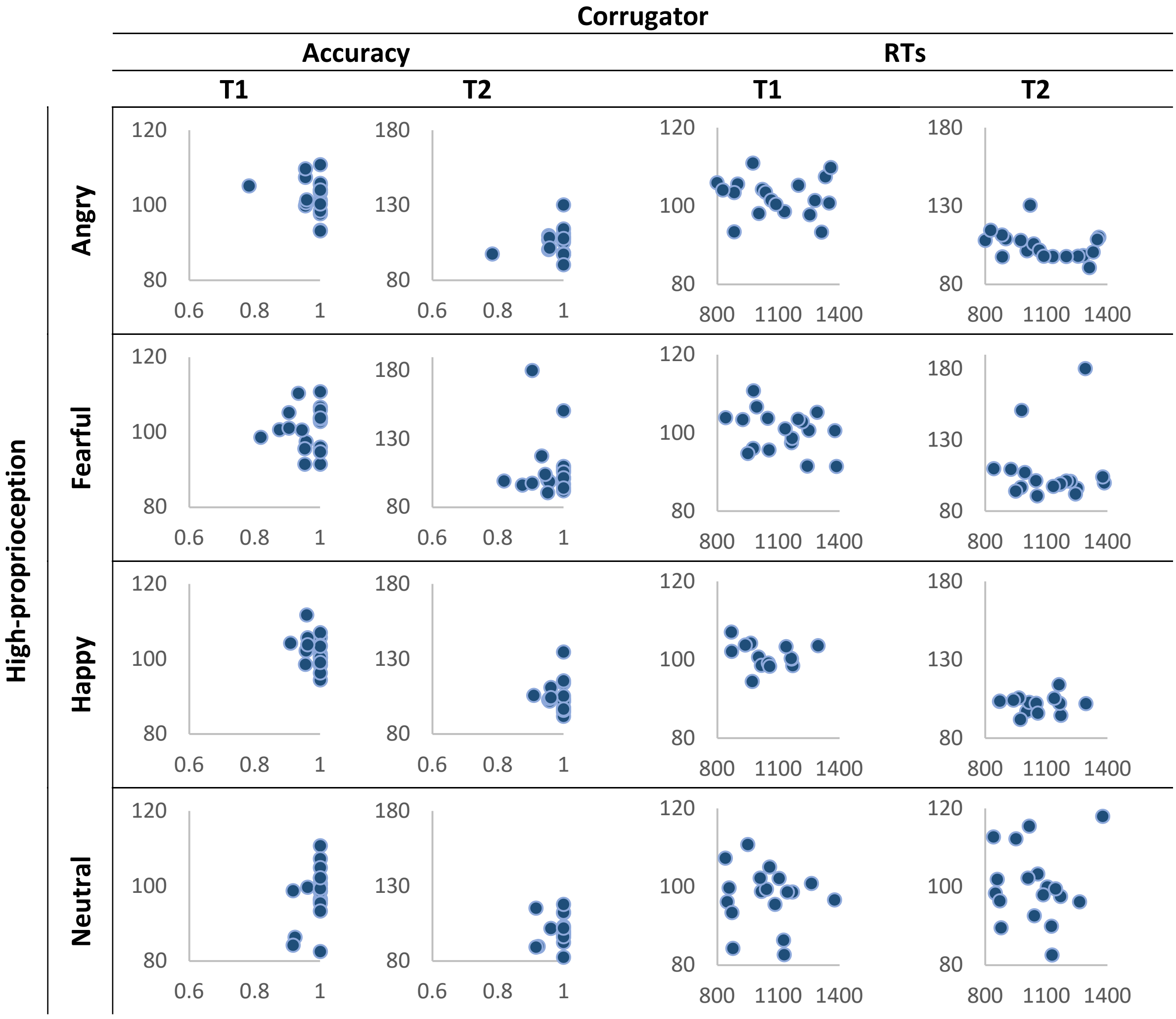
A1. Low proprioception - Corrugator



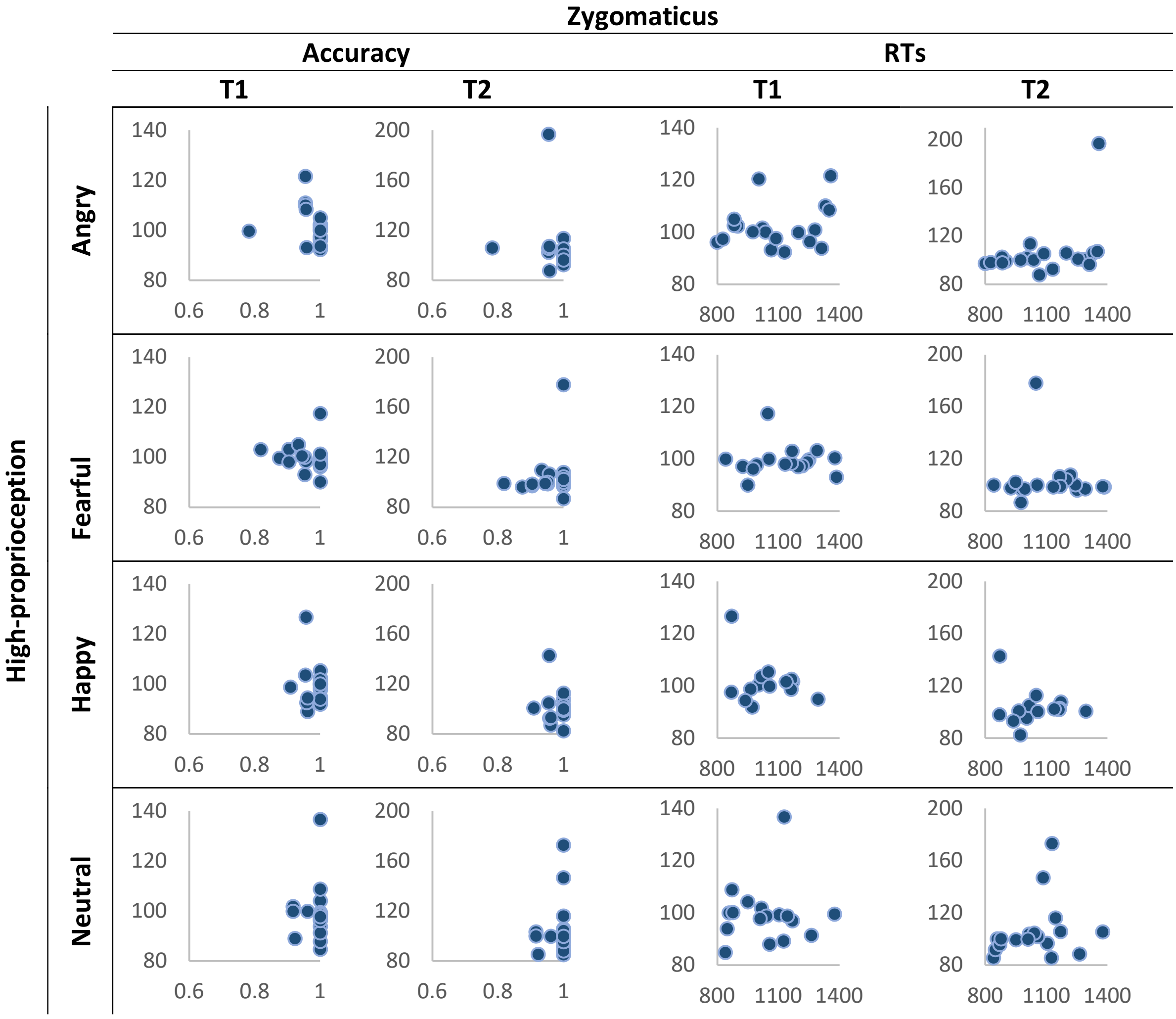
A2. Low proprioception – Zygomaticus



A3. High-proprioception – Corrugator



A4. High-proprioception – Zygomaticus



Appendix B

Study 2 scenarios

Neutral Scenarios

- Andy installed Microsoft Office on his computer at home
- Andy took the bus to the supermarket to do his weekly food shop
- Daisy went to a local café to buy an espresso
- Daisy went to get a new passport photo as hers had expired
- Dave was waiting for his doctor's appointment
- Dave went into the garage to get some tools to attach a shelf
- George boiled the kettle and made a cup of tea
- George walked to the local shops to buy a newspaper
- Jessica posted a package at the Post Office
- Jessica set her clocks forward for daylight savings
- Laura fed her pet cat and filled up the water bowl
- Laura put her phone on charge before going to sleep
- Rachel pre-heated the oven in preparation for cooking dinner
- Rachel took some old books to a charity shop
- Richard filled his water bottle up in the library
- Richard turned on the TV to find something to watch
- Sam filled his car up with petrol at the petrol station
- Sam took the bus home from the gym
- Wendy got dressed in the morning before going to work
- Wendy shut all the windows in her house before leaving

Positive Scenarios

- Andy was complimented on his new haircut
- Andy won three million pounds on the lottery
- Daisy's favourite song came on in the supermarket
- Daisy's job application for a top law firm was successful
- Dave got engaged on a romantic holiday
- Dave's wife made him his favourite food for dinner

- George got married to his childhood sweetheart
- George won the local marathon
- Jessica met her favourite author
- Jessica received a promotion after working for her company for only a few months
- Laura met up with a very good friend who she had not seen for five years
- Laura saw her favourite band live
- Rachel received a first for her final year dissertation
- Rachel was first place in a national dance competition
- Richard found a twenty-pound note on the floor
- Richard was complimented on his new jacket
- Sam found the name of a song that he had been searching for for a long time
- Sam's boss praised him for his work on his recent presentation
- Wendy became an auntie for the first time
- Wendy put on an art exhibition and it was later featured in a well-known newspaper

Negative Scenarios

- Andy saw someone steal an elderly lady's handbag
- Andy was late to work by five minutes and had to work unpaid overtime
- Daisy tidied the house for her family reunion but her sister took the credit for it
- Daisy's friends all went out together and did not invite her
- Dave had water splashed at him by a car speeding past
- Dave returned to his car to find a traffic warden giving him a parking ticket
- George fell over and ripped his favourite jeans
- George's team lost the football match because the other time cheated
- Jessica found that her car had been vandalised
- Jessica's husband insulted her mother
- Laura was on an overnight flight with a baby crying next to her
- Laura's mum threw out her favourite childhood toy
- Rachel saw her boyfriend kissing her best friend
- Rachel spent her whole week working on an assignment, only to be told that it was no longer required
- Richard had his wallet stolen on the train
- Richard went to see a film but someone was talking on their phone in the cinema
- Sam found out that his best friend had told his secret to a few people

- Sam was talking to a girl he liked and his friend made fun of him in front of her
- Wendy told an acquaintance about her degree and they laughed at her
- Wendy was falsely accused of taking her co-worker's lunch

Appendix C
Study 3 scenarios

Neutral Scenarios

- Andy set the radiators on
- Andy went to feed his fish
- Daisy closed her garden gate
- Daisy has just tied her shoes
- Daisy is going to brush her teeth
- Daisy put her wallet in her bag
- Dave checked his emails
- Dave put on his gloves
- Dave washed the dishes
- George changed his phone SIM card
- George got rid of some stale bread
- George put the trash bag in the bin
- George throw some old jeans away
- Jessica put the recycle bin outside
- Jessica set the chairs into the table
- Jessica watched the forecast on tv
- Jessica went to withdraw some money
- Laura got to her office at 9 this morning
- Laura has checked the daily forecast
- Laura locked her office before leaving
- Laura took the bus home from the gym
- Rachel grabbed her scarf and put it in her bag
- Rachel rescheduled a doctor’s appointment
- Rachel signed in to the student data system
- Rachel threw some wastepaper in the bin
- Richard checked if the mat was in his backpack
- Richard is waiting for the traffic light to turn green
- Richard put some drain cleaner in the water pipe
- Richard was waiting for his doctor's appointment
- Sam filled his car up with petrol at the petrol station
- Sam got dressed in the morning before going to work

- Sam put his phone on charge before going to sleep
- Sam put on his jumper as it got chilly in the room
- Wendy checked whether the pencil case was in her backpack
- Wendy took the bus to the supermarket to do her weekly food shop
- Wendy went home earlier to pass the vacuum in her room
- Wendy went to get a new passport photo as hers had expired

Positive Scenarios

- Andy has been offered the tickets for his favourite artist's concert
- Andy screenplay proposal has been accepted by a producing company
- Andy's book has been accepted by a very good publishing company
- Andy's research paper has been published in a very good journal
- Daisy will be maid of honour at her best friend wedding
- Daisy's audition was very successful and she got the part
- Daisy's favourite football team has won the championship
- Daisy's job application for a top law firm was successful
- Dave got the scholarship for an internship in his favourite country
- Dave has finally said to his parents that he is gay and they were happy about that
- Dave received a promotion after working for his company for only a few months
- Dave's restoration work of an ancient artwork was published in the newspaper
- George came first place in a national dance competition
- George is going to have a full body massage at the SPA
- George s favourite band scheduled a concert in his town
- George's wife made him his favourite dish for dinner
- Jessica got married to her childhood sweetheart
- Jessica is going on a Christmas holiday in Sweden
- Jessica received a first for her final year dissertation
- Jessica's new album is sold out after only a month
- Laura finally kissed the girl she has a crush on
- Laura got pregnant after many months of trying
- Laura just got the scholarship that funds her PhD
- Laura just realise she is in love for the first time
- Rachel is going on a trip to Greece
- Rachel is going to his honeymoon
- Rachel won a luxury holiday

- Rachel’s baby said his first word
- Richard found a twenty-pound note on the floor
- Richard got engaged on a romantic holiday
- Richard won three million pounds on the lottery
- Richard’ theatre play was much acclaimed
- Sam got the job position of her dreams
- Sam got the loan to open his yoga centre
- Sam made some new nice friends today
- Sam won free haircuts for an entire year
- Wendy met her favourite author
- Wendy saw her favourite band live
- Wendy’s PhD VIVA was very successful
- Wendy’s piano concert was a success

Negative Scenarios

- Andy bought a faulty second hand car and he had to scrap it right away
- Andy lost the draft of his PhD theses a month before the submission
- Andy tidied the house for her family, but his sister took all the credit for it
- Andy's team lost the football match because the other team cheated
- Daisy found out that her best friend had told her secret to a few people
- Daisy has not been paid for a job she has done for the entire day
- Daisy told an acquaintance about her degree and they laughed at her
- Daisy was on an overnight flight with a baby crying next to her
- Dave couldn’t pass the border control at the airport for new immigration laws
- Dave just realised that he got his boss’s instructions wrong and three days’ work got wasted
- Dave spent a whole week working on an assignment that it was no longer required
- Dave’s work of one month got wasted as his supervisor told her to rethink the project
- George booked flight tickets for a concert that got cancelled
- George has been told that he cannot take summer holidays
- George has just been told that his best friend has cancer
- George just discovered that his girlfriend is cheating on him
- Jessica accidentally dropped her phone in the toilet
- Jessica found out that she cannot have children
- Jessica’s favourite guitar was broken in two during a party
- Jessica’s friends all went out together and did not invite her
- Laura just realised that her wallet has been stolen

- Laura lost her baby after one month of pregnancy
- Laura saw some lipstick in her husband’s shirt
- Laura's mum threw out her favourite childhood toy
- Rachel has been hit by a car while she was cycling
- Rachel has been mocked in front the guy she likes
- Rachel just missed the train to Paris by a minute
- Rachel lost a luggage full of her favourite cloths
- Richard found that his car had been vandalised.
- Richard had his bag stolen on the train
- Richard has just been diagnosed with cancer
- Richard’s cat has just been run over by a car
- Sam failed the driving licence exam
- Sam hit his toe against the table
- Sam’s wife insulted his mother
- Sam’s phone screen just broke
- Wendy got a fine by the police
- Wendy had a fight with her mother
- Wendy has step onto her glasses
- Wendy just failed the exam