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Mimicry in the Recognition of Emotional Facial Expressions

A dissertation submitted in partial satisfaction of the
requirements for the degree Doctor of Philosophy

in

Cognitive Science

by

Joshua D. Davis

Committee in charge:

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2019

The Dissertation of Joshua D. Davis is approved, and it is acceptable in quality and form for publication on microfilm and electronically:

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ABSTRACT OF THE DISSERTATION

Mimicry in the Recognition of Emotional Facial Expressions

by

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Doctor of Philosophy in Cognitive Science

University of California San Diego, 2019

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Facial expressions signal emotions and influence social interactions. One mechanism hypothesized to support the recognition of facial expressions is sensorimotor simulation—the observer simulates the observed expression internally and this affords a first-person, experiential understanding of how the target feels. Given enough sensorimotor simulation, this internal activity can be expressed externally in facial mimicry. Numerous studies have found that interfering with mimicry interferes with emotion recognition, particularly when decoding subtle expressions. This implies that mimicry reflects a form of computation that facilitates recognition when needed.

The Embodied Computation model of mimicry hypothesizes that simulation helps recognition by compensating visual mechanisms when visual emotion information is sparse—the more challenging an expression is to decode, the more simulation is involved in decoding it. It makes the unintuitive prediction that more mimicry will occur when emotion evidence is less available, but only if decoding the emotion is necessary. The Motor-Matching model of mimicry hypothesizes that mimicry is based on an automatic action-perception link (Chartrand & Bargh, 1999; Hess & Fischer, 2013). It makes the prediction that mimicry will reflect the emotion evidence: the more evidence, the more mimicry. If recognition is required, this will only increase attention and amplify the overall mimicry. The Emotional Mimicry in Context model hypothesizes that mimicry is not necessarily based on the amount of emotion evidence that is seen but whether or not the signal is interpreted to promote affiliation (Hess & Fischer, 2014). It predicts that the affiliative meaning of the observed expression determines whether or not mimicry occurs.

These hypotheses were tested in three experiments measuring EMG elicited by emotional faces in various challenging conditions. Results are argued to support a novel proposal that combines the insights of the embodied computation and emotional mimicry in context models.

Chapter 1: Literature Review and Introduction to the Present Research

1.1 Introduction

Emotional facial expressions (from here on referred to as expressions unless noted) are important social signals. These expressions signal affective and emotional states (Ekman, 1992; Russell, 1980) and these states are associated with action tendencies (Frijda, Kuipers, & Ter Schure, 1989). Recognizing these expressions helps predict behaviors. The ability to decode expressions is a critical skill for successfully navigating the social complexities of our gregarious society. When the signaling system is compromised, social interactions break down (Adolphs, Baron-Cohen, & Tranel, 2002; Damasio, 1994, 1996). This makes the mechanisms involved in recognizing expressions a topic of fundamental importance for social cognition. The present research addresses the functionality of a controversial mechanism, spontaneous facial mimicry. (From here out spontaneous facial mimicry will be referred to as mimicry unless otherwise noted).

Within the literature on the recognition of expressions, there are strong claims made for (e.g., Niedenthal, 2007) and against (e.g., Rives Bogart & Matsumoto, 2010) mimicry playing a causal role. Arguably, the strongest evidence in favor it is research demonstrating that disrupting mimicry-related motor activity impairs the recognition of expressions (Davis, Winkielman & Coulson, 2017; Maringer, Krumhuber, Fischer, & Niedenthal, 2011; Neal & Chartrand, 2011; Niedenthal, Halberstadt, Margolin, & Innes-Ker, 2000; Korb et al, 2015; Oberman, Winkielman & Ramachandran, 2008; Ponari, et al., 2012). The strongest evidence against this is a study that included 37 participants with congenital facial paralysis, patients with Möbius Syndrome, and found that they performed on par with matched control participants when recognizing prototypical expressions (Rives Bogart & Matsumoto, 2010).

This appears contradictory but it is only contradictory when it comes to the strong claim that mimicry is needed to recognize any expression. The data suggest that mimicry may be more functionally important when expressions are subtle. In a study that included 3 participants with Möbius Syndrome, stimuli that ranged from prototypical to low intensity expressions were used. One participant performed on par with controls when recognizing low intensity expressions but 1 was at borderline levels and the other was significantly impaired (Calder et al., 2000). Although it is difficult to generalize from one participant, it makes the story a bit more complicated. The larger study did not include low intensity expressions (Rives Bogart & Matsumoto, 2010). Low intensity expressions are closer to neutral and have less evidence of emotion in them. This makes the emotions in them more difficult to decode (Hess, Blairy & Kleck, 1997). Mimicry may be more important when expressions have relatively less emotion evidence in them. The relationship between mimicry, emotion evidence, and recognition is a central theme of the present research.

Consistent with the hypothesis mimicry may be more important when recognizing expressions low in emotion evidence comes from research on typically developing participants as well. Some studies have found that interfering with mimicry impairs detecting when expressions change from one emotion to the other, but this occurs when the expressions are still relatively subtle (Niedenthal, Halberstadt, Margolin, & Innes-Ker, 2000), and sometimes only in female participants (Korb et al., 2015). Other research that had participants rate the intensity and valence of expressions interfered with mimicry but found no behavioral differences as a function of the interference manipulation. Differences were only detectable using a sensitive measure of semantic processing, the face N400 event-related brain potential (ERP); and even in this study, the N400 was not influenced when processing high intensity expressions (Davis, Winkielman, &

Coulson, 2017). These indicate that the effects of mimicry on emotion recognition may be subtle and relatively more influential when emotion evidence is low.

However, inferences from Möbius patients and inferences from interference studies both make arguments about typical processing by virtue of atypical situations. This is informative but has limitations. Assuming facial expression recognition involves both visual and mimicry related mechanisms, it is possible that Möbius patients, in the absence of mimicry, have developed visual expertise that goes beyond what typically developing individuals do. They could be exceptions to the rule. This makes drawing inferences about typical cognitive processing problematic. The interference research also has inferential limitations. As pointed out by Rives Bogart & Matsumoto (2010), many of the interference manipulations are quite awkward and those that lack equally awkward control conditions, leave interpretation open for alternative explanations. The effects could be driven by distraction. Although more recent research has taken pains to create minimally different control conditions that vary only in whether they disrupt mimicry related motor activity (e.g., Davis, Winkielman, & Coulson, 2017), they still suffer from the distraction problem. Interfering with a spontaneous and automatic response may simply be distracting in and of itself, and mimicry is a spontaneous and automatic response (Dimberg, Thunberg & Gruendel, 2002; Korb, Grandjean, & Scherer; 2010).

Because of these limitations, it is important to design experiments that can address the functionality of mimicry in the recognition of expressions using typically developing participants and measuring mimicry itself. That is the aim of the present dissertation. Namely, we test the profile of mimicry as a function of emotion evidence and task. Details of the models and methods are described at the end of this chapter. However, the basic hypothesis is that if mimicry plays a functional role in recognition, one way it may do so is by increasing in activity when expressions are relatively low in emotion information (chapters 2 & 3). Another way is by filling in emotion relevant information when expressions are missing it (chapter 4) and when emotion recognition is required. Additionally, if mimicry plays a functional role in recognition, then it should partially mediate between the evidence of emotion in the stimuli and the emotion participants indicate the stimuli are expressing (chapters 2-4).

The remainder of the chapter will provide a literature review on the topics that are relevant to the motivation of this research. This includes the topics of emotion and emotion recognition, mimicry, and the embodiment research that motivates the hypothesis that mimicry should play a functional role in recognition. This will be followed by a summary of why the research is important, the hypotheses tested, and the general methods used throughout each of the experiments (chapters 2-4).

1.2 Emotion and emotion recognition

1.2.1 Emotion

Since the topic of this research is on the role of mimicry in emotion recognition, it is important to say something about what emotions are. However, as Fehr & Russell (1984) put it, "Everyone knows what an emotion is, until asked to give a definition. Then, it seems, no one knows" (p. 464). This section provides a brief consensus view of the functions and components of emotion that are generally agreed upon by emotion researchers. Following this is a brief description of the model of emotion that this dissertation adheres to, and the practical and empirical reasons why that model was chosen.

As mentioned, emotions are notoriously difficult to define. Perhaps the best description is a composite summary based on the input from multiple emotion researchers. Izard (2010) collected definitions of emotion from 34 emotion scientists, compiled a survey of statements based on their responses, and then had them rate how much they agreed upon each statement. The statements covered the functions of emotions, their components, and their eliciting events. The function that was most agreed upon was that emotions recruit response systems. Also generally agreed upon was that emotions organize and coordinate responses. These responses include relatively basic approach and avoidance responses, but they also include those that are more complex. Emotions motivate, coordinate and organize cognitive responses, and corresponding actions. According to the results of the Izzard (2010) study, not only do emotions elicit responses, they provide meaning and information. One specific way they do this is by assessing the significance of events. Another characteristic of emotions is that they are relational and social in nature. Regarding the components or structures that constitute emotions, the most agreed upon statement was that emotion processes have neural systems that are dedicated in part to them. Aside from neural systems, emotions activate response systems more generally. Emotions include a felt sense and a cognitive interpretation of those felt senses. Another component of emotion that was generally agreed upon was that they involve antecedent cognitive appraisals. Most critically for this dissertation, emotions include an expressive behavior or signaling system.

There are numerous models of emotion. The two that are most frequently used are discrete models of emotion and dimensional models of emotion. Discrete models of emotion are models that propose that there are different types of emotions. One well known version of this is the basic emotion model, which claims that the categories of joy, sadness, anger, disgust, surprise, and fear are distinct from each other (e.g., Ekman, 1992; Ekman & Friesen 1971). A well-known dimensional model is the circumplex model, which claims that emotions are not discrete categories but fall into a continuum along the dimensions of valence and arousal (e.g., Russell, 1980).

The present research approaches emotion recognition from the discrete emotion perspective. This is due to pragmatic reasons but there is also empirical evidence suggesting that basic emotions are distinct. The pragmatic reasons are we are examining emotion categorization, in particular the categorization of anger, joy, and sadness. Anger, joy, and sadness are colloquial terms that participants are familiar with; we assume participants are at least somewhat familiar with prototypical expressions of these emotions (there are emojis of these expressions on most smart phones); the facial expression databases we constructed our stimuli from are organized according to basic emotions; and we are assessing emotion evidence in our stimuli using computer vision software that analyzes the evidence of basic emotions (The Computer Expression Recognition Toolbox, CERT, Littlewort et al, 2011). In addition, the argument based on Möbius patients that mimicry is irrelevant to emotion recognition also used stimuli from a discrete emotion database (Rives Bogart & Matsumoto, 2010). Along with the pragmatic reasons, there is empirical data that backs up the hypothesis that emotions have a discrete nature to them.

Discrete emotions are associated with dissociable patterns of autonomic and neural activity. Research using multi-voxel pattern analysis (MVPA) has revealed that discrete, self-reported emotional states can be predicted by distinct patterns of autonomic activity (Kragel & LaBar, 2013). It should be noted that discrete emotions are not associated in discrete brain areas, instead, different emotions activate distributed brain areas. A meta-analysis of brain imaging studies has shown that different emotional states activate distributed and interacting brain regions that are commonly associated with both emotional and non-emotional processes (Lindquist, Wager, Kober, Bliss-Moreau & Barrett, 2012). MVPA of functional magnetic resonance brain imaging (fMRI) data has found that distributed patterns of brain activity within local neural ensembles and distributed across the brain can predict discrete emotions (Kragel & LaBar, 2015). In a review of MVPA research on emotion and the brain, Kragel and LaBar (2016) concluded that discrete emotion models capture brain responses with higher accuracy than dimensional models. It has also been reported that MVPA of somatosensory cortex activation can predict the first-hand experience of different discrete emotions (see Schirmer & Adolphs, 2017). This report is quite intriguing and is relevant to the underlying motivation for the hypothesis that mimicry facilitates emotion recognition. The connection will be elaborated upon later but the basic idea behind it is that embodied representations (e.g., somatosensory, or sensorimotor in the case of mimicry) ground conceptual meaning and extracting meaning from an expression is part of the recognition process.

In summary, emotions are difficult to define but there is general agreement that they are elicited by events, they motivate actions and behaviors, they have a felt sense, they are distinguishable, they are social in nature, and they include a signaling system. Recognizing the emotions in others is important for social interactions. While the felt sense cannot be observed, behavioral signals such as facial expression can be observed. In addition, there are other cues available to facilitate this process. That is the topic of the next section.

1.2.2 Cues to emotion recognition

The attribution of emotions to others involves the integration of multiple cues. These cues can be perceptual in nature, based on prior knowledge and situational context, and they can be influenced by an observer's own emotional or physiological state.

Visible cues include facial expressions (elaborated upon in the next section), gait (Roether, Omlor, Christensen, 2009), body posture, and other behaviors (Aviezer, Trope, & Todorov, 2012; Coulson, 2004; Dael, Mortillaro, & Scherer, 2012). Auditory cues include pitch, speech, and vocal expressions (Koolagudi & Rao, 2012; Russel et al., 2003). There are also haptic cues, as people can recognize emotions based on how another person touches them (Schirmer & Adolphs, 2017). Another cue to how someone is feeling is when they report it themselves (Barrett, 2004; Mauss & Robinson, 2009). Emotions can also be inferred based on prior knowledge and context (Aviezer et al., 2008; Barrett, Lindquist & Gendron, 2007; Barrett, Mesquita & Gendron, 2011). It should be noted that not all cues are created equally. Some physical cues are more influential than others (Aviezer, Trope, & Todorov, 2012). Expressions can be concealed and faked (Ekman, 1970). Sometimes people do not report their feelings honestly or accurately (Mauss & Robinson, 2009). Perhaps this is one reason why we sometimes turn inward and rely on endogenous information to infer the emotions of others.

One source of endogenous information is one's own feeling state. Given that emotions involve appraisals and provide information about situations (Izard, 2010), they can be useful sources of information about how others are likely feeling. Of course, they can also be inaccurate. Consistent with this, manipulating an observer's emotional state influences how they perceive other people's emotions in an emotion congruent manner (Niedenthal, Halberstadt, Margolin, & Innes-Ker, 2000). Clinically depressed individuals take longer than controls to recognize facial expressions of happiness (Joorman & Gotleib, 2006). Individuals with alexithymia have a difficult time recognizing, describing and distinguishing their own bodily sensations. They also have a difficult time recognizing other people's emotions, including other people's facial expressions (Parker, Taylor, & Bagby, 1993), and verbal and nonverbal cues

(Lane, Lee, Reidel, & Weldon, 1996). Amongst individuals with autism, it is the degree to which they experience alexithymia that predicts their ability to recognize emotions in facial expression, not their severity of autism (Cook, Brewer, Shah & Bird, 2013). The relationship between how an observer is feeling and their attribution of emotion to others is one mechanistic explanation for how mimicry can influence the recognition of expressions. As discussed later, in the mimicry section of this introduction, mimicry has been hypothesized to induce emotional contagion, the spreading of emotions in a social situation. Very recent research has lent credibility to this long held assumption (Olszanowski, Wrobel, & Hess, 2019). If mimicking a facial expression can induce an emotional response within an observer, and if an observer's emotional response influences how they infer other people's emotions, then mimicry has the potential to influence emotion recognition.

This section outlined different cues that are used in emotion recognition. Some are physical cues, some are knowledge based, and others rely on how an observer feels within their own body. The endogenous cues provide one route through which mimicry can influence the recognition of facial expressions. However, facial expressions are visual signals. Vision also plays a fundamental role in recognition. In the next section, facial expressions will be elaborated upon. This will be followed by a section that describes hierarchical models of facial expression recognition. In that section, the connection between will be made between visual analysis and endogenous cues in the recognition process.

1.2.3 Facial expressions

The purpose of this section is to outline what emotional facial expressions are and briefly describe some of their social functions. Their social functions go beyond signaling affect and emotion. Their impact on social cognition is rather broad. This is relevant to this dissertation for two reasons. One, it strengthens the argument for why it is important to understand the mechanisms underlying how they are recognized. Two, it provides context for the emotional mimicry in context model, a model which makes competing hypotheses from other models tested in this dissertation. That model will be described in a later section. First, facial expressions will be discussed more generally.

Darwin proposed that there were remarkably similar patterns in the way that emotions were expressed in the faces and bodies of humans and animals (Darwin, Ekman, & Prodger, 1998). He proposed that these similarities evolved for two reasons, one to signal critical social information, and two, to prepare organisms to adaptively respond to recurring environmental stimuli and situations. For instance, anger is associated with aggression. Its expression involves the baring of teeth. Fear is associated with the need for environmental vigilance and involves the widening of the eyes. Recent research has lent credibility to the signaling and adaptivity hypotheses. Statistical models of the appearance of fear and disgust expressions indicate that these two expressions have nearly opposite patterns of expression, making them good signals. Additionally, the different shapes fit the different functions. Measurements of visual field perception and the regulation of air born particles entering the nose indicate that fear expressions are configured to enhance sensory acquisition while disgust expressions are configured to dampen it (Susskind et al., 2007). The form likely follows the adaptive function, but the form is also adaptive from a communicative perspective. It is not just fear and disgust that look quite different from each other, computational analysis of the structural aspects of expressions of joy, sadness, anger and surprise are all visually distinctive (Smith, Cottrell, Gosselin, & Schyns, 2005).

Motivated by Darwin’s theory, Ekman (1970) hypothesized that there were universal movements of facial muscles associated with different emotions. According to Ekman and Friesen (1971) prototypical expressions for six basic emotions—anger, happiness, fear, surprise, disgust, and sadness—exist and are recognized cross culturally. Although universal, they remain alterable. Expressions can be masked and faked, and their intensity can be influenced by arousal and cultural display rules (Ekman, 1970). It should be noted that the universality hypothesis is not universally accepted (Jack, Garrod, Yu, Caldara & Schynns, 2012; Gendron, Roberson, van der Vyer, & Barrett, 2014).

Consistent with the universal expression hypothesis, however, is cross cultural research comparing of the facial muscle activity of sighted Olympic athletes and blind Paralympic athletes from 23 countries. They found that the blind and sighted athletes’ expressions were nearly identical at emotionally significant moments, such as when the winners found out they had won their final matches and when they were awarded gold medals, and when losers found out they had lost and when they received silver medals. This is important because many of the blind individuals were blind from birth and thus had no way of seeing what expressions should look like, implying that basic emotional expressions are innate (Matsumoto & Hwang, 2019). Further evidence that emotions are expressed similarly comes from a meta-analysis of emotion recognition studies within- and across cultures. Performance was above chance regardless of which culture was being tested on another culture. However, individuals were most accurate when recognizing expressions from members of their own culture, and when recognizing expressions of individuals from cultures they were familiar with, indicating that there is also some cultural variability (Elfenbein & Ambady, 2002).

While the primary aim of this research is to investigate recognition of expressions on the dimension of emotion, it is important to know that expressions do more than signal affect and emotion. For instance, they can signal dominance and affiliation (Knutson, 1996), and mental effort (Hess, Philippot & Blairy, 1998) as well. They are social signals and do more than simply provide a cue to underlying emotional states. For these reasons, it is also important that we understand the mechanisms involved in their recognition. For instance, displaying fear does more than indicate that a target is frightened. It also alerts others of danger. This has an important social consequence in that it can increase group vigilance (Frith, 2009). Expressions are social in nature. Individuals are more likely to smile when there is an audience observing them then when an audience is absent (Fridlund, 1991; Krout & Johnston, 1979). Expressions also communicate intentions, an important mechanism for organizing and coordinating dynamic social systems and team work (Keltner & Haidt, 1999; Schalemann, Eckel, Kacelnik, & Wilson, 2001). Expressions influence trustworthiness (Boone & Buck, 2003; Krumhber et al., 2007), and the credibility of witnesses in court (Kaufmann et al., 2003; Vrij & Fisher, 1997). They also influence judgments of attractiveness (Mueser, Grau, Sussman, & Rosen, 1984; O'Doherty et al., 2003), and even gender (Hess, Adams, Grammer, & Kleck, 2009), both of which have social implications.

The social nature of expressions is important when it comes to mimicry. It is also important for the purposes of this dissertation. One of the models tested in the present research is the emotional mimicry in context model. It is grounded in part on the assumption that expressions are social in nature and therefore, so is mimicry. This will be discussed in further detail when describing the models tested and the predictions they make. Before it is time for that discussion, it is time to describe models of face recognition.

1.2.4 Models of expression recognition

Expressions are visual signals. This makes recognizing them primarily a visual problem. The visual system is well equipped to analyze expressions. “Face perception may be the most developed visual perceptual skill in humans” (Haxby, Hoffman & Gobbini, 2000; pg. 223). This section describes the gist of hierarchical models of face recognition and then goes into greater detail describing an influential anatomical model that begins to make the connection between vision to mimicry.

Hierarchical models of face recognition propose that recognizing expressions occurs in a series of stages (Adolphs, 2002; Bruce & Young, 1986; Haxby, Hoffman & Gobbini, 2000). Although it is sequential, there is also considerable feedback throughout the process. Early processing involves analysis in a core visual system. Coarse, lower spatial frequency features are encoded before detailed higher frequency ones. Separate processing streams encode static and dynamic features. Static features are involved in the recognition of identity and dynamic features are involved in the recognition of expressions. After analysis in the core visual system, the processing continues in an extended system. Recognition is followed by the activation of conceptual knowledge.

It is at the conceptual stage that mimicry is hypothesized to be relevant (e.g, Niedenthal, 2007). To draw the connection from visual analysis to mimicry, an influential anatomical model will be described. The model does not include mimicry and the specific connection to mimicry will be made in the following section.

According to Adolphs (2002), when an expression is initially presented to the eyes, early visual cortices rapidly extract course visual features. Subcortical regions including the amygdala process highly salient features such as those indicative of a potential threat. Affective significance is detected early and continues to be processed in later stages. As mentioned previously, there is considerable feedback throughout the encoding sequence. After the early visual analysis, visual association cortices engage in processing more detailed representations and configural relationships. Static configurations involved in the representation of identity are processed in the lateral fusiform gyrus, and dynamic configurations involved in the representation of expressions are processed in the superior temporal sulcus. While these processes in the core visual system continue, the extended system involved in recognition comes online. For emotion recognition, the extended system includes regions such as the amygdala and the orbitofrontal cortex. The amygdala and orbitofrontal cortex link perceptual representations to conceptual knowledge, which are represented in a cognitive system. The cognitive system includes the somatosensory cortices. Conceptual knowledge is hypothesized to be activated in three different ways: 1) via feedback to temporal and occipital cortices for fine-tuned visual representations associated with visual categories; 2) connections to the hippocampus and cortical regions associated with conceptual knowledge; and 3) connections to somatosensory and sensorimotor structures, the hypothalamus, and brainstem nuclei. According to Adolphs (2002; 2004), these structures are hypothesized to afford a simulation of what it is like to be in the sensorimotor and somatic state of the observed expression. Through this simulation, the observer obtains an experiential impression of what it is like to be in the observed state.

The connection between sensorimotor simulation and mimicry is not difficult to make, as mimicry involves matching an observed motor state with one’s own face. Sensorimotor simulation is the link by which facial mimicry is hypothesized to aid in the recognition of emotional facial expressions (Wood, Rychlowska, Korb, & Niedenthal, 2016). This is the second mechanism proposed to connect mimicry and emotion recognition. The first was emotional contagion. The constructs are not mutually exclusive. Since sensorimotor activity is an important link between vision and mimicry, it will be discussed in greater detail.

1.2.5. Sensorimotor activation

If sensorimotor simulation is relevant to emotion recognition, then there should be evidence that recognizing emotional expressions activates sensorimotor systems in the brain. Indeed, there is some evidence that supports this. fMRI data has revealed that evaluating the intensity of emotions in expressions activates premotor and motor cortices (Kilts, Egan, Gideon, Ely & Hoffman, 2003). Additionally, categorizing expressions, relative to passively viewing them, activates somatosensory cortices (Winston, O'Doherty & Dolan, 2003). Each of these findings are consistent with the hypothesis that recognizing expressions engages sensorimotor and somatic systems for the purposes of simulation. However, is simulation the only explanation?

Individuals with cortical blindness also show increased activation of somatosensory and motor cortices when presented with full-body expressions of anger (relative to neutral expressions) even though they are not aware of what was presented to them (Van den Stock et al., 2011). It seems plausible that early subcortical regions such as the amygdala are activating somatosensory and motor cortices in preparation to take action, to fight or take flight. The sensorimotor activation could be a simulation or a reaction in preparation for action.

A similar simulation/reaction issue pertains to mimicry. Individuals tend to partially mimic expressions that they see (e.g., Dimberg, 1982; Dimberg & Thunberg, 1998). These responses could be affective reactions, simulations, emotional mimicry or the more conceptually barren behavioral mimicry described in the next section. Distinguishing between mimicry, emotional reactions, and simulations is not always easy. Experiments are often not designed to distinguish between these alternatives (see Hess & Fischer, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015).

1.3 Mimicry

Mimicry is much broader than the spontaneous facial mimicry that this dissertation addresses. From a broad perspective, it includes the intentional or unintentional copying of behavior and is it observed in humans and some nonhuman animals. Broadly, it can coordinate social interactions, and influence learning (for reviews see Heyes, 2009; Hoppitt & Laland, 2008; Iacoboni, 2009). However, the remainder of this section will focus on spontaneous mimicry of behaviors expressed in the bodies and the faces of humans.

1.3.1 Behavior

Behavioral mimicry is the tendency to automatically and unconsciously imitate the vocal, facial and body postures of individuals in a social setting (Chartrand & Bargh, 1999; Hess & Fischer, 2014). It is associated with increased interpersonal liking and rapport (Chartrand & Bargh, 1999; Lakin & Chartrand, 2003), emotional contagion (Hatfield, Cacioppo, & Rapson, 1993; Hatfield, Bensman, Thornton, & Rapson, 2014; Chartrand & van Baaren, 2009) and empathy (Chartrand & Bargh, 1999; Hatfield et al., 2014; Iacoboni, 2009) and can increase prosocial behaviors (van Barren, Holland, Kawakami, & van Knippenberg, 2004).

Chartrand & Bargh (1999) developed a highly influential model of behavioral mimicry, the chameleon effect: the spontaneous mimicry of verbal and nonverbal social behaviors. It is in part motivated by spreading activation theories that link perception, memory, and action (Berkowitz, 1984), theories which propose there is partial overlap between schemas for interpreting and producing behaviors (Carver, Ganellan, Froming & Chambers, 1983), and by Prinz's (1990) extension of Lashley's (1951) common-coding hypothesis: the hypothesis that there is a shared representation between perception and action. Observing an action primes production of that action (Brass, Bekkering, & Prinz, 2001). For spontaneous mimicry, the proposal is that observing a behavior activates common action-perception code. If the level of activation in the common code reaches a certain threshold, a motor response will spontaneously occur (Chartrand & van Baaren, 2009).

The mechanism is relatively simple: observing an action primes the production of the same action. This is important because this is the motivation for what Hess & Fischer (2014, 2016) have called the matched-motor hypothesis of mimicry. It is one of the hypotheses tested in this dissertation. It will be described again later. However, it is worth mentioning that it differs from the other hypotheses that will be tested. Two important characteristics of the matched-motor hypothesis are that it is a relatively simple mechanism for which output matches input, and its function is to increase affiliation and facilitate social rapport.

These functions were testes by Chartrand & Bargh (1999). In the first of three experiments, participants interacted with a confederate. In this experiment, participants tended to mimic the confederate's foot tapping and face touching behaviors. They also found that the disposition of the confederate mattered; there was more behavioral mimicry of confederates who smiled than confederates who did not. In a second experiment, mimicry was manipulated by having confederates mimic (or not mimic) participants. In the mimicry condition, participants rated the confederates as more being likable and the discourse as smoother. Participants also reported that they did not notice the mimicry. In a third experiment, it was found that participants who scored higher on a perspective-taking empathy test engaged in more mimicry than those who scored low on it, demonstrating that there are individual differences in the degree to which people mimic strangers. These results were interpreted as demonstrating that behavioral mimicry increases liking, improves discourse fluency, and the degree to which it is expressed is modulated by individual differences in perspective taking abilities.

Another function associated with behavioral mimicry is emotional contagion, observable in humans and other animals (Hatfield, Cacioppo, & Rapson, 1993). It is the tendency to emotionally converge with others. It is hypothesized to be caused by the spontaneous mimicry of affective behaviors, postures, facial expressions, and vocalizations of others (Hatfield, Bensman, Thornton, & Rapson, 2014). The mechanism is proposed to be feedback based. Mimicking the affective behavior produces feedback in same somatic, motoric, and proprioceptive systems active when that behavior is produced by a genuine affective experience. Activation of the common code induces emotional contagion (Hatfield, Cacioppo, & Rapson, 1993).

Activating a common code between perception and behavior is also hypothesized to explain aspects of empathy (Chartrand & Bargh, 1999; Hatfield, Bensman, Thornton, & Rapson, 2014; Iacoboni, 2009). By activating the common code, mimicry affords a link between what is observed what is felt. Using that felt sense as a source of information affords inferences about how the observed individual is feeling, a crucial component of empathy (Hatfield et al., 2014). A potential neural mechanism for linking perception, action and empathy is the mirror neuron system (Iacoboni, 2009). Mirror neurons fire during the performance of an action and the observation of that same action—they share a common code for perception and action. The behaviors do not need to have an affective component. Mirror neurons have been hypothesized to facilitate inferences about the intentions of others, another important component of empathy, because they afford a mechanism for simulating the behaviors and inferring the goals that those behaviors are associated with (Iacoboni, 2009; Gallese, 2005; 2009; Gallese, Keysers & Rizzolatti, 2004).

The concept of simulation is important to this dissertation because mimicry has been hypothesized to be a form of sensorimotor simulation (Niedenthal, 2007). Sensorimotor simulation has conceptual affordances and can occur outside the mirror neuron system (Adolphs, 2002; Barsalou, Santos, Simmons, & Wilson, 2008; Blakemore & Decety, 2001). Sensorimotor simulation is important because it motivates two hypotheses tested in this dissertation: the hypothesis that simulation can function as a computational mechanism that can aid recognition when there is low emotion evidence in a stimulus, and the hypothesis that simulation can function as a pattern completion mechanism. These hypotheses will be explained in greater detail later. First it is important to discuss mimicry of facial expressions.

1.3.2 Mimicry of facial expressions

Similar to behavioral mimicry, mimicry of facial expressions can increase interpersonal attraction and liking (McIntosh, 2006; Likowski et al., 2008; Chartrand & Bargh, 1999; Lakin, Jefferis, Chang & Chartrand, 2003; Preston & de Waal, 2003). Also similar is the hypothesis that it can spread emotional contagion (Hatfield, Bensman, Thornton, & Rapson, 2014; Hatfield, Caciopppo & Rapson, 1993). The results on this have been mixed, however. Early research failed to detect a causal relationship (Hess & Blairy, 2001; Van der Shalk, et al., 2011) but recent research has found that mimicry does mediate between the expression observed and self-reported feelings (Olszanowski, Wrobel, & Hess, 2019). Mimicry is also hypothesized to play a functional role in the recognition of emotional facial expressions through sensorimotor simulation (Niedenthal, 2007; Oberman, Winkielman & Ramachandran, 2008; Wood, Rychlowska, Korb, & Niedenthal, 2016), a topic that will be discussed in detail in a the section on mimicry and emotion recognition.

While there are similarities between behavioral and facial mimicry, it is debatable whether they should be considered the same (Chartrand & Bargh, 1999) or different (Hess & Fischer, 2012, 2014) processes. Facial expressions have inherent social meaning whereas foot tapping type behaviors do not. Because they have social meaning, they are more contextually constrained. They do more than just increase liking and facilitate rapport, they also function to regulate social interactions (Hess & Fischer, 2012, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015).

Mimicry (again this will refer to the mimicry of emotional facial expressions unless otherwise noted) is the rapid and automatic copying of observed facial expressions (Dimberg, 1982). It can typically be detected around 300ms after stimulus onset (Dimberg & Thunberg, 1998) and rarely does it take longer than a second to initiate (Hess & Fischer, 2014). Mimicry is an automatic process. It occurs even when expressions are presented subliminally (Dimberg, Thunberg & Elmehed, 2000; Sonnby-Börgstrom, 2002) and when individuals actively try to inhibit their response (Dimberg, Thunberg, & Gruendal, 2002; Korb, Grandjean, & Scherer, 2010). However, even though it is automatic, it can be modulated by tasks that divert attention away from the emotional content of the face, (Cannon, Hayes, & Tipper, 2009; Murata et al., 2016; van Dillen, Harris, van Dijk & Rotteveel, 2015), by the observer's emotional state (Likowski et al., 2011b; Moody, McIntosh, Mann & Weisser, 2007) by individual differences in empathy (McIntosh, 2006; Sonnby-Borgstrom, 2008; Sonnby-Borgstom, Jonsson, Svensson, 2003), and by social context (Carr, Winkielman & Oveis, 2014; Likowski, et al., 2008; Stel et al., 2010).

Modulation due to social context is important to elaborate upon because of its relevance to one of the hypotheses tested in this research, which is based on social-regulation models of mimicry (Hess & Fischer, 2013, 2014). The emotional mimicry in context model hypothesizes that mimicry is based on an interpretation of an expression in its social context. This implies that the expression has already been recognized or anticipated to some extent before mimicry occurs. Mimicry is based on what is known more than it is based on what is seen (Hess, Houde & Fischer, 2014). It is not the automatic matching of activity on a muscle by muscle basis, it is instead the matching of affect based on an interpretation of the observed expression. In this way it is contrasted with the traditional matched-motor hypothesis of mimicry (Chartrand & Bargh, 1999; Hess & Fischer, 2013, 2014). It is also contrasted with the matched motor-hypothesis in that the matching is often more affect based rather than emotion specific (Hess & Fischer, 2013). It is more of a response signal than a reproduction of what is observed.

According to the emotional mimicry in context model, the primary function of mimicry is to promote affiliation, a function shared with traditional models of mimicry. However, the emotional mimicry in context model goes beyond that. It not only promotes affiliation, it signals it (Hess, Houde, & Fischer, 2014). Mimicry is a social signal that regulates and is regulated by social context (Hess & Fischer, 2013, 2014). Consistent with this, the relationship between the observer and the observed makes a difference. Mimicry can be modulated by power dynamics (Carr, Winkeilman, & Oveis, 2014). Observers are more likely mimic when they have positive rather than negative attitudes toward the individual they are observing (Likowski, et al., 2008; Leighton, Bird, Orsini, & Heyes, 2010). Social setting also matters. Expressions are not always matched. In an experiment that manipulated competitive, cooperative, and neutral social settings, mimicry occurred in the cooperative and neutral settings. The mimicry was virtually indistinguishable. However, in the competitive setting, facial responses were less congruent to what was observed and were sometimes even incongruent (Likowski et al., 2011a). Observers sometimes smile when they see their competition grimace (Lanzetta & Englis, 1989). Individuals low in empathy sometimes smile when they observe expressions of negative affect, even in a non-competitive setting (Sonnby-Borgstrom, 2003). Since expressions signal emotions and emotions are associated with intentions and behaviors, mimicry can be influenced by the type of expression as well. Anger signals hostility, and expressions of anger directed at an observer are less likely to be mimicked than expressions of happiness (Seibt, Mühlberger, Likowski, & Weyers, 2015). In sum, emotional mimicry in context model hypothesizes that mimicry is a function of the interpretation of an observed expression in a social context. Mimicry is a signal that is regulated by and that regulates social interactions. It is more complex than a physical mapping between perception and action. It is in part conceptual in nature since the expressions carry meaning and how the output relates to the input is moderated by that meaning in context.

The relationship between mimicry and conceptual representations is also the groundwork for why mimicry is hypothesized to have a functional role in emotion recognition. Both share a common code with conceptual representations of emotion, according to theories of embodiment. Representations for action, perception, and conceptualization partially overlap. Mimicry is a method for simulating the meaning of the observed expression. Embodiment and simulation is the topic of the next section.

1.4 Embodiment and simulation

Embodiment is the hypothesis that conceptual memory is grounded in sensorimotor and affective experience; understanding the meaning of a concept involves partially reactivating modal representations of experiences in memory (Barsalou, 1999; Glenberg, 1997; Lakoff & Johnson, 1980, 1999). Embodiment is a reaction to theories that concepts are represented in an amodal, abstract and proposition-like format in memory (Collins & Loftus, 1975; Newell, 1980;

Pylyshyn, 1984). Embodied simulation is a closely related topic and in many cases is used synonymously with embodied conceptualizations. In many ways they are the same. They both involve activating experientially grounded representations of meaning stored in perceptual, motoric, somatic, and affective structures. The main difference between the two is that simulation makes a mechanistic claim, namely that a simulation is occurring, whereas embodied representations simply imply that there is a conceptual representation grounded in experience. Typically, they indicate the same thing. For instance, there is no difference between an embodied representation and an embodied simulation of anger if an individual's dominant experience of anger is being angry and approaching a target. However, they diverge if the dominant experience associated with anger is fleeing. In this case, a sensorimotor simulation of anger would still entail representations associated with approach behaviors—anger is being simulated. However, if the dominant experience of anger is one of withholding from engaging in aggression and fleeing when confronted with expressions of anger, the embodied representation might very well be grounded in motor routines of avoidance rather approach. For the purposes of this dissertation, however, embodiment and simulation are used interchangeably, as they often are in the literature, unless specifically noted.

1.4.1 Embodied concepts

According to theories of embodiment, conceptual knowledge is represented in systems associated with perception, action, and affect. Conceptual representations are grounded in experience. Understanding the meaning of a word or a sentence involves activating those representations and simulating the meaning (Barsalou, 1999; 2008; Glenberg & Kaschak, 2002; Bergen, 2012).

Evidence that concepts are grounded in embodied experience comes from behavior and neuroimaging research. There are many experiments that have shown that comprehending an action word primes congruent motor actions (for reviews, see Barsalou, 2008; Bergen, 2012). However, arguments that the same results can be explained by spreading activation rather than activation of a common-code, make it difficult to evaluate the theory (Mahon & Caramazza, 2008; Mahon, 2014). Stronger support for embodiment comes from research that cannot be explained by spreading activation, interference-based research. The logic behind these designs is similar to that of classic dual-task interference studies. If the same representational code is being used for two unrelated processes at the same time, it should interfere with performance. For instance, Bergen, Lindsay, Matlock, & Narayanan (2007) had participants listen to sentences that described upward or downward events, such as “The mule climbed,” and “The chair toppled” immediately before they saw a square or a circle appear on a monitor. Their task was to press a button as quickly as possible to indicate which shape appeared. Critically, the shape appeared in either the upper or lower half of the screen. When the meaning of the sentence described a location that overlapped with the location of the shape (e.g., “The mule climbed,” and a circle appeared in the upper half of the screen), participants were slower to respond than if the locations mismatched. Brain imaging research also supports the embodied conceptual representations. Reading words about leg, hand, and face movements, e.g., kick, pick, and lick, was shown to increase BOLD responses in premotor and primary motor cortex in a somatotopic manner (Hauk, Johnsrude, & Pulvermueller, 2004). (For reviews of behavioral and brain research on embodied language, see Barsalou, 1999; Bergen, 2012; Buccino, Colage, Gobbi, & Bonnacorso, 2016; Fischer & Zwaan, 2008; Zwaan, 2014).

Although there is a large body of research that supports embodied conceptual processing, the results are not always consistent. For example, there is research showing that positive relationships between comprehending language about motion and perceiving motion. Perceiving motion can influence the comprehension of motion language (Kaschak et al., 2004) and comprehending motion language can modulate motion perception (Meteyard, Bahrami & Vigliocco, 2007; Pavan, Skujevskis, & Baggio, 2013). Comprehending motion language activates brain regions involved in motion perception (Saygin, McCullough, Alac, & Emmory, 2010), and induce motion aftereffects (Dils & Boroditsky, 2010). However, there is also research argues against it. There is research that finds comprehending motion language does not activate brain regions involved in motion perception (Dravida, Saxe, & Bedny, 2013). Likewise there is research finding that motion adaptation does not impair comprehension of motion language (Pavan & Baggio, 2012), arguing against the hypothesis that embodied representations play a causal role in language comprehension. It is not unlike the state of mimicry in emotion recognition.

Although recognizing facial expressions is different from comprehending language, both are hypothesized to rely on embodied processes. Both are motivated by a common conceptual code grounded in action and perception. The heterogeneous results in both domains of indicate a need to test models that make specific predictions about the functions of embodiment. In these ways, the research on mimicry in emotion recognition fits into the larger debate on embedment. Is embodiment epiphenomenal? Is it representational? Is it inferential? Is it more important in some contexts than others? These questions motivate the present research.

Prior to drawing a stronger connection between embodied concepts and emotion recognition by covering literature on embodied emotion concepts, it is worth mentioning an embodied language comprehension model that is somewhat analogous to the model relating vision and mimicry that motivates the present research. According to the language as situated simulation model (LASS, Barsalou et al., 2008), understanding verbal concepts relies on a fast word association mechanism and a slower sensorimotor simulation mechanism. The word association mechanism is quick but processes information relatively superficially. This is analogous to visual mechanisms in emotion recognition. The simulation mechanism is slower (though still rather fast, i.e., beginning within 200ms) and processes meaning more deeply and elaboratively in a contextually situated manner. This is analogous to simulation mechanisms such as mimicry.

According to Adolphs (2002) categorical perception and sensorimotor simulation may both be involved in emotion recognition. An emotion recognition model somewhat analogous to the LASS model could work in the following way. Recognizing prototypical expressions that are strong visual associates of an emotion, i.e., prototypical expressions high in visual evidence of a given emotion (analogous to strong verbal associates of a cue word) might be able to be solved primarily by visual mechanisms (analogous to verbal mechanism and an easy verbal association task) and require little or no simulation mechanisms such as mimicry. Expressions lower in visual evidence might require deeper processing in the context of recognition, and thus engage more simulation. This in part motivates our embodied computation hypothesis, a hypothesis that will be described in more detail near the end of this chapter. First, it is useful to describe some of the research on embodied emotion concepts.

1.4.2 Embodied concepts of emotion

Emotion concepts are hypothesized to be grounded in sensorimotor and perceptual experience in much the same way as affectively neutral concepts, with the addition that they are also partially represented in neural systems traditionally associated with emotional experience. Processing verbal concepts of emotion activates brain responses similar to those activates during emotional experience and the processing of nonverbal emotional stimuli. Relative to neutral words, reading words with positive and negative valence activates brain regions associated with emotion processing, including the insula and regions of the limbic system such as the amygdala (Kensinger & Schacter, 2006; Schlochtermeier et al., 2013). Processing emotion related words also activates the motor system (Moseley, Carota, Hauk, Mohr & Pulvermueller, 2012). Demonstration that emotion related words activate the motor system is important for sensorimotor theories of emotion concepts and the hypothesis that emotion concepts are partially grounded in mimicry. In addition to imaging research, multiple event-related brain potential (ERP) studies have found that processing affectively charged words induces ERPs similar to those found in response to affectively charged images (see Citron, 2012 for a review). In sum, processing emotion-related verbal concepts induces similar neural activity to processing nonverbal emotional stimuli. These data provide a link between perception, conceptualization, and action for the processing of emotional stimuli. While this is important for making the connection between mimicry and emotion recognition, a more direct link is research that relates mimicry to the processing of emotion language.

Much of the research on the embodied simulation of emotion language involves using facial EMG to measure electrical changes at the Zygomaticus major (which pulls the corners of the lips back, is involved in smiling, and is activated during the expression of positive affect) and the Corrugator supercilli (which pulls the inner brows down and together, and is involved in expressions of anger and sadness and negative affect more generally) muscle sites. (From here out Zygomaticus major will be referred to as zygomaticus and Corrugator supercilli will be referred to as corrugator). As with neural responses, there are similarities between conceptual processing and affective experience detectable in the activity of facial muscles. Processing words with a positive valence increases activity at the zygomaticus and processing negative words increases activity at the corrugator (Norris, & Cacioppo, 2003). Likewise, processing verbs associated with emotional expressions activates motor responses consistent with the production of those expressions (Foroni & Semin, 2009). This effect maintains even in second languages, although they are stronger in L1 than in L2 (Baumeister et al., 2017; Foroni, 2015). An important contribution is research that has presented words with positive and negative connotations and manipulated depth of processing. When participants had to evaluate the affective meaning of the words, positive words increased zygomaticus response and negative words increased corrugator response. However, when the task involved shallow processing—categorize the words as upper or lower case—the effect went away. This indicates the embodied response is not simply an affective reaction to a word (numerous Stroop studies demonstrate that people automatically infer some meaning simply by looking at words); instead it is a function of more thorough conceptual processing (Niedenthal, Mondillon, Winkielman, & Vermeullen, 2009).

Another important contribution made in that paper was the demonstration that interfering with the default motor response impaired comprehension of the affective feature of the words (Niedenthal, Mondillon, Winkielman, & Vermeullen, 2009). To interfere with motor responses, participants held a pen horizontally between their teeth their lips around it in a manner that prevented them from raising the corners of their lips into a smile or wrinkling their nose in disgust. Participants had to categorize words as being "related or unrelated to an emotion." The pen manipulation reduced accuracy for words that were related to joy and disgust but not those that were neutral or related to anger. The interference effect was systematically related to the emotional expression and meaning of the words. Similar effects have been found in other studies that have impaired motor responses during the processing of emotion related language (Foroni & Semin, 2009; Foroni, 2015), including research that manipulated muscle activity using Botox injections (Havas et al., 2010), and research that compared individuals high and low in alexithymia (Lane et al., 1996).

One limitation of the aforementioned research, however, was whether or not the interference effect was actually due to disrupted conceptual processing. Interfering with sensorimotor processes could potentially disrupt processing at multiple stages: perceptual, conceptual, or response related. To investigate this, we used a manipulation similar to the pen manipulation described above and included EMG measurements at the corrugator and zygomaticus as a check of the interference and language-based valence manipulations (Davis, Winkielman & Coulson, 2015). In addition to EMG, we recorded EEG, which has high temporal resolution and can distinguish between different processing stages in a way that behavioral measures cannot. Participants read carefully controlled, minimally different, positive and negative sentences and evaluated their valence and intensity. The EMG results replicated previous studies in the control condition of our mouth manipulation—increased zygomaticus response to positive sentences, increased corrugator response to negative sentences in the control condition—and indicated that interference condition interfered with zygomaticus but not corrugator response. This implies that only positive sentences should be affected by the manipulation if the simulation hypothesis was correct. Consistent with this, ERP data revealed that the manipulation impaired semantic processing (indexed by the N400 ERP) for positive sentences but not negative sentences. However, we found no effect on how participants evaluated valence and intensity as a function of the embodiment manipulation.

Together, these studies indicate that processing emotion concepts 1) activates brain areas associated with emotional processing, including motor areas, 2) engages facial motor responses that align with the valence of the concepts being processed, and 3) disrupting the motor responses interferes with conceptual processing. As with research investigating the embodiment of non-affective language, however, the results are not entirely consistent across the board: some studies find embodied effects during language comprehension in all cases; some find contextual moderation; some find neural but not behavioral effects. Again, this indicates that it is important to test specific hypotheses about embodiment and find boundary conditions. That is one aim in the present research. Prior to getting to the models, it is necessary to draw a stronger connection between mimicry and recognition by discussing research that specifically connects embodied processes and emotion recognition.

1.4.3 Neuropsychology and rTMS studies in emotion recognition

Some of the earliest research indicating that embodied processes are involved in emotion recognition comes from neuropsychology. Based on neuropsychological research, Damasio developed the somatic marker hypothesis (Damasio, 1994; 1996). According to this hypothesis, social knowledge is not located in a single brain module but distributed across multiple brain regions. Affective memory is stored in neural systems associated with affective, motoric and somatic experience. However, the ventromedial prefrontal cortex is needed to connect environmental stimuli with the somatic knowledge that corresponds to it. Damage to the ventromedial prefrontal cortex severs this connection and results in impaired social decisions. When environmental stimuli lose their somatic marking and their emotional significance, it impairs a broad range of social decisions (Damasio, 1994). One of these impairments is an ability to recognize emotional expressions. A study investigating patients with ventromedial prefrontal lesions (compared to patients with other prefrontal lesions) found that they were impaired on recognizing all six basic emotions from expressions (Heberlein et al., 2008).

Additional research in line with the theory that affective and emotion knowledge is represented in affective systems, and that this is critical for recognizing expressions, comes from research on individuals with amygdala damage. Adolphs, Tranel, Damasio and Damasio (1994) tested a woman with bilateral amygdala damage on her ability to recognize expressions. Relative to controls, she performed very poorly on the recognition of fear and, to a lesser extent, surprise and anger. However, she had no difficulty recognizing identity from faces. Follow up research found similar patterns when investigating multiple people with amygdala damage (see Calder, Lawrence & Young, 2001 for a review). Recognizing an emotional facial expression is partially dependent on systems outside of the visual system. This is in line with embodied theories of emotion recognition. Regarding the present research, this is relevant to mimicry since mimicry can elicit contagion Olszanowski, Wróbel & Hess, 2019) and contagion presumably activates affective neural systems, given that it is an affective experience.

More closely related to mimicry, which involves producing motor actions but also somatic feedback from those actions, is research connecting somatosensory lesions to impaired expression recognition. 108 patients with different focal brain lesions were tested on three different emotion recognition tests (Adolphs et al., 2000). Those who performed the worst on the recognition tests were those that had damage to their right somatosensory-related cortices (rSC). Also related, insular cortex, a visceral somatosensory region, is active in response to facial expressions of disgust but not fear (Phillips et al., 1997). A case study of a patient with relatively selective damage to his insular cortex revealed that he had a reduced disgust response and was selectively impaired in recognizing disgust expressions (Calder et al., 2000a). Together, these lesion studies indicate a role for embodied representations, including somatosensory regions, in the recognition of emotional expressions.

Two limitations of lesion research are that lesions are generally not entirely localized and they cannot be manipulated in humans. However, repetitive transcranial magnetic stimulation (rTMS) is a method for selectively and temporarily disrupting neural activity in humans. This affords the ability to manipulate brain activity and make causal inferences about embodied representations in the recognition of expressions. Different studies have found that rTMS to somatosensory and motor cortices impairs the recognition of expressions.

Pitcher, Garrido, Walsh, & Duchaine (2008) examined the role of the right occipital face are (rOFA), a core visual region in hierarchical models of face recognition (Haxby et al., 2000; Adolphs, 2002; also see section 1.2.4), and right somatosensory cortext (rSC) in the recognition of expressions using rTMS. rTMS was applied to rSC at two locations, a face region and a finger region as a control. They found that rTMS to the rOFA and face rSC equally impaired recognition of facial expressions but not identities. In a follow-up, they applied rTMS to rOFA, face rSC and the vertex (control), at different time points. They found that disrupting rOFA impaired recognition at early time points (60-100ms after stimulus onset) and disrupting rSC impaired recognition at later time points (100-170ms after onset). This study demonstrates three things relevant to the present research. One, embodied processes are causally implicated in emotion recognition. Two, it is not only embodied processes that matter, visual analysis plays an important role as well. And three, the visual processes are relevant to recognition relatively early, and the embodied mechanisms are relevant later. This is consistent with the hypothesis that mimicry and embodied computations might be involved in deeper conceptual processing in the recognition process.

Pitcher et al (2008), described above, found that rTMS to rSC impaired emotion recognition. Other research has found similar results. An experiment that applied rTMS to rSC, demonstrated that it impaired the ability to distinguish authentic from inauthentic smiles. They found similar results when rTMS was applied to the right inferior frontal gyrus, a sensorimotor region representing the face (Paracampo et al., 2017). Mimicry not only engages somatosensory cortices, it unquestionably engages face-related sensorimotor areas. A different rTMS study applied rTMS to right primary motor cortex (rM1), rSC, and the vertex, while also recording facial EMG to get an assessment of mimicry (Korb et al., 2015). Participants had to judge when morphed faces changed from one expression to another. The EMG results indicated that participants mimicked the expressions they viewed. rTMS applied to rSC and rM1 slowed the mimicry response, but only for female participants. Additionally, rTMS to rM1 impaired emotion recognition but also only in female participants.

1.4.4 Mimicry in the recognition of expressions

The strongest evidence in favor of the hypothesis that mimicry plays a functional role in recognizing emotional expressions comes from research showing that interfering with mimicry interferes with recognition.

One way this has been done is through the use of Botox injections and firming cosmetic facemasks. Botox induces muscle paralysis and thus impairs the ability to express or mimic an emotion. Gel facemasks prevent movement through resistance; thus, they prevent mimicry, but any muscle action will have its feedback amplified. When patients who had recently undergone Botox injections around their eyes were compared to a control group on their ability to recognize emotions expressed in the eyes (RMET: Reading the Mind in the Eyes Task; Baron-Cohen et al., 2001), those who had received Botox were less accurate than the control (Neal & Chartrand, 2011). In a follow up experiment, the same researchers applied a gel facemask around the eyes of a new group of participants. Relative to controls, these participants showed increased accuracy. These results were interpreted as demonstrating that amplified facial feedback facilitated recognition. However, a different research group used a similar mask manipulation and found the opposite result: it impaired the perceptual discrimination of expressions (Wood, Lupyan, Sherrin, & Niedenthal, 2016). They argued that the exaggerated feedback created a noisy signal, making it a less reliable source of information and making it more difficult to perceptually discriminate different facial expressions. Although one study was testing recognition and the other was testing perceptual discrimination, it is not clear why the results would go in opposite directions. What is consistent is that disrupting mimicry, or at least the sensorimotor and somatosensory feedback associated with it, influences how expressions are perceived and recognized.

Another way mimicry has been manipulated is by interfering with mimicry at the top or bottom half of the face and testing recognition of expressions whose diagnostic features are located more on the upper or lower half of the face. Expressions have distinct morphologies. Some are expressed more heavily in the upper half of the face (e.g., anger at the brows) and others more heavily on the lower half of the face (e.g., joy and smiles). This was demonstrated in an experiment that had participants categorize expressions of composite faces that were half neutral and half expressive. When the lower half was expressive, but the upper half was neutral, it impaired the recognition of anger, but it did not affect recognition of joy or disgust. Joy and disgust were recognized with the same accuracy as when the entire face was expressive. However, when the lower half was neutral and the expressions were only in the top half of the face, participants were highly inaccurate at recognizing joy and disgust. The diagnostic features of these expressions are predominantly in the lower half of the face. For anger, participants were better at recognizing top-half than bottom-half expressions (Ponari et al., 2012). Corresponding to these differences, impairing mimicry on the top half of the face impairs recognition of anger but not joy, and vice versa.

One way mimicry on the lower half of the face has been manipulated is to have participants hold a chopstick or pen horizontally between the teeth while keeping their lips in place. Different studies have used slightly different techniques. One variation requires holding the utensil very lightly between the teeth and lips and instructions not to move the lower half of the face (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Maringer, Krumhuber, Fischer, & Niedenthal, 2011; Rychlowska et al., 2014). This has been shown to disrupt the ability to discriminate between authentic and inauthentic smiles (Maringer et al., 2011; Rychlowska et al., 2014) and to slow the ability to discriminate when a smile morphs into a frown and vice versa (Niedenthal et al., 2001). The other variation involves applying pressure to the utensil to generate tonic sensorimotor noise and simultaneously impair lower face mimicry (Davis, Winkielman & Coulson, 2015, 2017; Oberman et al., 2008, Ponari et al., 2012). The noise generating manipulation has been shown to reduce accuracy when recognizing expressions whose diagnostic features are primarily located on the lower half of the face, e.g., expressions of joy and disgust but not anger or sadness (Oberman, Ramachandran & Winkielman, 2008; Ponari et al., 2012). An analogous noise-generating manipulation for the top half of the face involves tonically pulling the brows together to try and keep two stickers located there touching. This manipulation impaired recognition of anger and sadness but not happiness or disgust. These studies indicate that interfering with mimicry systematically interferes with recognition of emotional expressions.

Measures of behavior are very informative, but they are unable to distinguish between the mental processes that led to the changes in behavior. We wanted to know if interfering with mimicry led to impairments in semantic processing specifically, as this is the claim made by theories of embodied emotion recognition. To test this, we measured the face N400 ERP, which is associated with semantic processing and used a noise-generating lower face manipulation as described above as participants evaluated emotional expressions. As a minimally different control condition, participants held chopsticks loosely at the front of their lips. Participants viewed facial expressions of happiness, exuberant surprise (high-intensity expressions of joyful surprise), anger, and disgust and rated them on scale that ranged from expressing a feeling that was very good to very bad. We recorded EMG as a manipulation check and found that the interference condition (relative to the control) generated tonic muscle noise at the mouth but not the brow, as expected. It also prevented mimicry to expressions of happiness but not anger. Relative to the control manipulation, interfering with lower face mimicry activity impaired the semantic retrieval expressions of happiness and disgust but not anger (consistent with the behavioral findings of Oberman et al., 2007, and Ponari et al, 2012). Interestingly, it did not affect the N400 to expressions of exuberant surprise, expressions that had large smiles but were also highly expressive at the eyes. This could be because the expressions were so expressive at the eyes, but it could also be because the expressions were so obviously positive that any embodied activity was irrelevant. They may have simply been too easy to read. Another result worth noting was that the manipulation did not affect ratings for any of the expressions. Differences were only detectable via the more sensitive face N400 measure. While they are consistent with the hypothesis that mimicry plays a functional role in recognition, they also indicate that the effect can be subtle.

The research described in this section so far has shown that mimicry related motor activity plays a functional role in the recognition of expressions. However, the results are not entirely consistent. Gel masks can help (Neal & Chartrand, 2011) or hinder (Wood, Lupyan, Sherrin, & Niedenthal, 2016) the decoding of expressions. Other results seem somewhat inconsistent. Interfering with facial mimicry can impair behavioral measures of recognition relatively prototypical expressions (Oberman, Winkielman & Ramachandran, 2008; Ponari et al., 2012) and subtle judgments of smile authenticity (Maringer et al., 2011; Rychlowska et al., 2014). However, sometimes the behavioral effects are only apparent when expressions are subtle (Niedenthal et al., 2001) and sometimes the effects are not detectable behaviorally but are detectable with more sensitive measures and not for all the expressions that one might expect—i.e., expressions of happiness but not exuberant surprise (Davis et al., 2017).

Part of this heterogeneity may have to do with task difficulty. The experiments that found behavioral differences in the recognition of prototypical expressions used a 4- or 7- alternative forced choice recognition task (Oberman, Winkielman & Ramachandran, 2008; Ponari et al., 2012, respectively). Those that found differences only when expressions were subtle gave participants only one choice—indicate when an expression changes from one to the other (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001). We found effects the face N400 for expressions of happiness but not the more intense expressions of exuberant surprise which had large smiles but were also highly expressive in the eyes. Additionally, we found the mimicry manipulation did not influence how participants rated the expressions. Although we used a 6-point scale of valence and intensity, this is arguably an easier task than categorizing expressions. So, it is possible that interfering with mimicry only matters when the task is relatively difficult. This implies that mimicry plays a relatively minor role in recognition, and that other mechanisms, whether they be internal emotion-processing mechanisms or visual mechanisms, play a more important role. To build better models of emotion recognition, it is useful to systematically address each potential mechanism. The present research addresses mimicry, given that the above research implies that it plays a functional role.

Yet whether or not it does is questionable because there are alternative explanations for the interference research. As Rives Bogart & Matsumoto (2010) point out, the interference manipulations are somewhat awkward. They argue that many findings described above could be interpreted as demonstrating that making individuals do something distracting impairs the ability to recognize facial expressions. Although this seems like a plausible explanation at first glance, it doesn't explain why interfering with smiles interferes with the recognition of joy but not anger. Nor does it explain the findings of later research that has used carefully designed control manipulations that minimally differ from the experimental interference manipulation (e.g., Davis, Winkielman, & Coulson, 2017). Yet even the most carefully controlled studies still suffer from a potential alternative explanation based on distraction. Mimicry is an automatic behavioral response (Dimberg, Thunberg & Elmehed, 2000; Dimberg, Thunberg, & Gruendal, 2002; Korb, Grandjean, & Scherer, 2010; Sonnby-Börgstrom, 2002). Interfering with a default behavioral response may simply be distracting. Given that mimicry of anger does not entail an automatic smiling response, but mimicry of joy does, distraction could still explain the systematicity in each of the above studies.

Another challenge for the hypothesis that mimicry is involved in emotion recognition comes from research on individuals with congenital facial paralysis, Möbius Syndrome. Most studies on these participants have found that their ability to recognize expressions is intact.

However, like other research relating embodied activity to conceptual processing, the results are mixed. One case study of a woman with Möbius Syndrome found that she was completely impaired at recognizing facial expressions when examined in a naturalistic setting (Gianni et al., 1984). This supports the hypothesis, but it is just one participant and naturalistic settings are not as well controlled as laboratory experiments. Another study examined 3 individuals with Möbius Syndrome and tested recognition in the lab. When it came to prototypical expressions of six basic emotions, they performed on par with controls. However, when tested on low intensity expressions, one individual performed significantly worse than controls, one had a borderline deficit, and the other was unimpaired (Calder et al., 2002b). Again, the results are mixed, and the sample size is low. A more recent study recruited 37 participants with Möbius Syndrome and compared their performance to 37 matched controls on an emotion recognition task. The study used prototypical expressions of six basic emotions plus neutral expressions and found no difference as a function of Möbius Syndrome (Rives Bogart & Matsumoto, 2010). Based on the large sample size, they concluded that mimicry is not necessary and does not impact the recognition of expressions.

Clearly, the results described in this section do not line up cleanly. Since the recognition of expressions is a critical aspect of social cognition, it is important to try and sort out the mechanisms that matter. One thing that is clear is that the only way to circumvent the alternative explanation of distraction is to test whether there are signs that mimicry plays a functional role in recognition without interfering with it. Another thing that needs to be done is to test more specific models that investigate the way in which mimicry could facilitate recognition. That is the aim of the present research. In the remainder of this chapter, the models will be described, the importance of this research will be reiterated and then the general paradigm and predictions of the experiments in chapters 2-4 will be outlined.

1.5 The present study

A full description of the methods will appear in the individual chapters, but their gist is important for understanding the predictions of the models described next. Each experiment involves showing participants videos of emotional facial expressions depicting anger, joy, and sadness. All of them use repeated measures designs and record facial EMG from the corrugator (brow) and zygomaticus (cheek) muscles. Each experiment requires participants to categorize expressions using a 3AFC task. Experiments 1 and 2 (chapters 2 and 3) also include a passive viewing condition where participants simply watch the videos. The order of the categorization and passive viewing tasks were counterbalanced across participants. Based on the results from experiments 1 and 2, we got rid of the task manipulation in experiment 3 (chapter 4). Visual evidence of emotion is manipulated in each experiment and this manipulation is validated using facial expression recognition software. Experiment 1 manipulates evidence by contrasting normal and blurred expressions. Experiment 2 contrasts high and low intensity expressions. Experiment 3 presents only the top or bottom half of expressions at a time.

1.5.1 Models tested

1.5.1.1 Motor-matching

The motor matching model is grounded in traditional hypotheses about mimicry. Mimicry it is an automatic motor-matching response whose function is to promote affiliation and rapport in social interactions (Chartrand & Bargh, 1999). Hess and Fischer (2013, 2014) call this the matched-motor hypothesis. This hypothesis makes the prediction that mimicry should follow the activity of the muscles that are observed. If an expression is more or less expressive, mimicry should be more or less expressed. This does not make the prediction that the absolute intensity of what is observed should be matched, but that relatively more evidence should lead to relatively more mimicry. While it does not make specific claims about task, actively categorizing expressions may increase attention to the perceptual features and increase mimicry. If only part of an expression is observed, only part of an expression should be mimicked. To summarize, this is a low-level perception-action motor-matching model.

1.5.1.2 Emotional mimicry in context

The emotional mimicry in context model (Hess & Fischer, 2014) was developed in part as a response to the matched-motor hypothesis described above. Emotional mimicry is not an automatic low-level, perception-action mechanism. Unlike foot-tapping, emotional expressions have intrinsic meaning, and this influences how they are mimicked (Hess & Fischer, 2013, 2014). Not all facial reactions, even those that are congruent with an expression, are mimicry. Mimicry involves the production of a congruent display, but it also involves affiliative intent. Affiliative intent depends on social context (Hess & Fischer, 2013, 2014; Hess, Houde & Fischer, 2014). The function of mimicry is to promote affiliation, to regulate social interactions, and facilitate recognition (Hess & Fischer, 2014). Recognition is an automatic process when processing social stimuli mimicry is not necessary to do it (Hess & Fischer, 2013, 2014). However, the model also claims that mimicry may help identify subtle emotional expressions, though it does not strong claim about the mechanism that affords it. It could be through a feedback process that elicits an emotional state in the observer (Olszanowski, Wróbel & Hess, 2019). It could be through a third variable such as motivation to try and understand the observed individual (Hess & Fischer, 2013). It could also be that mimicry signals concern, and this in turn could facilitate self-disclosure on the part of the individual being observed (Yabar & Hess, 2007; Hess & Fischer, 2014).

As mentioned, mimicry requires affiliative intent. In the absence of affiliative intent, congruent and incongruent responses to expressions are emotional reactions (Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). Reactions are emotional signals. They indicate how the other individual should behave, such as by approaching or withdrawing (Hess & Fischer, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). The nature of the signal is often less specified than the emotional expression observed, and often reflects only valence (Hess & Fischer, 2013).

This model predicts that task should not matter because even in passive viewing participants implicitly evaluate the meaning of expressions (Hess & Fischer, 2013). Emotion evidence should also not matter, since facial responses function as social signals and there is no social manipulation in this research that would motivate detailed signaling as might be the case in a naturalistic setting. Since mimicry and facial reactions are signals based on the interpretation of expressions, mimicry should occur even in response to muscles that are not observed (Hess & Fischer, 2014). As previously mentioned, a key aspect of this model that distinguishes emotional mimicry from mimicry of behaviors such as foot-tapping, is that emotional expressions have inherent social meaning. Joy has social significance. It is affiliative. Since mimicry is primarily affiliative, joy is most likely to be mimicked (Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). Mimicry of sadness is also affiliative, but it implies empathy and concern. In the world outside of the laboratory, it is more socially expensive than mimicking expressions of joy (Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). This makes it somewhat less likely to be automatically mimicked. Mimicry of anger, particularly observer directed anger, has a high social cost. It can escalate fights. It is the least likely to be mimicked. Often, what appears to be mimicry of anger is actually a general negative affective reaction (Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015).

1.5.1.3 Embodied computation (amplification and pattern completion)

The embodied computation hypothesis assumes that mimicry is a contextually situated inferential mechanism grounded in sensorimotor simulation. Visual and simulation mechanisms work together. Visual mechanisms do much of the work, but simulation mechanisms provide meaning and supplement vision. It is motivated by research that suggests mimicry may be more important when expressions are more difficult to recognize. One way the computation mechanism may function is by amplifying the mimicry signal to increase endogenous context and resolve environmental ambiguity (e.g, Adolphs, 2006). A second way is by pattern completion (e.g., Barsalou, 2013). The amplification function predicts that mimicry should increase when emotion evidence is low, and the task requires recognizing emotional expressions. It is tested in experiments 1 and 2. Data consistent with this hypothesis would provide the strongest evidence that mimicry is an active computational mechanism. Pattern completion is tested in experiment 3 in which only half a face is shown at a time. The embodied computation model predicts that mimicry will occur at muscle sites that are not observed. Although it makes the same prediction as the emotional mimicry in context model in this experiment, it differs from the predictions of the motor-matching hypothesis. It should be noted that the social-regulation and the pattern-completion function are not mutually exclusive. Data that supports this hypothesis would be consistent with the hypothesis that mimicry plays a functional role in recognition, but not rule out that the function is social signaling.

1.5.2 Importance of the present research

This research is important for multiple reasons. First, it addresses an important topic in social cognition, emotion recognition. Emotion recognition plays a fundamental role in social interaction. Second, it addresses mechanisms involved in the recognition of emotions from facial expressions in particular. How facial expressions are recognized is important because facial expressions have a wide range of social influence beyond those related to emotion per se. These influences range from assessments of attractiveness (Mueser, Grau, Sussman, & Rosen, 1984) to the perceived authenticity of witnesses in courts of law (Kaufmann et al., 2003). Third, this research ties into a broader debate in cognitive science, the role embodiment in the representation and derivation of meaning. This research has the potential to inform the broader debate because it addresses particular ways in which embodied processing could influence cognition. It assumes that multiple mechanisms with complimentary functions are involved in emotion recognition (analogous to the LASS model of language comprehension, Barsalou et al., 2008), and tests potential ways in which the mechanisms could relate to each other. The embodied computation hypothesis proposes an inferential mechanism that supplements visual mechanisms and could be used to solve high level problems and resolve ambiguities. Social interactions are replete with ambiguity. A creative simulation-based mechanism that could actively generate information to resolve problems in contexts where information is sparse, has been suggested but not yet found (Adolphs, 2006). Like the embodied computation hypothesis, the embodied pattern-completion hypothesis addresses a way that modal mechanisms might complement each other. In this case, it is a specific form of problem solving—pattern completion. Evidence for either of these hypotheses has the potential to inform embodied research in domains other than emotion recognition. Last but not least, this research is important because it tests mimicry as a mechanism for recognition. From a theoretical standpoint, mimicry is quite controversial in this regard. There are relatively strong arguments that it plays a causal role (e.g., Niedenthal 2007) and relatively strong arguments that it is epiphenomenal (e.g., Rives Bogart & Matsumoto, 201). Part of the reason that it is controversial is because results that have found positive evidence for it, interference-based research, can be explained via the alternative explanation that the effects are driven by distraction.

The present research uses two methods to evaluate whether mimicry plays a functional role in recognizing expressions without using an interference manipulation. One method involves examining the profile of mimicry. This method tests the models described in sections 1.5.1.1-1.5.1.4: motor matching, social regulation, embodied computation, and embodied pattern completion. The other method involves testing whether mimicry mediates between the emotion evidence observed in the stimuli and how they are categorized. It is possible that mimicry plays a functional role but not in ways outlined by the embodied computation or pattern matching hypotheses. For instance, mimicry could initiate contagion, and this could facilitate recognition. It is also possible that facial reactions, even those inconsistent with mimicry, could facilitate emotion recognition. If recognition is grounded in embodied experience, and not necessarily simulation per se, then facial reactions could facilitate memory retrieval and recognition. The mediation results can speak to these possibilities. It can also provide an estimate of the functional relevance of embodied and visual mechanisms in the recognition of expressions.

1.5.2 Basic paradigms used in this dissertation and their logic

In each of our experiments we assessed mimicry using facial EMG at two muscle sites, the corrugator and the zygomaticus. These are the two muscle sites most frequently recorded from in the mimicry literature. The corrugator pulls the brows together and is active in the expressions of anger and sadness. It relaxes below baseline during the expression of joy. The zygomaticus pulls back the corners of the lips back. It is the dominant muscle for producing a simile. It is active in the expression of joy and is reduced relative to joy in expressions of sadness and anger (Hess, 2016; van Boxtel, 2010).

Experiments 1 and 2 used an identical paradigm but different stimuli. Both experiments were designed around testing the embodied computation hypothesis: whether a decrease in emotion evidence leads to an increased mimicry response when the task requires recognition. In order to evaluate this, we needed a minimum of three factors in our design—emotion category, emotion evidence, and task. Experiment 3 tested the embodied pattern completion hypothesis. It used the same paradigm as experiments 1 and 2 with the exception that it did not include task. Experiments 1 & 2 used a 3(emotion) x 2(emotion evidence) x 2(task) repeated measures design. Experiment 3 used a 3(emotion) x 2(emotion evidence) repeated measures design. The design choices for each factor are described below.

Although obvious, in order to test recognition, we needed to contrast emotions. We selected expressions of joy, sadness, and anger. We recognize that this is unbalanced in terms of valence. Unfortunately, there is only one basic emotion that is positive. We wanted to stick with basic emotions because we wanted to make sure our participants understood the categories and were familiar with their prototypical expression. We included two negative expressions to make the task somewhat more challenging. Mimicry of anger and sadness both increase corrugator response and reduce zygomaticus response, so they cannot be distinguished in terms of mimicry in our design. However, they can elicit differentiating responses that are consistent with the social regulation but inconsistent with the other models. The emotional mimicry in context model predicts that participants are less likely to mimic anger than sadness; participants may even display an opposite response to anger (i.e., a positive response to anger) that is consistent with an appeasement or backing down reaction (Seibt, Mühlberger, Likowski, & Weyers, 2015; Sonnby-Borgstrom, 2003).

Since the motivating hypotheses of this research address the relationship between visually accessible emotion evidence and mimicry, we needed to manipulate visual evidence. In experiment one, we contrasted blurry videos and normal videos. From an ecological perspective, this is akin to someone who needs prescriptive lenses and is or is not wearing them. In experiment two, we manipulated emotional intensity. Low intensity expressions were close to neutral and high intensity expressions were close to a full, prototypical expression. Outside the lab, subtle expressions are more common than full blown prototypical ones. As mentioned in the section describing the models, the motor-matching hypothesis predicts mimicry will match the evidence, social-regulation hypothesis predicts evidence will make no difference, and the embodied computation hypothesis predicts that reduced evidence will increase mimicry as a function of task relevance. In experiment three, we manipulated evidence by presenting only the top or bottom half of a face at a time. It is not uncommon for people to wear clothing that conceals part of their face, such as scarves in cold weather or eye shields in industrial contexts. The motor matching hypothesis predicts mimicry of what is observed. The embodied pattern completion and emotional mimicry in context models both predict mimicry will occur across the face regardless of which half is presented.

In order to test the embodied computation hypothesis, which hypothesizes that the cognitive aspects of mimicry are task dependent, we needed to contrast task. We needed a measure of mimicry as a function of recognition and we needed a baseline for comparison. Since diverting attention away from the emotional aspects of a face reduces mimicry (Cannon, Hayes, & Tipper, 2009; van Dillen, Harris, van Dijk & Rotteveel, 2015), we opted to contrast our emotion recognition task with a passive viewing condition. Passive viewing has been used to assess mimicry in numerous experiments, and we felt it was the best assessment of baseline mimicry (e.g., Dimberg 1982; Dimberg & Thunberg, 1998; Dimberg, Thunberg & Elmehed, 2000; Dimberg, Thunberg & Gruendal, 2002). As mentioned, the embodied computation hypothesis predicts an interaction with task and emotion evidence, with more mimicry to low evidence stimuli when categorization is required. The motor-matching hypothesis predicts that increased attention during the categorization task may amplify mimicry overall. The emotional mimicry in context model predicts that task should not matter, given that observers automatically infer emotions and facial reactions are a response to this inference.

In each of the experiments we included manipulation checks. One manipulation check was accuracy and response time. If participants are paying attention, they should be fairly accurate at recognizing expressions high in emotion evidence and accuracy should be somewhat reduced in the low evidence condition. Higher accuracy should correspond with relatively faster response times, indicating that there is not a speed-accuracy trade off. Although we do not have a behavioral measure of attention in the passive viewing, mimicry during passive viewing would suggest the participants are attending to the stimuli.

We also validated that out emotion evidence manipulations were successful. To do this we used the Computer Expression Recognition Toolkit (CERT; Littlewort et al., 2011). CERT provides fast, reliable, and normalized summary estimates for the evidence and intensity of basic emotional expressions and individual action units (AUs) associated with different muscles. AUs roughly correspond to individual muscle sites. AUs are relevant to experiment 3 where overall emotion evidence could not be evaluated since only half of the face was shown. CERT software has been used in numerous peer-reviewed publications (for a sample, see Davis, Winkielman &

Coulson, 2017; Gordon, Pierce, Bartlett, & Tanaka, 2014; Peterson et al., 2016). It scored well above baseline measures of success at the Facial Expression Recognition and Analysis (FERA) challenge at conference proceedings (Littlewort, Whitehill, Wu, Butko, Ruvolo, Movellan & Barllett, 2011), and has been shown to outperform untrained humans in the decoding of deceptive expressions (Bartlett, Littlewort, Frank, & Lee, 2014).

This concludes the introduction. Additional methodological details will be provided in each of the experimental chapters.

Chapter 2: Experiment 1 - Blurred Expressions

2.1 Present research

As individuals who wear corrective lenses are well aware, the world can be blurry. Blurry objects are visually ambiguous and often disambiguated via contextual cues (Oliva, Torralba, 2007). According to embodied computation, one way to resolve environmental ambiguity is to amplify mimicry and use that as a source of information. To test this, we measured mimicry as participants watched videos of joy, sadness, and anger expressions that differed in visibility: blurry or not blurry. To test the model's hypothesis that engaging in embodied computation occurs when needed for recognition, we contrasted an emotion categorization task with a passive viewing task. The experiment used a repeated measures design 3 (emotion) x 2 (visibility) x 2 (task).

The embodied computation model predicts that mimicry will be amplified when emotion evidence is low (blurry), and categorization is required. The motor-matching hypothesis predicts that should be more mimicry when there is more emotion evidence (normal videos), since mimicry follows perception. Also consistent with this hypothesis is a main effect of task, as attention may increase mimicry. The emotional mimicry in context model predicts that task and visibility should not matter so long as the expressions are discriminable. In the absence of a social manipulation, facial expressions only imply social context. For instance, gender, race, and eye gaze can imply affiliation (Hess & Fischer, 2014). Additionally, different emotions signal different affiliative intents (Hess & Fischer, 2013, 2014). Since mimicry is primarily a mechanism of affiliation, joy is most likely to be mimicked (affiliative with low social cost), followed by sadness (affiliative but more social cost), and anger will likely not be mimicked but may elicit an indistinguishable negative affect response or the absence of a response (Seibt, Mühlberger, Likowski, & Weyers, 2015).

In addition to testing the profile of mimicry, we are testing its functionality via mediation analysis. If mimicry mediates between the evidence of emotion in the stimuli and the way they are categorized, it would be consistent with the hypothesis that mimicry is functional.

2.2 Methods and procedure:

2.2.1 Participants:

Thirty-seven undergraduates (25 females, mean age = 20.5 years old) from the University of California, San Diego (UCSD) were recruited through the UCSD undergraduate subject pool. All participants provided written informed consent prior to the experiment, were debriefed after the experiment, and received course credit for their participation.

2.2.2 Apparatus

The experiment was presented using E-Prime 2.0 software (Psychology Software Tools, Pennsylvania, USA) on a 17 inch Dell monitor. EMG signals were recorded at 2000Hz using BioPac's BioNomadix two-channel wireless amplifier, their MP 150 acquisition platform, and their AcqKnowledge 4.11 recording software. Participants were affixed with Biopac Systems Inc.'s (California, USA) EL504 disposable silver/silver chloride electrodes after skin preparation using rubbing alcohol and Biopac Nuprep gel.

2.2.3 Materials:

Forty-eight videos were used as stimuli. Twenty-four of the videos came from the Amsterdam Dynamic Facial Expression Set (ADFES: van der Schalk, Hawk, Fischer, & Doosje, 2011). These videos were of 8 models (4 female) from the ADFES video database. For each model there was a separate video corresponding to the expressions of joy, sadness, and anger.

Each model was trained on how to display prototypical expressions of basic emotions by certified FACS coders (see van der Schalk et al, 2011 for additional details and behavioral validation). In each of our stimuli, the model remained neutral for one second and then displayed the intended emotion for the remainder of the 6s video. The remaining 24 stimuli were the same videos but with a blur filter applied in Final Cut Pro (Apple Inc). (See Figure 2.1 for a depiction of the stimuli).

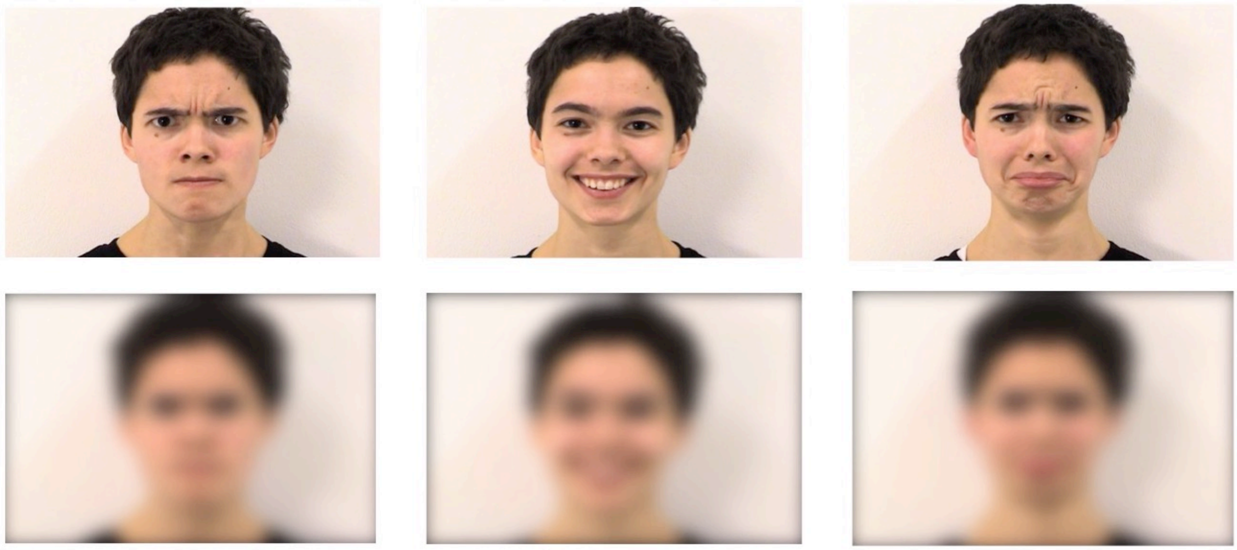

Figure 2.1 Stimuli. Examples of anger (left), joy (center), and sadness (right), with normal visibility on the top row and their blurred counterpart on the bottom row. The videos were 6 seconds long, with the first second corresponding to a neutral expressions and the remaining 5 seconds an emotional display. Images are from the final frame of the videos.

2.2.3.1 Stimulus evaluation using CERT:

We evaluated our stimuli using the Computer Expression Recognition Toolbox software, (Littlewort, et al., 2011.) Although CERT has not been tested on blurred faces to our knowledge, it has been tested under different illumination conditions and texture maps and shown to be on par with expert FACS coders so long as the illumination is uniform (Stratou, Ghosh, Debevec & Morency, 2011). Given that our blurs were not drastic, did not affect illumination, and were uniform in texture across the images, we felt that CERT estimates of the blurry videos would be informational and appropriate.

2.2.3.2 Stimulus evaluation CERT analysis and results:

For each video, we measured CERT's mean estimate of evidence for joy, sadness, and anger during the time period that the emotions were expressed (1000-6000ms). To make it easier to interpret the estimates as they related to our stimulus set, and to center our EMG data for linear mixed effect modeling, we normalized the estimates by z-scoring them. We then modeled each type of evidence estimate using the lmer package in R (Bates, Maechler, Bolker, & Walker, 2015) in the following manner: evidence ~ emotion * visibility + (visibility | video). The fixed effect of emotion had 3 levels: joy, sadness, and anger. The fixed effect of visibility had two: normal, blurry. Since the blurry videos were simply the normal videos with a blur filter, and thus correlated pairs of videos, we included a random intercept of video, which indexed the video regardless of the visibility condition, and visibility as a correlated random slope. We were interested in the difference between the means of each condition, so we assessed this by submitting the lmer models to the anova() function of lmer test (Kuznetsova, Brockhoff, & Christensen, 2017). This function is designed to output ANOVA tables for lmer models. The ANOVA was Type III and denominator degrees of freedom were estimated using Satterwaite's method.

For evidence of joy and sadness, there were main effects of emotion and visibility that were qualified by significant emotion by visibility interactions. For anger, there was a main effect of emotion qualified by an emotion by visibility interaction. Interactions were followed up with contrast tests using lmerTest (Kuznetsova, Brockhoff, & Christensen, 2017). In each case, there was significantly more overall emotion evidence for a given emotion (e.g., more joy evidence to expressions of joy than expressions of sadness or anger), and more evidence in the normal than in the blurry condition for a that emotion (e.g., there was significantly more joy evidence in the normal joy than the blurry joy videos). This confirmed that our manipulation was overall effective. See Table 2.1 for data analysis and Figure 2.2. for means.

Table 2.1 Stimulus evaluation analysis via CERT estimates

	F	*p*
CERT Joy evidence estimates		
Emotion	$F(2, 15) = 109$	$p < 0.001$ ***
Visibility	$F(1, 9) = 8.9$	$p = 0.012$ *
Emotion x Visibility	$F(2, 39) = 39$	$p < 0.001$ ***
CERT Anger evidence estimates		
Emotion	$F(2, 22) = 73$	$p < 0.001$ ***
Visibility	$F(1,14) = 2.3$	$p = 0.15$
Emotion x Visibility	$F(2, 30) = 20.4$	$p < 0.001$ ***
CERT Sadness evidence estimates		
Emotion	$F(2, 13) = 57.6$	$p < 0.001$ ***
Visibility	$F(1, 8) = 13.4$	$p < 0.001$ ***
Emotion x Visibility	$F(2, 21) = 21.9$	$p < 0.001$ ***

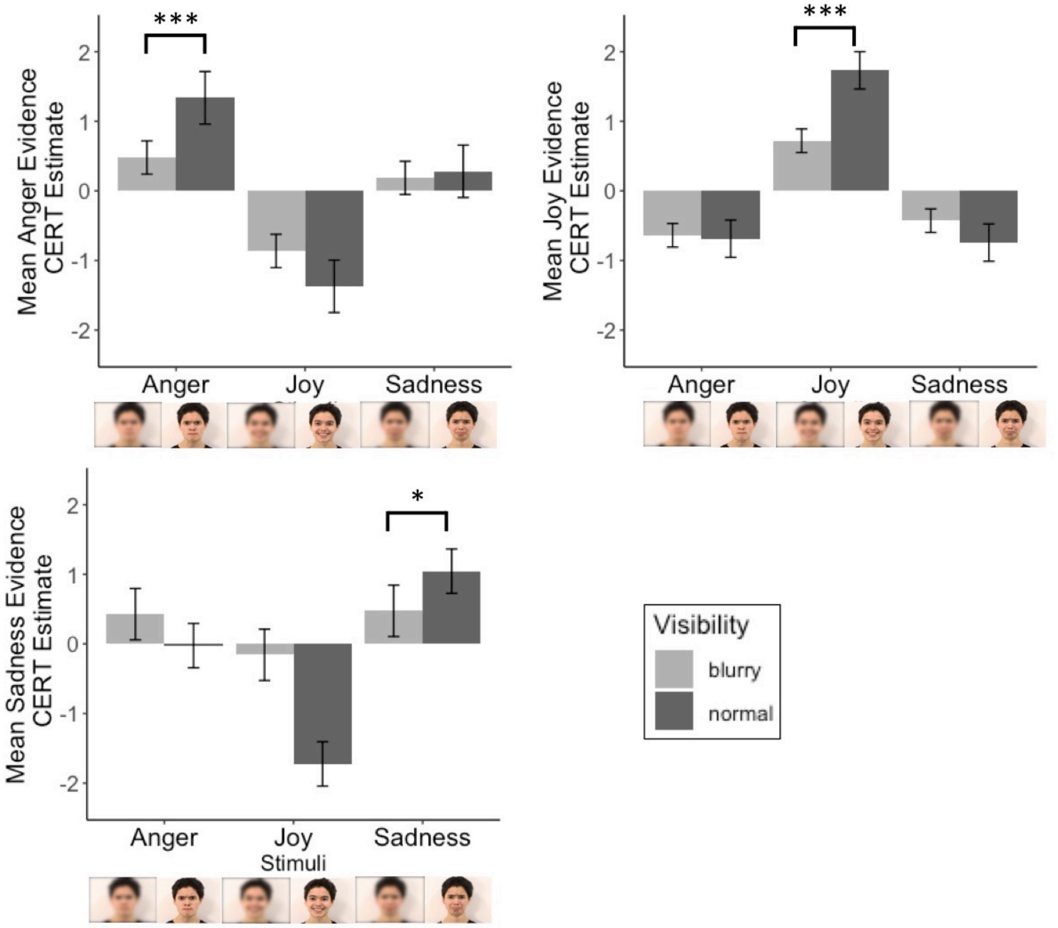

Figure 2.2 Stimulus evaluation. Mean z-scored CERT estimates of joy, anger, and sadness evidence in the stimuli. Error bars indicate 95% confidence intervals. Since there are numerous possible comparisons, the only comparisons marked for significance in each type of emotion evidence are between the normal and blurry levels of the corresponding emotion (e.g, normal and blurry joy stimuli for joy evidence). *** $p < 0.001$, ** $p < 0.01$.

2.2.4 EMG data collection:

For the collection of facial EMG, a wireless transmitter was secured to the participant's left shoulder. Zygomaticus major and Corrugator supercilli muscle sites on the left side of the participant's face were prepped and affixed with bipolar derivations of electrodes according to facial EMG guidelines (Fridlund & Cacioppo, 1986). The left mastoid was used as a reference. Conductivity was tested by having participants move parts of their face (without mention of emotions or emotional expressions) as the experimenter visually inspected the EMG signals in real-time. Participants could not see the EMG signals and were not informed of what the electrodes were recording. When facial actions induced appropriate, clear signals, the experiment began.

2.2.5 Procedure:

After participants were affixed with facial EMG, they read instructions for the experiment while the experimenter was in the room. The experimenter answered any questions they had regarding the task they were to perform but nothing else about the experiment. These were the instructions that appeared at the beginning of the experiment:

> "Welcome to the experiment! In this study you will be asked to observe video clips of some students who are known to be helpful around campus. Your job is to watch the videos and act naturally. It is important that you don't wiggle around too much or touch your face while we are collecting data. (Press the SPACEBAR to continue). Each trial starts with a button press. We will be collecting data from the moment you press the button until the next time a screen appears asking you to press another button. If you need to take a break and stretch or anything, do that before starting the trial. Waiting until you are relaxed and ready to attend to the video will provide us with your best data. (Press SPACEBAR to continue) There will be two blocks of videos. Each block will have slightly different instructions. We will tell you those at the beginning of each block. Thank you. (Press SPACEBAR to begin experiment)"

The experiment consisted of 2 blocks of 24 trials each. Each block consisted of a different task—passively viewing the videos or categorizing the expressions of the videos using a 3AFC button press (anger, sadness, or joy). Task order was counterbalanced across participants. At the onset of the passive viewing block, participants were presented with the following instructions: "WATCH VIDEOS BLOCK: In this block you will be watching videos of the students. Press B when you are ready to begin the block." At the onset of the categorization block, the instructions were as follows: "CHOOSE FEELINGS BLOCK: In this block of trials you will be watching videos of students. After each video, you will be asked to choose whether the student was feeling angry, happy, or sad. Press B to begin the block." The stimuli were pseudo randomly assigned to each block and counterbalanced on emotion, visibility and sex of the actors. Stimuli were presented in a random order within each block. Items did not repeat within a participant.

The passive viewing and categorization trials were designed to be as similar as possible. The only difference between passive viewing and categorization blocks was whether or not participants categorized the videos. See Figure 2.3 for a schematic representation of a categorization trial.

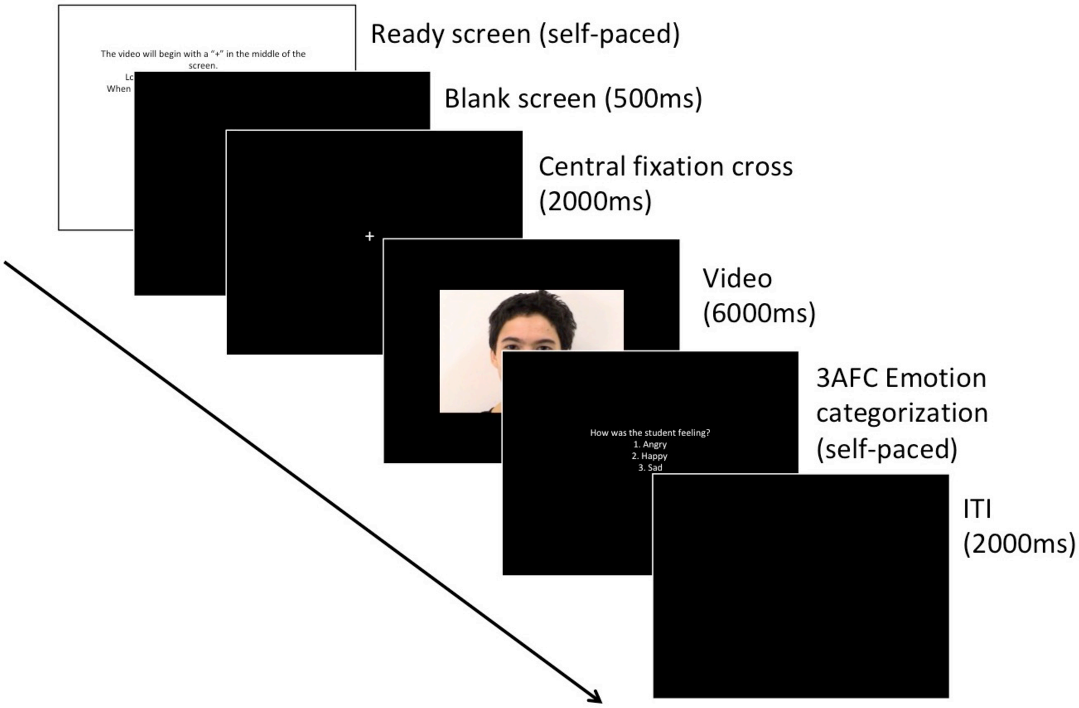

Figure 2.3 Schematic of a categorization trial. Passive viewing trials were identical except that they did not include the 3AFC emotion categorization task.

2.2.6 Data preparation and cleaning:

After EMG data collection, the signals were processed offline using MindWare EMG software package 2.52 (MindWare Technologies Ltd. Ohio, USA). EMG signals were band pass filtered between 30-500Hz with a 60Hz notch filter, binned into 500ms intervals, rectified, integrated, and the mean area under the curve was output for further processing. R software was used to clean, normalize, and analyze the signals.

For each trial, there were 16 data points: 4 baseline (2s during fixation cross), 2 neutral expression (1sec), 10 experimental data points during which the expression was displayed and maintained by the actor (5 secs). These data were z-scored within participants and muscle sites to account for individual differences between participants, muscle sites and recording sessions. Data were cleaned by removing data points above and below 3 standard deviations of the mean of each muscle. This procedure resulted in the removal of 1.4% of the EMG data. The remaining data were renormalized and the mean baseline activity was subtracted from each data point. This procedure is common in the literature (e.g., Carr, Winkielman & Oveis, 2014; Neufeld, Ioannou, Korb, Schilbach, & Chakrabarti, 2016). For data analysis we subtracted the baseline from each trial and then took the mean of the time points that corresponded to the display of the expression. We used the mean for two reasons. We had no predictions about time and because the models we were using to test our hypotheses were already quite complex: 3 way interaction of fixed effects plus maximal random effects.

Data was further cleaned based on behavioral criteria. We removed trials with excessively slow (longer than 5500ms) responses (median response time prior to removal was 1577ms). This resulted in the removal of 2.8% of the categorization trials. In addition, trials that were inaccurately categorized were removed from response time and EMG analysis.

2.2.6.1 EMG dependent variable -- the emotion index variable

We analyzed our data using an emotion index variable. This variable was created by subtracting the mean z-scored corrugator response from the mean z-scored zygomaticus response for each trial. As such positive values are consistent with the mimicry of joy (a positive expression) and negative values are consistent with the mimicry of sadness and anger (negative expressions). This is not the traditional measure used in the field. Traditionally, the muscles are analyzed separately. However, the pattern of activity is the same as in traditional analyses. Experiments that measure activity from zygomaticus and corrugator, index joy by an increase in zygomaticus and a decrease in corrugator response, while sadness and anger are indexed by just the opposite pattern, a decrease in zygomaticus and an increase in corrugator response (for reviews of traditional EMG analysis methods see Hess, 2016; van Boxtel 2010). From this standpoint, the two methods are not different. However, mimicry is based not on single muscles but by the joint activity of multiple muscles across the face. Likewise, single muscle analysis is not always a reliable measure (see Hess et al., 2017) and this is the direction prominent researchers in the field are going (e.g., Hess et al., 2017; Hess & Blairy, 2001; Olszanowski, Wróbel & Hess, 2019).

2.2.7 Data analysis:

All analysis was performed in R. Our emotion index, accuracy, and reaction time data were modeled with linear mixed effect regressions using the lmer function in the lme4 package (Bates et al., 2015). For analysis purposes, the lmer models were submitted to the anova function in the lmerTest package (Kuznetsova et al., 2017). We used lmer modeling because the random effects structures afford a way to account for individual differences and because this modeling technique is more sensitive than traditional statistical analyses used in the field of social cognition. The anova function (Kuznetsova et al., 2017) is designed to output a traditional ANOVA table for lmer objects. We opted to analyze our data this way because we were interested in testing hypotheses for significant differences between our fixed effects (as in a traditional ANOVA analyses), and this does just that. In addition ANOVA output is much easier to interpret than regression estimates in a complex interaction model with factors that have multiple levels.

Each of our lmer models included the maximal random effects structures for which the models would converge (Barr, Levy, Scheepers, and Tily, 2014) with bobyqa as the optimizer and maxfun set to 100,000 iterations. Specific models are described in the results section. The anova analysis used Type III sum of squares and denominator degrees of freedom were estimated using Satterwaite's method. Least-squares means, 95% confidence intervals, and post hoc pairwise comparisons were assessed using ls_means() in the lmerTest package (Kuznetsova et al., 2017).

For the mediation analyses, we tested whether participants' facial responses (i.e., emotion index) mediated between the emotion evidence in the stimuli and how participants categorized those stimuli. Prior to analysis, we made sure that the data were appropriate for mediation analyses (Baron & Kenny, 1986; Shrout & Bolger, 2002). Mediation was performed using mediate() in R's mediation package (Tingley, Yamamato, Hirose, Keele, & Imai, 2014) with 10,000 simulations using quasi-Bayesian approximations. The regressions used in the mediation analysis were modeled in lmer (Bates et al., 2015) and included subject as a random intercept. We ran separate mediation analyses for each type of categorical response (joy, sadness, anger). Since we were interested in how motor activity influenced recognition (i.e., categorization) rather than accuracy, we included all of the trials. Categorical response was coded in a binary format (e.g., joy or not joy for the mediation analysis of joy responses). As in previous analyses, the CERT emotion estimates and the EMG emotion indices were z-scored means. The Reported *p*-values are for the average causal mediation effect (ACME); quasi-Bayesian confidence levels were set to 0.95.

2.3 Results:

2.3.1 Accuracy and response time results:

Accuracy and response times were each modeled on a per trial basis: DV ~ emotion*visibility + (1 | subject) + (visibility | video). As a reminder, this data is only for the categorization task since participants simply passively viewed the videos in the other task condition. For accuracy there was a main effect of emotion, $F(2, 46)= 6.3$, $p = 0.004$ and a main effect of visibility, $F(1, 15)= 21.4$, $p < 0.001$ that were qualified by an interaction, $F(2, 53)= 6.9$, $p = 0.002$. Participants were highly accurate, above .9 for all normal visibility emotions and blurry joy videos, but were significantly less accurate at categorizing blurry anger and sadness videos (See Figure 2.4 for means). For response times, there were no significant differences. (See Figure 2.4 for mean accuracy and response times).

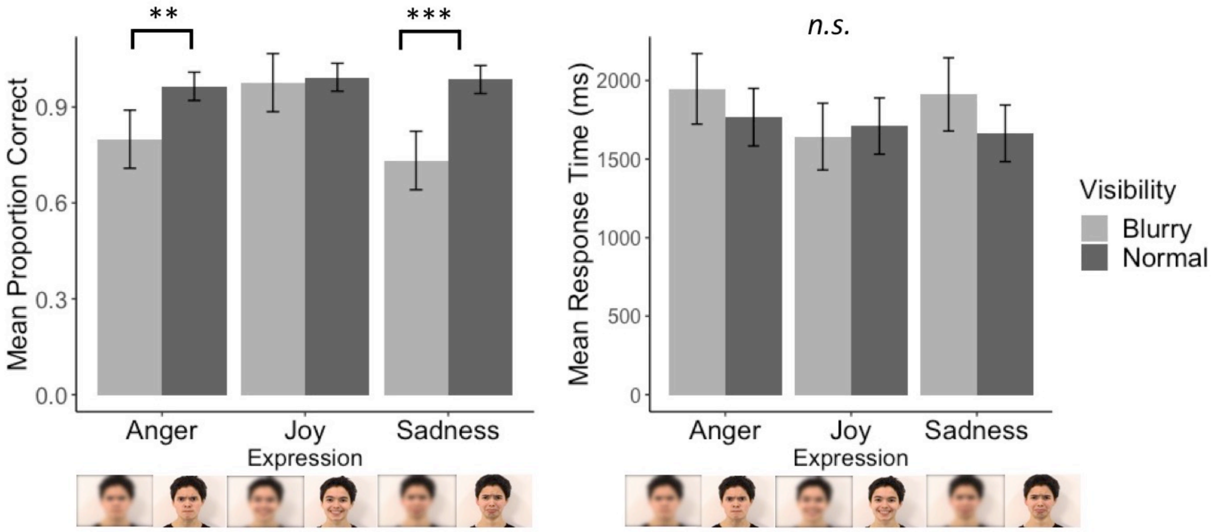

Figure 2.4 Behavioral Results. Mean proportion correct (left) and mean response times in ms (right) for the categorization task. Error bars reflect 95% confidence intervals. Response time data only includes trials that were correctly categorized. Only significant between visibility levels within an emotion are marked for significance: *** $p < 0.001$, ** $p < 0.01$.

2.3.2 EMG results:

For EMG analysis, the following model was used: emotion index ~ emotion*visibility*task + (emotion + visibility + task | subject) + (visibility | video). As a reminder, emotion index is a contrast variable (mean z-scored zygomaticus activity – mean x-scored corrugator activity), positive values are consistent with an expression of joy; negative values are consistent with expressions of sadness and anger. Interaction terms were not included as random slopes because the model would not converge. These data included all passive viewing trials and accurate categorization trials.

There was a significant main effect of emotion $F(2, 38) = 7.6$ $p = 0.002$, EMG responses to joy videos differed from sad and anger videos but responses to sad and anger videos did not differ. The direction of results was consistent with mimicry (See Figure 2.5 for means). There was also a main effect of visibility, $F(1, 72) = 12$, $p < 0.001$. The emotion index was positive for normal videos (mean = 0.05, se = 0.05) and negative for blurry videos (mean = - 0.16, se = 0.06). This indicates that there was more positive affect expressed in response to the normal than the blurry videos. This is likely due to perceptual fluency—greater perceptual fluency induces relatively more positive affect (e.g., Winkielman, Schwarz, Fazendeiro, & Reber, 2003)—or perhaps the blurry videos were boring to passively view and recognizing emotions in them was overall more effortful (e.g., Hess, Philippot, & Blairy, 1998). Since it did not interact with emotion, it is not relevant to our hypotheses and won't be discussed further.

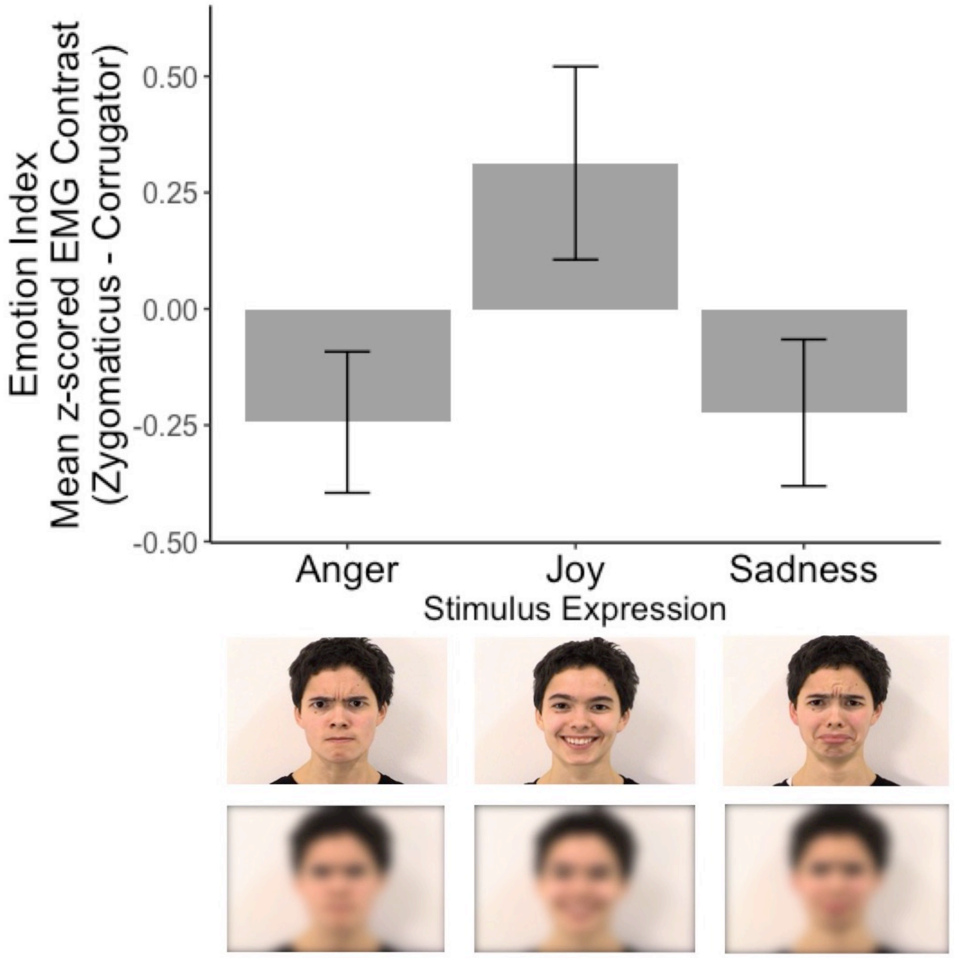

Figure 2.5 EMG results: a main effect of emotion. Emotion index data are consistent with a pattern of mimicry. Positive values on the y-axis index the expression of positive affect (more zygomaticus than corrugator activity) and negative values index displays of negative affect (more corrugator than zygomaticus activity). Error bars indicate 95% confidence intervals.

2.3.2 Mediation results:

We tested whether participants' facial responses (mean z-scored emotion index values) mediated between the visual evidence of an emotion (mean z-scored CERT emotion evidence estimates) and how they categorized that emotion. We ran one analysis for each type of emotion. We found that participant's facial responses significantly partially mediated between evidence of joy and the categorization of joy, and between the evidence of anger and the categorization of anger but there was no significant finding for sadness. (See Table 2.2 for statistical analysis and Figure 2.6 for regressions of significant results).

Table 2.2 Mediation analysis results. ACME = average causal mediation estimate (the indirect effect). Emotion refers to the analysis that assessed whether participants' EMG response mediated between CERT evidence of that emotion in the stimuli and whether participants categorized those stimuli as expressing that emotion. Note that although the results for anger and joy are statistically significant, the amount of mediation (ACME) is quite small.

Emotion	ACME Estimate	Lower 95% CI	Upper 95% CI	p-value
Anger	0.009	0.003	0.02	0.006 **
Joy	0.007	0.002	0.01	0.003 **
Sadness	0.001	-0.004	0.01	0.58

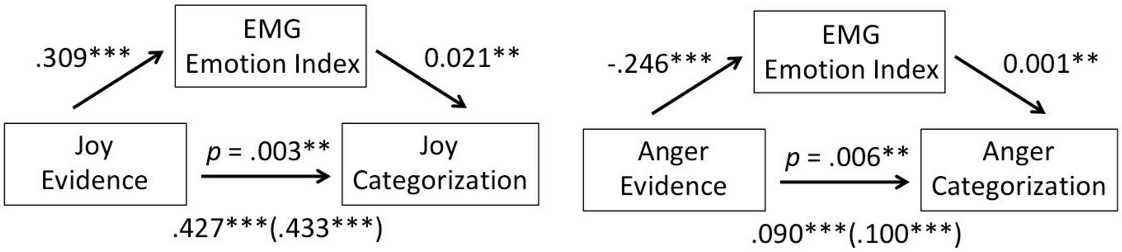

Figure 2.6 Mediation analysis regressions. Data are for the significant mediation analyses. The *p*-value indicates the *p*-value for the ACME test of indirect effects. All other values are regression estimates. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

2.4 Discussion

This experiment was designed around the hypothesis the mimicry plays a functional role in recognition. To test this, we tested the profile of motor responses and whether they mediated between visual emotion evidence and how expressions were categorized. The discussion will begin with the behavioral data, followed by the EMG data (mimicry profile), and then the mediation analyses.

The behavioral data served two purposes. One, to examine the functional role of mimicry in recognition, we needed to measure recognition. The categorization task provided us with that data. Two, the behavioral data served as a manipulation check. If participants were highly inaccurate, or if there was a speed-accuracy trade-off, it would suggest that participants were not attending to the recognition task. We did not find that. Instead we found that participants were highly accurate, particularly when it came to expressions of joy. Although the CERT emotion evidence estimates indicated there was a significant difference in the amount of visual joy evidence between the blurry and non-blurry videos, this did not matter. It is worth noting that the difference in the joy evidence means for normal and blurry joy videos was greater than the difference in the sadness evidence for sadness videos, and anger evidence in anger videos, although each difference was significant. Participants are simply good at recognizing joy, even when it is low intensity (Hess, Blairy, & Kleck, 1997). The recognition for joy advantage has been found elsewhere in the literature, even when not specifically testing for that (see Oberman, Winkielman, & Ramachandran, 2008; Adolphs, Tranel, Damasio, & Damasio, 1994; Adolphs et al., 2000). While these data only account for half of the experimental trials, we assume that participants attended to the videos in the passive viewing condition as well. This is further supported by the EMG data.

We found that participant's facial responses to the videos were consistent with patterns of mimicry at the level of the emotions that were expressed. There was no difference as a function of task or visibility. This result is inconsistent with the motor-matching model, which predicted that mimicry would follow the profile of the expressions. It is also inconsistent with the amplification function of the embodied computation model, which predicted an increase in mimicry when recognition was required, and the emotion evidence was low. Instead, there data are most consistent with the emotional mimicry in context model (Hess & Fischer, 2014).

According to the emotional mimicry in context model, mimicry is based on the interpretation of an expression in context (Hess & Fischer, 2013; 2014). We did not manipulate context, however, the instructions at the beginning of the experiment state that the videos are of students known to be helpful around campus. According to this model, emotion recognition is automatic (Hess & Fischer, 2013). A recognition task is not needed. The lack of a difference between passive viewing and emotion categorization is consistent with this result. Another important prediction of this model is that individuals mimic what they know, not what they see (Hess, Houde, & Fischer, 2014). This is consistent with the lack of a difference as a function of the visibility manipulation.

Our mediation analyses revealed that participants' facial responses significantly mediated between the visual evidence of joy and anger and the categorization of joy and anger, respectively. There was no mediation between visual evidence of sadness and the categorization of sadness. This difference between emotions warrants further exploration. These results are consistent with the hypothesis that mimicry has a functional role in emotion recognition, at least sometimes. It rules out the hypothesis that the facilitative effects of mimicry on recognition are entirely due to the way mimicry affects social interaction dynamics, such as by getting an interlocuter to feel more comfortable and disclose more personal information (Hess & Fischer, 2014; Yabar & Hess, 2007). While mimicry is likely to facilitate recognition that way, that can't explain the current results. The mediation was a function of muscle activity. This effect could be caused by accessing embodied representations (e.g., Niedenthal, 2007), sensorimotor simulation (e.g., Wood, Rychlowska, Korb, & Niedenthal, 2016), or contagion (e.g, Olszanowski, Wróbel &

Hess, 2019). It is worth noting that the mediation effects were small, and the visual evidence was a greater predictor of how participants categorized the expressions than was the mimicry. This is consistent with research indicating that interfering with mimicry has a small effect on recognition (e.g., Davis, Winkielman, & Coulson, 2017).

To summarize, we did not find evidence that an embodied computation mechanism facilitates the recognition of expressions low in visual evidence by amplifying simulation detectable in mimicry, at least not as a function of task. If participants were implicitly categorizing the expressions during the passive viewing task, then finding no difference in mimicry whether the emotion evidence was reduced (blurry) or not indicates that either there was additional mimicry to the low emotion evidence stimuli or reduced mimicry to the high evidence stimuli—they were matching at a categorical level. This is possible but not what we predicted. Yet we did find that mimicry partially mediated between visual emotion evidence and the categorization of expressions, which does support a computational role for mimicry. The effect was small and inconsistent across emotions, but mimicry did influence categorization above and beyond the visual evidence in the stimuli.

While blurring expressions is an ecologically valid way of reducing emotion evidence, at least as it relates to individual with corrective lenses, not everyone has experience with this way of seeing the world. Even those that do, generally wear their corrective lenses. If embodied representations are grounded in experience, then this may matter. One way in which visual evidence of emotions differs that all sighted individuals have experience with, is emotional intensity. Expressions are often subtle. Subtle expressions are more difficult to recognize (Hess, Blairy, & Kleck, 1997). It has also been hypothesized that mimicry may be most relevant to recognition when expressions are subtle (Davis, Winkielman, & Coulaon, 2017; Hess & Fischer, 2013, 2014; Niedenthal, Halberstadt, Margolin, & Innes-Ker, 2000; Wood, Rychlowska, Korb, & Niedenthal, 2016). In the next chapter use an identical paradigm but manipulate emotion intensity rather than visibility.

Chapter 3: Morph Intensity Experiment

3.1 Present research

As in experiment one we are presenting participants with videos of 3 emotions (anger, joy, and sadness) and manipulating two levels of emotion evidence (high, low intensity) under two different task conditions (passive viewing and emotion categorization). Again, we are testing three hypotheses with our experimental manipulation. The amplification function of the embodied computation hypothesis predicts a relative increase in mimicry in response to low intensity expressions when they need to be categorized. The matched-motor hypothesis predicts mimicry will follow the intensity of the expressions. The emotional mimicry in context model predicts that mimicry will occur at a categorical level unaffected by task or intensity. It also predicts that mimicry is most likely to occur in response to expressions of joy and least likely in response to expressions of anger. As in experiment one (chapter two), in addition to testing the profile of mimicry, we are testing whether it mediates between the visual evidence of emotion in the stimuli and how they are categorized.

3.2 Methods and procedure

3.2.1 Participants

Forty-seven undergraduates (43 = female, mean age = 20.4 years old, range = 18 to 24 years old) from the University of California, San Diego subject pool participated in the experiment. All participants provided written informed consent prior to participation, were debriefed at the conclusion of the experiment, and received course credit as compensation.

3.2.2 Apparatus

EMG recording and signal processing was consistent across experiments. See section 2.2.2 for apparatus details.

3.2.3 Materials

Forty-eight facial expression morph videos were used: 3 emotion blends (neutral-joy, neutral-sadness, neutral-anger) x 2 expression intensities (high, low) x 8 identities (4 male, 4 female). (See Figure 3.1 for a depiction of the stimuli). The videos were constructed using Abrasoft FantaMorph Pro Software. For each identity and emotion, a blend was constructed from two high-resolution photographs from the Warsaw Set of Emotional Facial Expression Pictures (WSEFEP) (Olszanowski, et al., 2015). Emotional expressions in the WSEFEP were generated by actors who had been trained in the Stanislavski method acting tradition. Method acting involves recalling emotional experiences from one's own life and embodying that feeling in order to convey an emotion, with the assumption that this generates a more authentic emotional display than thinking about what an expression looks like and trying to mimic that (See Olszanowski et al, 2015 for additional details on the stimuli, including validation of the items in the stimulus set). For the blends that we created, one photograph depicted a neutral expression and the other depicted a full expression of the emotion. All photographs had closed mouths to avoid artifacts associated with blending between images that did and did not show teeth.

For each pair of photographs in a blend, corresponding facial landmarks were identified by hand (e.g., one landmark could be the outer left canthi of the left eye). Approximately 200 corresponding landmarks were identified in each pair of photographs. Corresponding landmarks are the basis for the dynamic structural changes in a morph video, and having this many afforded smooth morph transitions.

To generate high and low intensity stimuli, we selected sections from the full transition range. High intensity stimuli were videos corresponding to the transition from .7 to .9 of the full emotional expression (i.e., .3 to .1 neutral). Low intensity blends transitioned from .1 to .3 of the full emotional expression. These setting were for both the feature and shape transition curves in the software. The stimuli were exported as six-second videos at 14 frames per second and a resolution of 720 x 540 pixels.

3.2.3.1 Stimulus evaluation

We evaluated our stimuli using CERT (Littlewort et al., 2011), which provides an objective measure of emotion evidence in videos (see section 2.2.3.1 for a discussion of CERT and its validation**).** To assess our stimuli, we modeled mean estimates of anger evidence, joy evidence, and sadness evidence using the following model: evidence ~ emotion*intensity + (1 | morph). Models were fit using the lmer function in the lme4 package of R lmer (Bates, Maechler, Bolker, & Walker, 2015). Morph in this case refers to the low and high intensity versions of the same blend. This random intercept was included to account for variation between actors expressing particular emotions and because high and low intensity videos for a given actor and emotion were created from the same two images. To assess whether the stimuli differed by condition we used the anova function with Type III sum of squares followed up with the ls_means function, both from the lmerTest package in R (Kuznetsova, Brockhoff, & Christensen, 2017). Degrees of freedom estimates used Satterwaite's method. We found significant interactions for each type of evidence in the direction predicted, e.g., there was significantly more evidence of joy for joy expressions, with more joy expressed in the high intensity than in the low intensity version; the same pattern held for anger and sadness. (See Table 3.1 for ANOVA analysis and figure 3.2 for means).

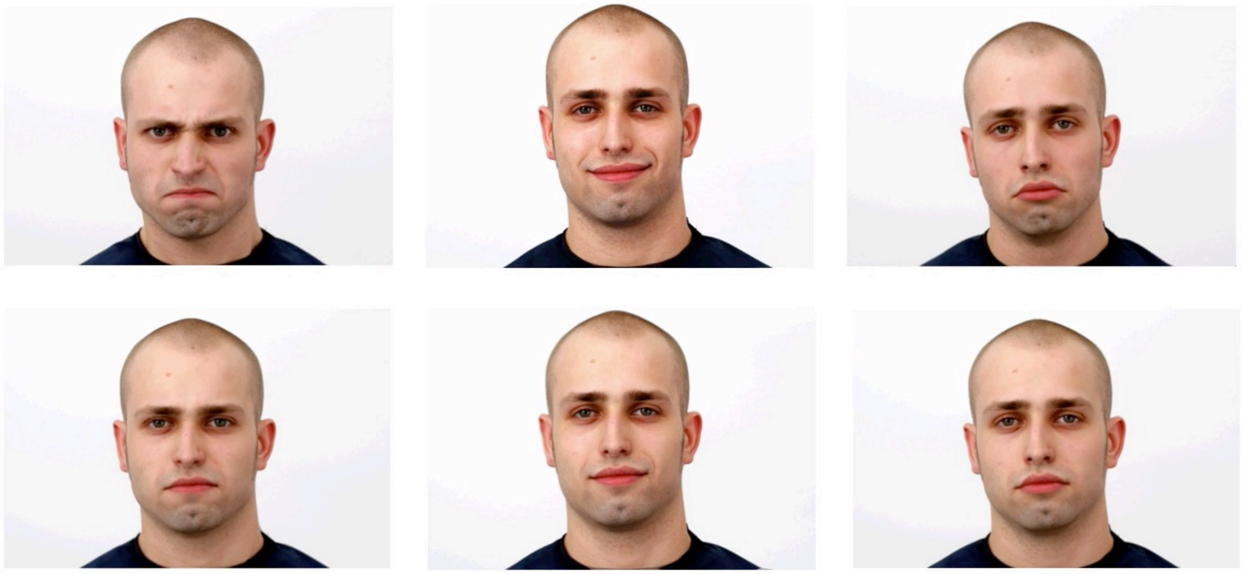

Figure 3.1 Stimuli. Examples of morph video stimuli. From left to right: anger, joy, sadness. Top row is high intensity; bottom row is low intensity. Images are from the final frame of the six-second videos.

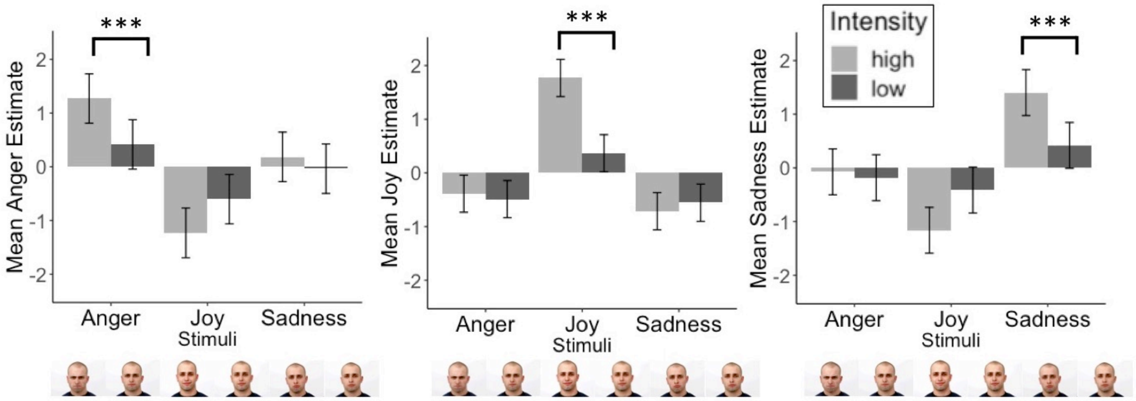

Figure 3.2 Stimulus evaluation. Mean z-scored CERT estimates of joy, anger, and sadness evidence in the stimuli. Error bars indicate 95% confidence intervals. Since there are numerous possible comparisons, the only comparisons marked for significance in each type of emotion evidence are between the high and low intensity levels of the corresponding emotion *** p < 0.001, ** p < 0.01.*** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

Table 3.1 Stimulus evaluation. Models were submitted to Type III Sum of Squares ANOVAs using Satterthwaite's method for estimating degrees of freedom.

	F	*p*
CERT Joy evidence estimates ~ emotion*intensity + (1|morph)		
Emotion	$F(2, 20) = 30.5$	< 0.001 ***
Intensity	$F(1, 28) = 51.2$	< 0.001 ***
Emotion x Intensity	$F(2, 28) = 59.1$	< 0.001 ***
CERT Anger evidence estimates ~ emotion*intensity + (1|morph)		
Emotion	$F(2, 21) = 28$	< 0.001 ***
Intensity	$F(1, 27) = 1.8$	0.19
Emotion x Intensity	$F(2, 27) = 14.4$	< 0.001 ***
CERT Sadness evidence estimates~ emotion*intensity + (1|morph)		
Emotion	$F(2, 24) = 38.8$	< 0.001 ***
Intensity	$F(1, 28) = 1.0$	0.32
Emotion x Intensity	$F(2, 32) = 19.1$	< 0.001 ***

3.2.4 EMG data collection

For the collection of facial EMG, a wireless transmitter was secured to the participant's left shoulder. Zygomaticus major and Corrugator supercilli muscle sites on the left side of the participant's face were cleaned with rubbing alcohol and prepped with NuPrep gel, then affixed with bipolar derivations of electrodes according to facial EMG guidelines (Fridlund & Cacioppo, 1986). A reference electrode was placed on the participant's cleaned and prepped left mastoid. Conductivity was tested by having participants move parts of their face (without mention of emotions or emotional expressions) as the experimenter visually inspected the EMG signals in real-time. Participants could not see the EMG signals and were not informed of what the electrodes were recording. When facial actions induced appropriate, clear signals, the experiment began.

3.2.5 Procedure

The procedure was identical to that used in experiment one (see section 2.2.5 for complete details). The only difference was the stimuli used. This experiment used morph videos of high and low intensity expressions while experiment one used videos of actors displaying spontaneous emotional expressions that were or were not blurred. This experiment used a repeated measures design 3(emotion: anger, joy, sadness) x 2 (morph intensity: high, low) x 2 (task: passive viewing, emotion categorization). The only difference between the tasks was whether or not the stimuli had to be categorized as displaying anger, joy, or sadness. Task order was counterbalanced across participants. (See Figure 3.3 for a schematic of a categorization trial).

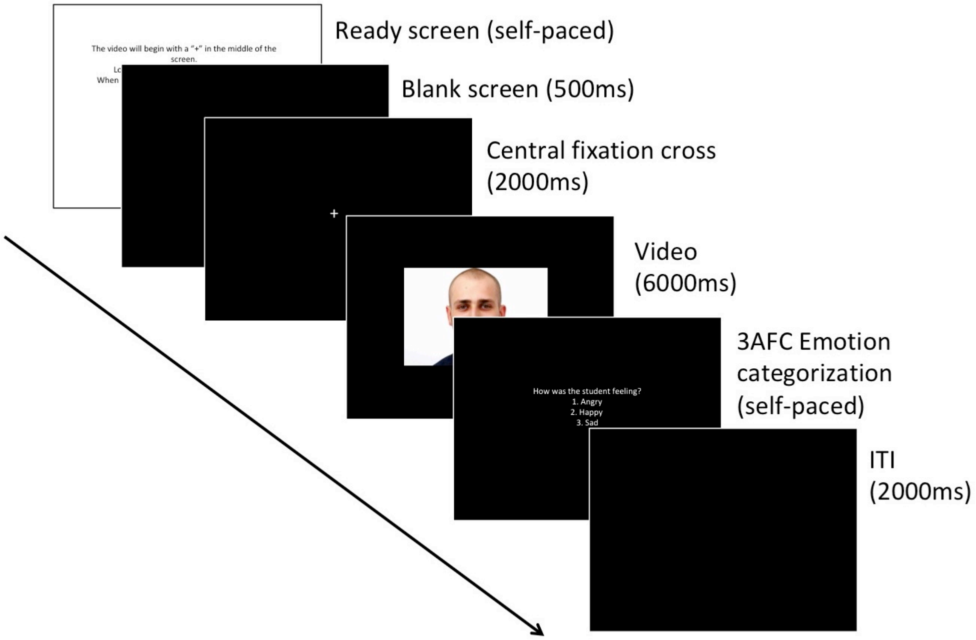

Figure 3.3 Trial schematic. This depicts a categorization trial. Passive viewing did not include 3AFC task, otherwise the conditions were identical.

3.2.5 Data preparation and cleaning

After EMG data collection, the signals were processed offline using MindWare EMG software package 2.52 (MindWare Technologies Ltd. Ohio, USA). EMG signals were band pass filtered between 30-500Hz with a 60Hz notch filter, binned into 500ms intervals, rectified, integrated, and the mean area under the curve was output for further processing. R software was used to clean, normalize, and analyze the signals.

There were 16 datapoints for each trial. Four corresponded to the baseline (2000 ms) and 12 corresponded to the time during which the video was presented (6000 ms). As in experiment one (chapter 2), the data were normalized within participants and muscle sites to account for individual differences in participants, muscle sites and recording sessions. The data were cleaned by removing epochs that were +/- 3 standard deviations from the mean (resulting in the removal of 1.3% of the data). After cleaning, the remaining data were z-scored once again within participants and muscles sites. (For similar treatment, see Carr, Winkielman & Oveis, 2014; Neufeld, Ioannou, Korb, Schilbach, & Chakrabarti, 2016). The data were then averaged and baseline corrected on a per trial basis. As in chapter 2, we used an emotion index as our EMG dependent variable. We created this by subtracting the mean corrugator activity from the mean zygomaticus activity on a per trial basis.

For response time data, we excluded trials to which responses took longer than 5000 ms (median response time prior to trimming was 1480 ms). Rejection of these slow trials resulted in the removal of 3.6% of the categorization trials. For analysis of response times, we only examined accurate trials.

3.2.6 Data analysis

All analyses were conducted in R. Data were modeled using the lmer function in the lme4 package (Bates et al., 2015). Models included the maximal random effect structures for which the models would converge (Barr, Levy, Scheepers, and Tily, 2014) with bobyqa set as the optimizer and maxfun set to 100,000 iterations. Specific models for each analysis are described in the results section. As in chapter 2, we assessed our fixed effects using the anova function in the lmertest package (Kuznetsova et al., 2017). This function provides an anova summary table for lmer models. Denominator degrees of freedom were estimated using Satterwaite's method and Type III sum of squares were used. Mediation analyses were performed using the mediate function in the mediation package of R (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014).

3.3 Results

3.3.1 Accuracy and response time results

Accuracy was modeled on a per trial basis: accuracy ~ emotion*intensity + (emotion + intensity | subject) + (intensity | morph). Note: morph in the random effects structure refers to the blend from which the high and low intensity versions of a given stimulus were generated. There was a main effect of emotion $F(2, 27) = 7.5$, $p = 0.002$, and intensity $F(1, 18) = 25.7$, $p < 0.001$, qualified by an interaction between emotion and intensity $F(2,27) = 9.9$, $p < 0.001$. Participants were highly accurate > 90% on all but the low intensity sadness and anger trials, for which they were significantly less accurate (See Figure 3.4 for means). Response time data, for which only accurate trials were included, was fit to the same model as the accuracy data with the exception of the DV. There were no significant differences in response times, all $p > 0.41$.

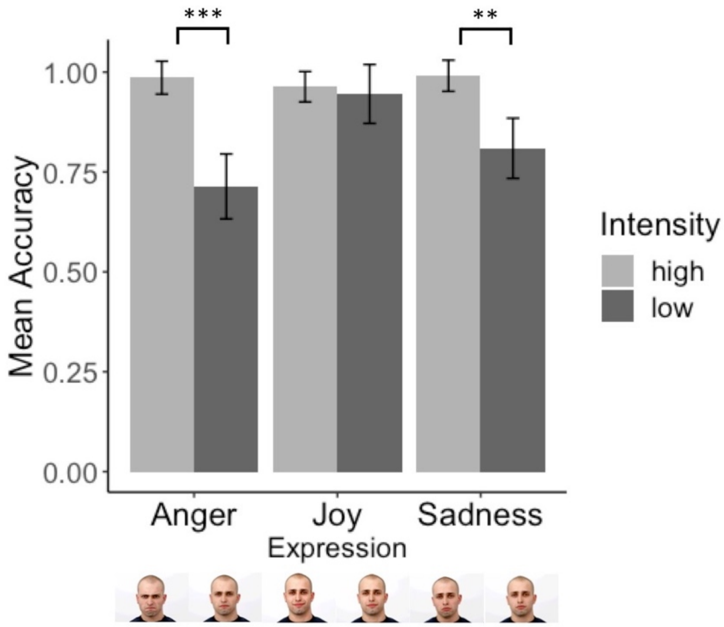

Figure 3.4 Accuracy results. Mean accuracy for the emotion by intensity interaction. Error bars reflect 95% confidence intervals. Only significant differences between high and low intensity stimuli from the same emotion category are marked for significance. *** $p < 0.001$, ** $p < 0.01$.

3.3.2 EMG results

EMG data were modeled using the maximum model that would converge: Emotion index ~ emotion*intensity*task + (emotion + intensity + task | subject) + (1 | morph). This resulted in a main effect of emotion, $F(2, 49) = 13.2$, $p < 0.001$ that was qualified by two significant interactions. There were significant interactions of emotion x intensity, $F(1, 2560) = 7$, $p < 0.001$, and emotion x task, $F(1, 2575) = 4$, $p = 0.018$. For the emotion x intensity interaction, there was mimicry to joy and sadness with non-significant trends of increased mimicry to the high (relative to low) intensity levels. However, for anger, there was a pattern consistent with mimicry to the low intensity stimuli but a muted response in the opposite in reaction to the high intensity stimuli. This is consistent with the embodied compensation prediction but also consistent with an appeasement or backing down emotional reaction to high intensity anger. This difference between high and low intensity anger was significant. (See Figure 3.5 for means). For the emotion x task interaction, there was mimicry to sadness and joy in both the categorization and passive viewing tasks. For anger there was mimicry in the categorization but not the passive viewing task. For both joy and anger, there were non-significant trends of more mimicry during the categorization task (relative to passive viewing). There was no such difference for sadness. (See Figure 3.6 for means). (See supplementary materials at the end of the dissertation for a presentation of the data that includes all conditions and individual muscle sites).

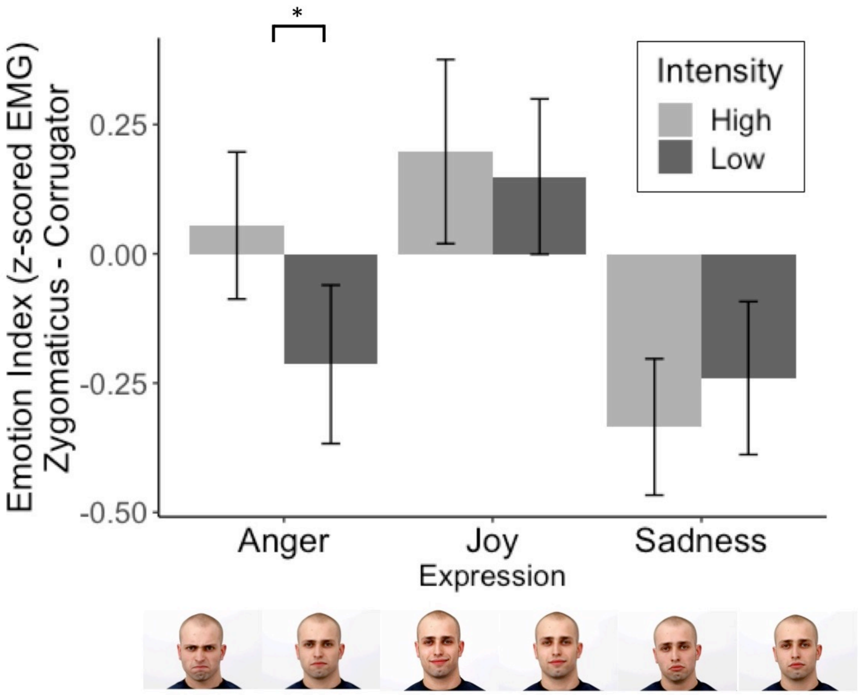

Figure 3.5 EMG emotion x intensity results. * $p < 0.05$. Error bars reflect 95% confidence intervals.

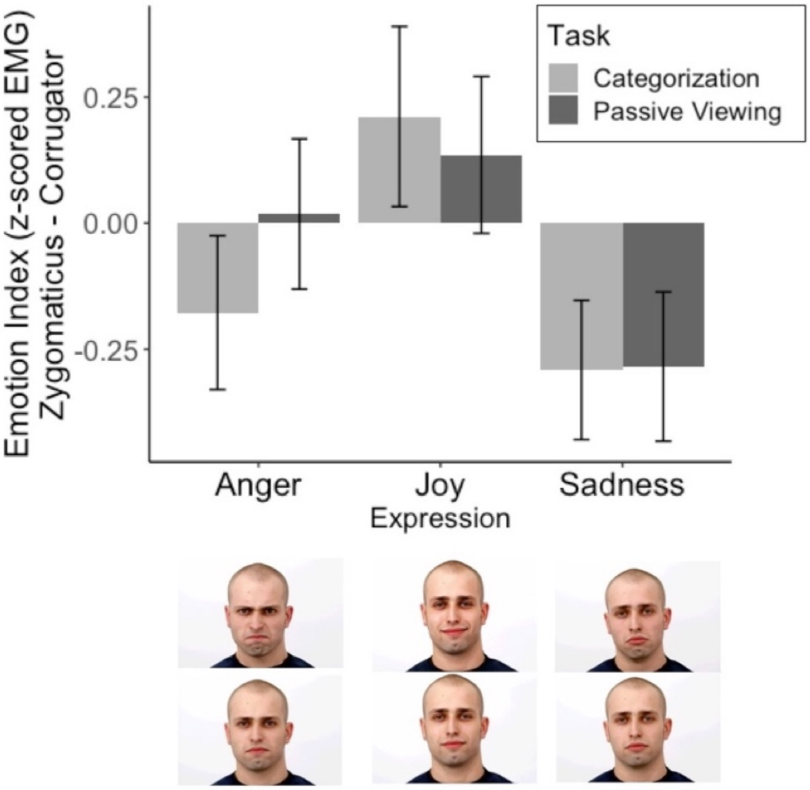

Figure 3.6 EMG emotion x task results. Although the interaction was significant, there were no significant differences within an emotion as a function of task. Error bars reflect 95% confidence intervals.

3.3.3 Mediation results

We tested the hypothesis that emotional facial motor responses (EMG emotion index) mediated between the visual evidence of an emotion in an expression (assessed by CERT emotion evidence estimates) and how participants categorized that expression. Separate analyses were run for each type of emotion (i.e., mediation between joy evidence and joy responses, between sad evidence and sad responses, and between anger evidence and anger responses). We found that participants' facial activity significantly mediated between the evidence and how the stimuli were categorized for joy and sadness but not anger. (See Table 3.2 for statistical analysis and Figure 3.7 for regression estimates).

Table 3.2 Mediation analysis results. ACME = average causal mediation estimate (the indirect effect). Emotion refers to the analysis that assessed whether participants' EMG response mediated between CERT evidence of that emotion in the stimuli and whether participants categorized those stimuli as expressing that emotion.

Emotion	ACME estimate	Lower 95% CI	Upper 95% CI	*p*-value
Anger	-0.001	-0.003	0.00	0.47
Joy	0.004	0.001	0.01	0.006 **
Sadness	0.003	0.0004	0.01	0.022 *

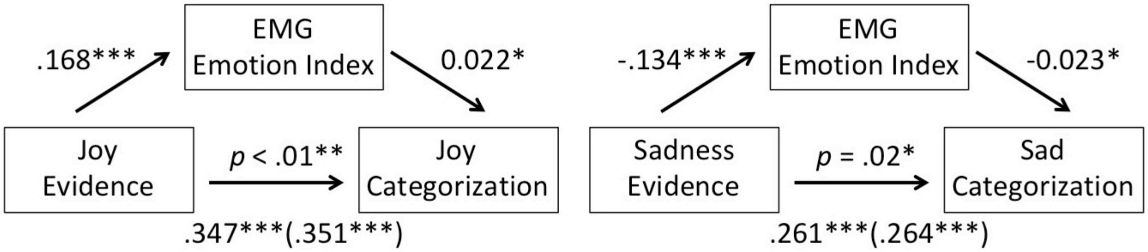

Figure 3.7 Mediation analyses regressions. Estimates are for significantly mediated emotions. Emotion index = mean z-scored zygomaticus – corrugator EMG. Joy evidence is based on CERT analysis. Categorization is binary did/did not categorize the expression as that emotion. *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$.

3.4 Discussion

This experiment used two analyses to address the functional role of mimicry in the recognition of expressions. The first was to obtain a profile of mimicry using a 3(emotion) x 2(intensity) x 2 (task) repeated measures design. The second was to assess whether mimicry mediated between the emotion evidence in the stimuli and the way the stimuli were categorized based on the emotion recognition task data alone. After discussing the behavioral data, which served primarily as a manipulation check and a means to address mimicry's role in recognition, each analysis will be discussed in turn.

Although the behavioral data only include half of the experimental trials, we assume that if the behavioral results indicated participants were attending to this part of the experiment, they were likely paying attention during the passive viewing task. Evidence that they were attending to the stimuli in the passive viewing task, however, is better judged by whether or not they displayed mimicry in that condition (and they did). As in the previous experiment, emotion interacted with the emotion evidence manipulation for accuracy but there were no differences in response times. Also replicating the previous experiment, participants were best at detecting expressions of joy. This was true even though a) the range of the morph spectrum from which the low intensity stimuli taken was equivalent across each of our emotions, and b) the CERT analysis demonstrated a significant difference in emotion evidence between high and low intensity stimuli. As in experiment one, the biggest numerical difference in emotion evidence was between high and low intensity expressions of joy. Participants are good at recognizing joy, even when it is low intensity (Hess, Blairy, & Kleck, 1997). This advantage for expressions of joy has been found even when not specifically contrasting low and high intensity expressions (see Oberman, Winkielman, & Ramachandran, 2008; Adolphs, Tranel, Damasio, & Damasio, 1994; Adolphs et al., 2000). Joy aside, reducing intensity made the task more difficult to recognize sadness and anger. This makes sense, given that there was less visual evidence to make decisions off of. These data indicate participants were actively engaging in the task and attending to the stimuli. Although the passive viewing condition does not have this manipulation check, we assume that if participants attended to one half of the experiment, they attended to the other half as well. This is further confirmed by the EMG data.

The 3(emotion) x 2(intensity) x 2(task) design of our experiment was used to contrast hypotheses from three models of mimicry. One was the amplification function of the embodied computation model, which predicted that mimicry would act as a compensatory mechanism to visual analysis and increase when emotion evidence was reduced, and recognition was required. Our data did not support this, except for in the case of anger. This could be due to simulation or social regulation. The second hypothesis was the motor-matching hypothesis (Chartrand & Bargh, 1999; see Hess & Fischer, 2013), which predicted mimicry would follow the evidence, increasing in response to high intensity stimuli and decreasing in response to low intensity stimuli. Our data did not support this hypothesis either. The third hypothesis was based on the emotional mimicry in context model (Hess & Fischer, 2013; 2014; Hess, Houde, Fiscer, 2014) which hypothesized that task and intensity would not make a difference, however, joy was most likely to be mimicked and anger was least likely to be mimicked. This was the hypothesis that best described the data in the previous experiment. It is also the best description of the data in this experiment.

In experiment one we found a main effect of emotion. Task and evidence did not matter. In this experiment we found an emotion by task interaction, and an emotion by evidence interaction. We will first discuss the emotion by task interaction. Although this interaction was significant as a whole, there were no significant differences as a function of task for any of the emotions. There is relatively little research that measures mimicry while contrasting a recognition tasks with a different condition. Those that have used a task that required participants to focus on a non-social dimension of the stimuli, such as eye color, have found that it reduces mimicry relative to a categorization task (Cannon, Hayes, & Tipper, 2009; van Dillen, Harris, van Dijk & Rotteveel, 2015). Murata et al., (2016) did contrast categorization with passive viewing. They found that there was more mimicry when participants were categorizing expressions compared to when they were passively viewing them. However, this was because they found mimicry when participants categorized expressions but not when they passively viewed them. As in experiment one, we found mimicry during passive viewing and emotion categorization. Mimicry in response to passively viewed expressions is relatively common (e.g., Dimberg & Thunberg, 1998; Dimberg, Thunberg, & Elmehed, 2000), particularly when the expressions are presented as dynamic videos (e.g., Sato & Yoshikawa, 2007; Rymarczyk, Zyrawski, Jankowaik-Siuda & Szatkowska, 2016). Since there were no significant differences as a function of task within an emotion, there is little else to conclude from this interaction. It is noticeable, however that passively viewing anger was centered near 0 on the emotion index, indicating that there was no mimicry at that level of the experiment (See supplementary figure S2 for a breakdown by muscle and task). Anger mimicry is an interesting topic that will be discussed in greater detail in response to the emotion by intensity interaction.

Emotion interacted with intensity in an interesting way. Although the means of the high intensity sadness and joy levels were slightly higher than those of their low intensity counterparts, there was clearly no significant difference. Once again, the data are inconsistent with the motor-matching model of mimicry. Even if one assumes that emotion recognition is automatic, these data would not support the amplification hypothesis of the embodied computation model. The lack of a difference for joy and sadness as a function of intensity is similar to the results in experiment one, and consistent with the emotional mimicry in context model. Although the intensity manipulation did not affect motor responses to expressions of sadness or anger, it did make a significant difference for expressions of anger. Participants displayed a congruent response to low intensity anger, but they did not for anger. This too aligns with the emotional mimicry in context model (Hess & Fischer, 2014), which predicts that anger is the least likely of our three expressions to be mimicked. The anger results align with the embodied computation predictions as well but sing we did not find that mimicry mediated recognition of anger, a social regulation interpretation seems more plausible than a computational interpretation.

Anger is an interesting emotional facial expression. It signals aggression. If the anger is directed at an observer, it implies aggression toward that observer. Our stimuli had eyes directed at the participant. In the real world, mimicking faces such as the ones our participants did not mimic could lead to a fight. From the perspective of the emotional mimicry in context model, it is not surprising that the high intensity expressions induced a relatively flat affective reaction. The literature on anger mimicry is mixed. Some studies have found mimicry (e.g., Dimberg 1982; 1986), others have found that it is not mimicked at all (Rymarczyk et al., 2016), and others have found that it is responded to with a smile (Sonnby-Borgstrom, 2003).

If the facial responses to anger were not simulation based, then finding that they did not mediate recognition of anger is not surprising from a simulation account, at least (Davis, Winkielman, & Coulson, 2017; Niedenthal 2007; Wood, Rychlowska, Korb, & Niedenthal, 2016). However, it is inconsistent with theories that propose facial reactions facilitate mimicry not by simulation but by accessing experience based embodied representations of emotion concepts (e.g., Niedenthal, 2007). It is inconsistent because how participants reacted to these stimuli is likely similar to how they do so in everyday experiences—a subtle expression of anger likely elicits some negative affect but a high intensity expression of anger likely induces a facial reaction that reduces the probability of escalating an aggressive reaction. From the perspective of recognition being facilitated by reactivating grounded experiences, this should have facilitated recognition.

Although we did not find motor activity mediated between visual evidence of anger and the recognition of anger, we did find that it mediated between the evidence and recognition of joy and sadness. This is somewhat different from the finding in experiment one. In experiment one we found mediation for joy and anger. The mediation effects were once again small, further supporting the hypothesis that mimicry plays a minimal role and not all of the time. It also argues against the hypothesis that mimicry only helps recognition by facilitating social disclosure. It also argues against the hypothesis that the results from mimicry-based interference research is driven exclusively by distraction.

To summarize, although we did not directly replicate the results of experiment one, our EMG response profile data best support the emotional mimicry in context model. The mediation data did not fully match the results of experiment one either. Although we found partial mediation for joy in each experiment, experiment one found mediation for anger but not sadness, and experiment two found it for sadness but not anger. In experiment three we will test for mediation once more and see if joy remains most reliable, and whether there are effects for sadness or anger. In experiment three we still manipulate visual emotion evidence. However, we are dropping the task manipulation since it did not make a difference in experiments one or two. Additionally, we are no longer testing the amplification function of the embodied computation model, since there was no indication of it being supported in either of the previous experiments. In the next experiment, we are testing the pattern-completion function of the embodied computation hypothesis by presenting participants with only the top- or the bottom- half of an expression at one time. In the real world, this is somewhat analogous to when people have clothing or heavy eye protection occluding parts of their face.

Chapter 4: Experiment 3 (Half-Faces)

4.1 Present Research

Another way that visual emotion evidence is reduced in expressions is by occlusion. Scarves, goggles, and other clothing or equipment worn on the head can occlude much of the face. How does this influence mimicry and how does that influence recognition? According to the embodied computation model, one way mimicry might facilitate recognition is via a pattern completion process (for related hypotheses see Adolphs, 2006; Barsalou, 2013). This model predicts that mimicry will occur at muscle sites that are unobserved. According to the emotional mimicry in context model, mimicry is a function of what is inferred and specifically not based on low level perceptual matching (Hess & Fischer, 2014). This hypothesis predicts the same outcome. The motor-matching hypothesis makes a different prediction, namely, only what is observed will be mimicked (Bargh and Chartrand, 1999; Hess & Fischer, 2013).

Since the previous two experiments found no difference in facial response as a function of task, that factor was dropped. Otherwise the paradigm is the same but with different stimuli. 3(emotion) x 2 (face-half: top, bottom). Another change is the way we are analyzing the EMG. Since we want to know if individual muscles display a pattern of mimicry even when those muscles are not observed, we are analyzing the corrugator (brow) and the zygomaticus (cheek) muscle sites separately. Another difference from the previous experiments is that we cannot evaluate global emotion evidence because CERT failed to recognize expressions when only half of a face was presented. Therefore, we evaluated the stimuli prior to cutting them in half and used CERT evidence from the action units that corresponded to the zygomaticus (AU 12) and the corrugator (AU 4), as proxies for emotion evidence.

4.2 Methods

4.2.1 Participants

Forty University of California, San Diego undergraduates (mean age = 20.6 years old, range = 18-49 years old, 32 female) were recruited from the UCSD experimental participation subject pool. All participants provided written informed consent prior to the experiment and received course credit for their time. Three participants were removed from analysis because their mean accuracy on the categorization task was less than 70%. All analysis and results were based on the remaining 37 participants.

4.2.2 Apparatus

The same setup was used in experiment three as in experiments one and two (see section 2.2.2 for details).

4.2.3 Materials

The stimuli consisted of 6-second videos of emotional facial expression morphs displaying only the top- or bottom-half of the face at a time. There were 48 stimuli in total: 3 emotional expression morphs (joy, sadness, anger) x 2 face-half (top, bottom) x 8 actors (4 male, 4 female). The stimuli were based on the outcome of a norming study. The videos that went into the norming study (n = 12) were created by taking the high- and low- intensity emotional expression morphs described in chapter 3 and putting a black rectangle over the top or bottom half of the face and placing them on a back background (See figure 4.1 for an example of the stimuli.) In the norming study there were 96 videos: 8 actors (4 female, 4 male) x 3 emotional expressions (joy, sadness, anger) x 2 intensities (high, low) x 2 half of the face (top, bottom). Participants categorized each video as expressing joy, sadness, or anger via a 3AFC button press. Stimuli were presented in a random order.

To select stimuli for the present experiment, we first removed any top/bottom stimulus pair (for a given identity and emotional expression) for which mean accuracy was less than 50% for either the top or the bottom of the face. This excluded 63% of the low-intensity expressions of anger and joy, and 38% of the low-intensity expressions of sadness. In these cases, we selected the high-intensity counterpart for inclusion in the experiment by default. For the remaining items, we selected the intensity level for which the average accuracy for top and bottom came closest to 85%. Additionally, since different facial muscles and regions of the face have been found to be more diagnostic of different emotions than others (e.g., Ekman & Friesen, 1978; Ponari, Conson, D'Amico, Grossi, & Trojano, 2015; Smith, Cottrell, Gosselin, & Schyns, 2005), and since we wanted to make sure our stimuli were typical in this regard, we only included joy stimuli for which accuracy in response to the bottom half of the face (i.e., the half with the Zygomaticus) was equal to or greater than accuracy for the top half of the face; and sadness and anger stimuli for which accuracy in response to the top half of the face (the half with the Corrugator) was greater than or equal to that for the bottom half of the face. (See Figure 4.1 for mean accuracy and response times from norming study).

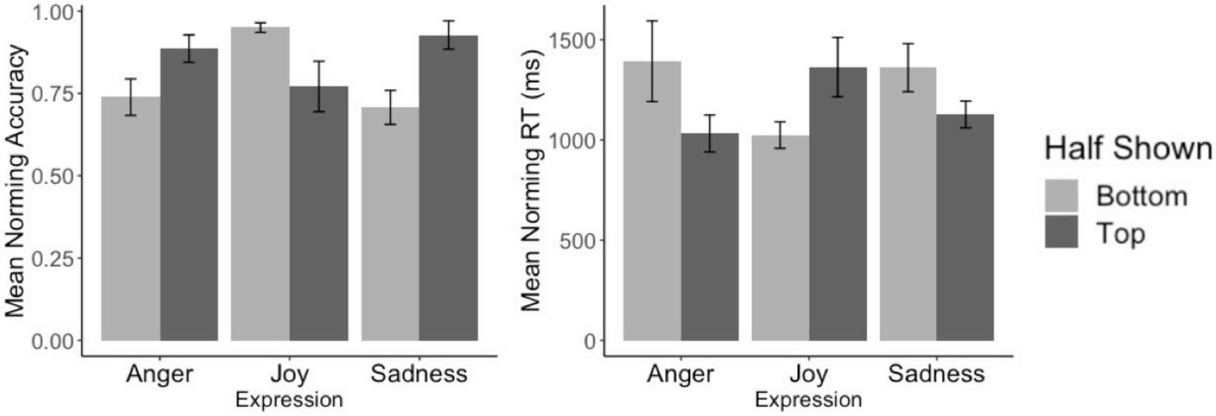

Figure 4.1 Stimulus norming. Norming results for stimuli selected for inclusion in the experiment. Error bars reflect 95% confidence intervals.

4.2.3.1 Stimulus Evaluation

After stimulus selection, we assessed our bottom face stimuli for evidence of AU 12 (Zygomaticus) activation and top face stimuli for evidence of AU 4 (Corrugator) activation using CERT software (Littlewort, Whitehill, Wu, & Fasel et al., 2011; see chapters 2 and 3 for descriptions of the software and its validation). Mean AU estimates were first fit to the following model, AU ~ emotion + (1 | actor), using the lmer function in the lme4 package (Bates, Maechler, Bolker, & Walker, 2015). Actor was included as a random intercept to account for potential differences in acting quality. After fitting the model it was submitted to the anova function in the lmerTest package (Kuznetsova, Brockhoff, & Christensen, 2017) with Type III sum of squares in order to assess if there was a significant difference in emotion between the stimuli. Differences between means were determined using the ls_means function in the lmerTest package. Degrees of freedom were estimated using Satterwaite's method. There was a main effect of AU 12 (Zygomaticus) evidence, $F(2, 14) = 27$, $p = 27$, with significantly more AU 12 evidence in response to joy than sadness, $t(14) = 6.4$, $p < 0.001$, and anger, $t(14) = 6.3$, $p < 0.001$. There was no difference between sadness and anger. Analysis of AU 4 (Corrugator) evidence revealed a main effect of emotion, $F(2, 14) = 6.3$, $p = 0.011$, with greater AU 4 greater AU 4 evidence in the anger than the joy videos, $t(14) = 3.5$, $p = 0.003$ but only marginally greater AU 4 evidence in the sad than the joy expressions, $t(14) = 1.5$, $p = 0.09$. (See Figure 4.2 for means and comparisons). Although there was not a significant difference in Corrugator between sadness and joy, Corrugator activity is not the only upper face AU that differentiates joy and sadness. Sadness also involves the Frontalis pars medialis AU 1, which raises the inner brow and is visible on upper half stimuli, while joy does not; and joy involves the Obicularis oculi AU 6 activation, which sadness does not (Ekman & Friesen, 1978). These differences help to explain how the upper half expressions of sadness and joy could be categorized so accurately in the norming study even though they did not statistically differ in Corrugator activity (Figure 4.1).

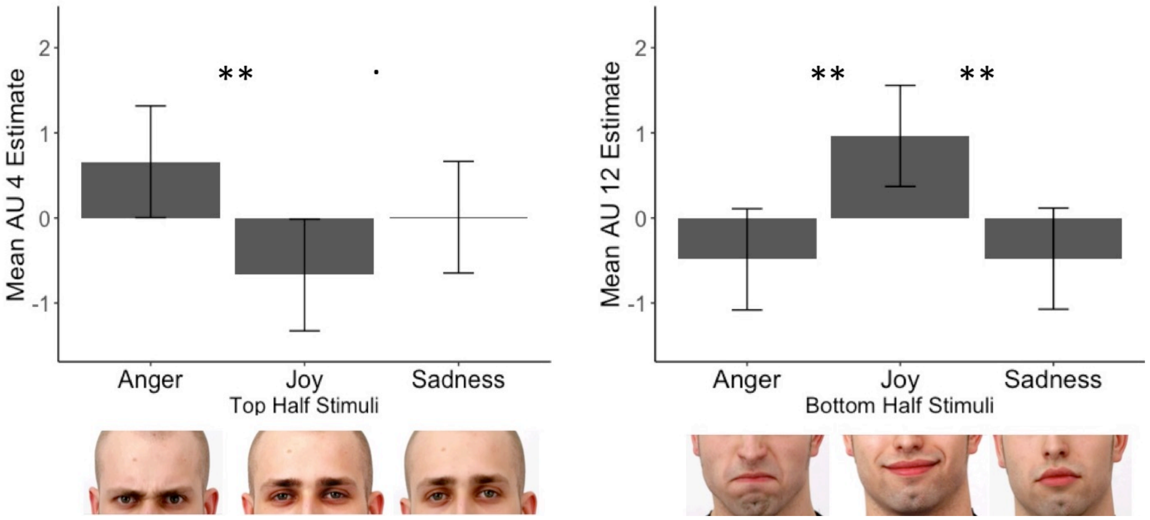

Figure 4.2 Stimulus evaluation. Half face images are from the final frame of the videos of 1 actor. AU 4 (Corrugator) estimates are for top half stimuli and AU 12 (Zygomaticus) estimates are for bottom half stimuli. Mean AU estimates are z-scored within stimulus set. Error bars reflect 95% confidence intervals. ** $p > 0.01$, . $p > 0.10$.

4.2.4 Procedure

After participants were affixed with EMG, they entered their age and sex into the computer and began the experiment. Instructions were presented on the monitor. If the participant had questions about their task after reading the instructions, they were answered. They were informed that any other questions would be answered at the conclusion of the experiment. Once they had no questions about the task, the experimenter left the room and the experiment commenced. The instructions at the beginning of the experiment were as follows:

“Welcome. In this experiment you will be watching videos that show part of a person’s face. After each video, a screen will appear asking you to categorize the emotion that was expressed. Wait until you see that screen to indicate your response. Please try to remain attentive yet relaxed, as that will give us your best data. Also, try to avoid touching your face or the sensors attached to it during the experiment. (Press SPACEBAR to continue).”

Each trial began with the following instructions: “The trial will begin with a “+” in the middle of the screen. Look at that and then watch the video that follows. After the video is over, you will be asked to select how you think the person in the video was feeling. When you are relaxed and ready to begin, press the SPACEBAR.” This was followed by a 500ms blank screen + 2000ms fixation cross + 6000ms video + 500ms black screen + Categorization screen. On the categorization screen the following was displayed: “How was this person feeling? 1. Angry 2. Happy 3. Sad” and participants responded via a keyboard button-press. This was followed by a 2500ms black screen and then the next trial began. (See Fig 4.3 for a trial schematic).

There were 48 trials corresponding to the 48 stimuli used in the experiment: 3 emotional expressions x 2 halves of the face x 8 identities. Stimuli were presented in random order for each participant. At the conclusion of the experiment, participants were debriefed.

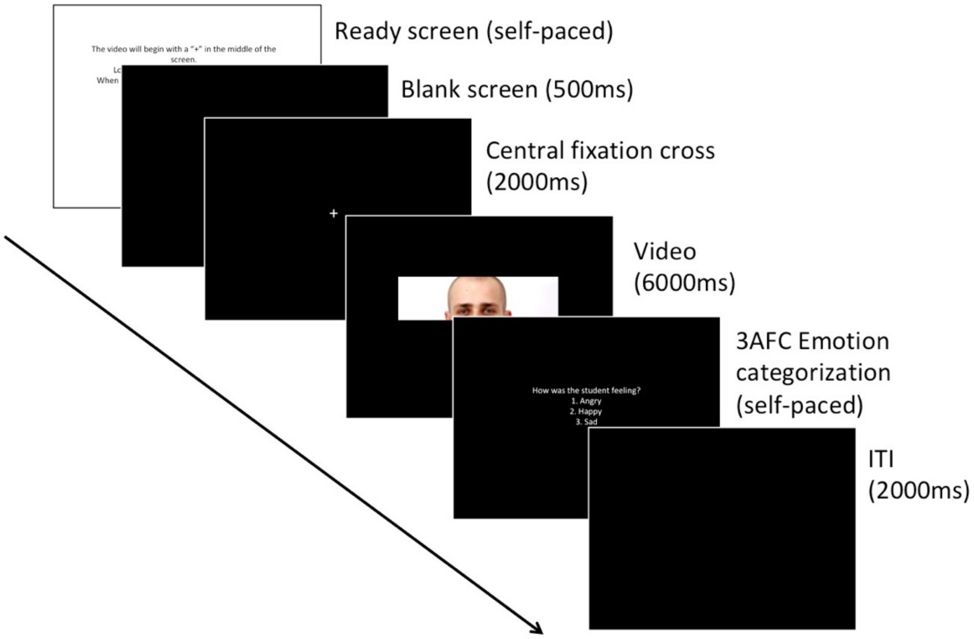

Figure 4.3 Trial Schematic.

4.2.5 EMG collection

For the collection of facial EMG, a wireless transmitter was secured to the participant's left shoulder. Zygomaticus major and Corrugator supercilli muscle sites on the left side of the participant's face were cleaned with rubbing alcohol and prepped with NuPrep gel, then affixed with bipolar derivations of electrodes according to facial EMG guidelines (Fridlund & Cacioppo, 1986). A reference electrode was placed on the participant's cleaned and prepped left mastoid. Conductivity was tested by having participants move parts of their face (without mention of emotions or emotional expressions) as the experimenter visually inspected the EMG signals in real-time. Participants could not see the EMG signals and were not informed of what the electrodes were recording. When facial actions induced appropriate, clear signals, the experiment began.

4.2.6 Data Processing and cleaning

Zygomaticus and Corrugator EMG data were processed in the following manner. Signals were first rectified and integrated in 500ms bins using MindWare EMG software package 2.52 (MindWare Technologies Ltd. Ohio, USA) and exported for further processing in R. Each trial consisted of 2 seconds of baseline activity and 6 seconds of activity corresponding to when the video was presented. The bins were normalized by z-scoring the data within participants and muscle sites. Bins that were above or below 3 standard deviations from the mean were removed. This resulted in the removal of 1.2% of the data points. The remaining data were once again normalized (z-scored) within participants and muscle sites. The mean baseline activity for each trial was then subtracted from that trial. Trials with response times longer than 5500ms were removed from analysis (median response time across all participants and all experimental and filler trials prior to removal was 1133 ms). This resulted in the removal of 3.1% of the trials. Of the remaining trials, only those with accurate responses were considered for RT and EMG analysis. However, inaccurate response trials were included in the mediation analysis, as we were interested in whether EMG mediated between what participants saw and how they categorized what they saw. Response time data included only accurate trials.

4.2.5.1 Data Analysis

Data were fit via the lmer function in lme4 (Bates et al., 2015) using maximal random effects structures for which the model would converge (Barr, Levy, Scheepers, & Tily, 2014). Specific models are described in the results section. After fitting the models, we used the anova function in the lmerTest package with Type III sum of squares and denominator degrees of freedom estimated using Satterwaite's method (Kuznetsova et al., 2017). This function provides anova summary tables for lmer models.

Mediation was performed using the mediate function in the mediation package (Tingley, Yamamoto, Hirose, Keele, & Imai, 2014). Mediation was performed according to recent guidelines which, unlike earlier guidelines (e.g., Baron & Kenny, 1986) indicate that it is valid to test for mediation when the independent variable (CERT muscle evidence) does not predict the dependent variable (categorical response), so long as there is theoretical motivation to test if the mediating variable (participant motor response) influences the other relationship (Kenny, 2018; Shrout & Bolger, 2002). In the previous chapters we tested between the overall emotion evidence in the stimuli and how they were categorized. However, CERT does not work on half faces. Therefore we used CERT on whole faces and relied upon the corrugator estimates for top half stimuli and the zygomaticus estimates for the bottom half stimuli.

4.3 Results

4.3.1 Accuracy and Reaction Time Results

Accuracy data was fit to the following lmer model: accuracy ~ emotion*half + (emotion + half | subject) + (1 | subject). Anova analysis of this model revealed a significant interaction between emotion and face half (2, 42) = 6.8, $p = 0.003$ (See Figure 4.2 for means). Main effects of emotion and face half were not significant, $p > 0.11$. Overall, participants were most accurate when presented with lower half facial expressions of joy. Lower half expressions of joy were categorized more accurately than top half expressions of joy $t(43) = 2.35$, $p = 0.023$, top half expressions of anger $t(44) = 2.1$, $p = 0.041$, bottom half expressions of anger $t(44) = 2.5$, $p = 0.016$ and bottom half expressions of sadness $t(43) = 4$, $p < 0.001$. In addition, participants were significantly more accurate at recognizing expressions of sadness when observing the top than the bottom half of the face, $t(43) = 2.8$, $p = 0.007$. This pattern is generally consistent with the norming data, indicating that nothing out-of-the ordinary occurred.

Response times were fit to the same model as accuracy with the exception of the dependent variable. For response time there was also a significant emotion*face half interaction, $F(30) = 3.4$, $p = 0.047$ (See Figure 4.4 for means). There were no significant differences between top and bottom half within an emotion. However, participants were fastest to respond to lower half expressions of joy and slowest to respond to lower half expressions of sadness, a difference that was statistically significant $t(39) = -2.4$, $p = 0.019$. The relationship between accuracy and response times indicate that the accuracy results were due to difficulty and not a speed-accuracy trade-off.

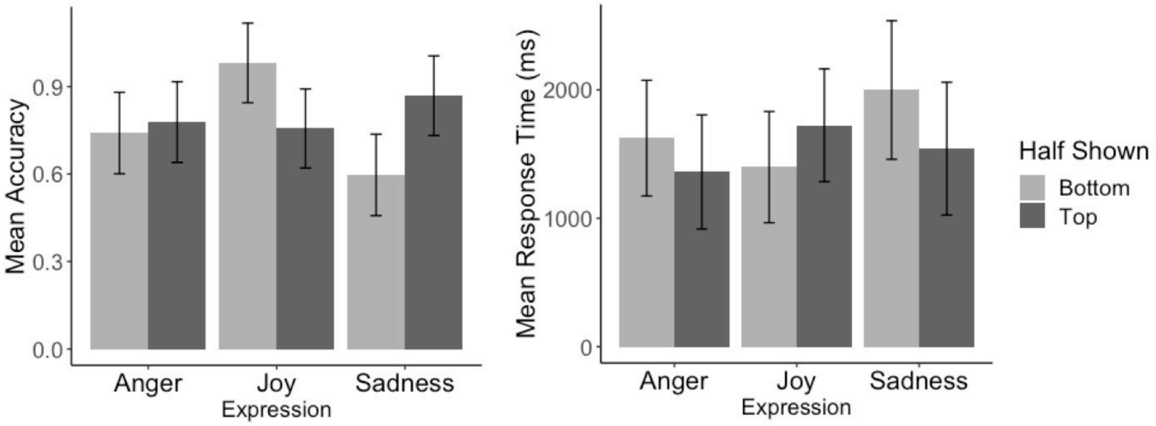

Figure 4.4 Behavioral data. Participants were faster on conditions they were more accurate in, demonstrating that there was no speed accuracy trade-off. This indicates that the data reflect task difficulty and that participants were paying attention to the task. Error bars reflect 95% confidence intervals.

4.3.2 EMG Results

EMG data were fit to the following lmer model: EMG ~ emotion* half + (emotion*half | subject) + (1 | item). This was followed with anova analysis of each model. For Corrugator, ANOVA analysis revealed a main effect of emotion, $F(2, 35) = 11$, $p < 0.001$ that was consistent with mimicry, with significantly greater activation in response to anger than joy, $t(36) = 3.7$, $p < 0.001$, and in response to sadness than joy $t(35) = 4.5$, $p < 0.001$. There was also a main effect based on which half of the face was shown $F(1,36) = 50$, $p < 0.001$, with greater corrugator response to expressions displayed on the top half of the face (the half that displayed the corrugator). The interaction between emotion and face half was not significant, $p = 0.55$. (See Figure 4.5 for means). For the zygomaticus data, there was a main effect of emotion, $F(2, 38) = 6.7$, $p = 0.003$ in a pattern consistent with mimicry. There was significantly greater zygomaticus activity in response to expressions of joy than to anger, $t(36) = 3$, $p = 0.004$, or sadness, $t(39) = 3.1$, $p = 0.003$. There was no significant difference between sadness and anger, $p = 0.98$ (See Figure 4.6 for means). There was not a significant main effect of face half, $p = 0.15$, nor an interaction, $p = 0.12$. (See supplementary materials at the end of the dissertation for a presentation of the data that includes all conditions for the individual muscle sites).

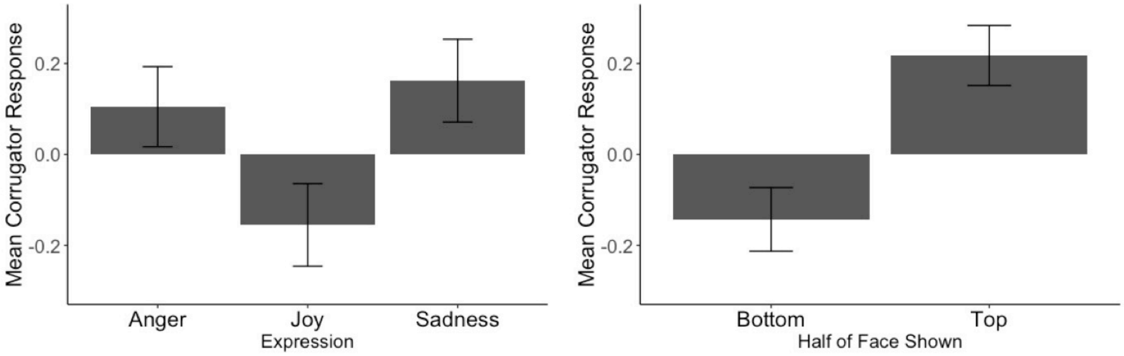

Figure 4.5 Corrugator EMG results. Corrugator response to emotion and face half. The emotion response is consistent with mimicry. There was more corrugator response when participants could see the corrugator in the stimuli (top half stimuli). Means are least squares means of z-scored EMG data. Error bars reflect 95% confidence intervals. *** $p > 0.001$.

Figure 4.6 Zygomaticus EMG results. Results are consistent with a mimicry response. Means are least squares means of z-scored EMG data. Error bars indicate 95% confidence intervals.

4.3.4 Mediation Analysis Results

Mediation was performed to test whether the overall pattern of participants' motor responses mediated between observed corrugator (AU 4) and zygomaticus (AU 12) evidence in the stimuli and the way those stimuli were categorized by the participants. Overall motor response was evaluated using the same emotion index described in chapters 2 and 3 (mean z-scored zygomaticus – corrugator EMG). As in chapters 2 and 3, we used the mediate function in R's mediation package (Tingley, Yamamato, Hirose, Keele, & Imai, 2014) with 10,000 simulations that used quasi-Bayesian approximations. The regressions used in the mediation analysis were modeled in lmer (Bates et al., 2015) and included subject as a random intercept. We ran separate mediation analyses for each type of categorical response in the top-half and in the bottom-half stimuli. Note that we ran mediation analyses even when CERT corrugator evidence did not significantly predict sadness responses, since we had a theoretically motivated reason to hypothesize that participants' motor activity could influence that relationship (see Kenny, 2018; Shrout & Bolger, 2002). We found that participants' motor responses significantly mediated between visual evidence (i.e., corrugator evidence in the top half stimuli and zygomaticus estimates in the bottom- half stimuli) and categorization of joy when recognizing joy in the top- and in the bottom- half of faces. There was also significant mediation for upper half expressions of sadness. Lower half expressions of sadness and both upper- and lower- half expressions of anger resulted in marginal but not significant differences. (See Table 4.1 for statistical analyses and Figure 4.7 for regression estimates for the cases where mediation was statistically significant).

Table 4.1 Mediation analysis results. Average causal mediation effect (ACME, indirect effect) statistics. Face half indicates the type of stimulus and the muscle evidence evaluated by CERT. Emotion describes the categorization response (binary). The mediating variable was the participants' EMG emotion index, a configural measure of overall facial motor response.

Face Half (muscle evid.)	Emotion	ACME estimate	Lower 95% CI	Upper 95% CI	*p*-value
Top (Corrugator)	Anger	0.0030	< 0.0001	0.01	0.052
	Joy	-0.0037	-0.0083	0.00	0.024 *
	Sadness	0.0031	< 0.0001	0.01	0.047 *
Bottom (Zygomaticus)	Anger	-0.0057	-0.0127	0.00	0.078
	Joy	0.0109	0.0051	0.02	< 0.001 ***
	Sadness	-0.0058	-0.0128	0.00	0.071

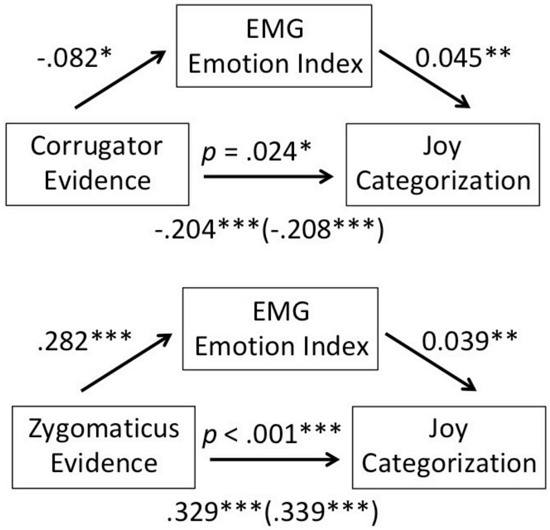

Figure 4.7 Mediation regressions. Depicted analyses are the with significant indirect mediation of participant muscle activity between AU evidence in the stimuli and how those stimuli were categorized. Upper face stimuli are on the top (with Corrugator CERT evidence) and lower face stimuli are on the bottom (zygomaticus evidence). labeled *p* value is significance of the average causal mediation effect (indirect effect). The other values are regression estimates. * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$

4.4 Discussion

We presented participants with videos displaying one half of a facial expression (top or bottom) at a time and had them to categorize the expressions using a 3AFC—joy, sadness, and anger—task. Participants were fastest and most accurate at categorizing lower-half expressions of joy (i.e., categorizing smiles as expressing joy). They were worst when observing lower face expressions of anger and sadness. This pattern of data (Figure 4.4) was similar to the patterns of the stimuli selected from the norming study (Figure 4.1). The relationship between the accuracy and response time data indicate that accuracy was not a result of a speed-accuracy trade-off. These results indicate that participants were attending to the task and actively attempting to categorize the expressions accurately. Given that the stimuli were selected for based on behavioral responses similar to this pattern (e.g., those selected based on norming), they only of interest as a manipulation check.

EMG was recorded at two muscle sites. We recorded from a muscle on the upper half of the face, the corrugator, which pulls the brows together. This muscle becomes activated in expressions of sadness and anger and relaxed in expressions of joy. We also recorded from muscle on the lower half of the face, the zygomaticus, which pulls the corners of the lips back and becomes activated when activated when smiling as in expressions of joy. It is relatively reduced when expressing sadness and anger (Hess, 2016). We found that each muscle responded in a manner consistent with the emotion expressed, regardless of which face half (and therefore, which muscle) was observed. Zygomaticus displayed patterns of mimicry whether the zygomaticus was observed (bottom stimuli) or whether it was not observed (top stimuli). The same pattern occurred for corrugator. As in each of the other two chapters, this outcome is inconsistent with the motor-matching hypothesis. These data are consistent with the pattern completion function of the embodied computation model. Pattern completion is hypothesized to be one way that mirroring can aid emotion recognition (Barsalou, 2013). These data are also consistent with the emotional mimicry in context model, which postulates that mimicry is a function of how an expression is interpreted in its explicit or implicit social context (Hess &

Fischer, 2014). This experiment was neutral regarding social context. We did not ask participants how they felt about the individuals in the videos. Anecdotally, however, multiple participants commented that they enjoyed the experiment. This is at least consistent with the possibility that they were implicitly construing the actors as neutral strangers in a safe environment or had some sort of prosocial affiliative stance toward them. Perhaps the act of categorizing expressions also contributed to this due to its relationship to empathy.

For the mediation data, we once again found partial mediation for joy. We found that mimicry (as measured by the emotion-index) mediated between corrugator (brow) evidence and the categorization of joy, as well as between zygomaticus (cheek) evidence. The partial mediation of joy has been consistent throughout all three experiments. The data also revealed that mimicry mediated between corrugator evidence and the recognition of sadness. There was no mediation between zygomaticus evidence and sadness, or either muscle for anger.

In the remaining chapter the results from all three experiments will be summarized and interpreted together.

Chapter 5: General Discussion

5.1 Summary of motivation for research

Facial expressions signal emotions (Darwin, Ekman, & Prodger, 1998; Ekman 1970). When the signaling system is compromised, social interactions break down (Adolphs, Baron-Cohen, & Tranel, 2002; Damasio, 1994, 1996). This makes it important to understand the mechanisms involved in emotion recognition. It is a process hypothesized to rely on both visual and non-visual mechanisms (Adolphs, 2002; Haxby, Hoffman, & Gobbin, 2000). One non-visual mechanism proposed to facilitate emotion recognition is sensorimotor simulation and its expression in mimicry (Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman, Winkielman & Ramachandran, 2008; Wood, Rychlowska, Korb & Niedenthal, 2016). However, its functional significance is debatable (e.g., Hess & Fischer, 2013; Rives Bogart & Matsumoto, 2010). Numerous experiments have found that interfering with mimicry impairs recognition, a result consistent with this hypothesis (Davis, Coulson & Winkeilman, 2017; Neal & Chartrand, 2011; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Korb et al., 2015; Maringer, Krumhuber, Fischer, & Niedenthal, 2011; Oberman, Winkielman & Ramachandran, 2008; Ponari et al., 2012; Rychlowska et al., 2014; Wood, Lupyan, Sherrin, & Niedenthal, 2016). However, not all of the data supports this hypothesis. Individuals with congenital facial paralysis appear relatively unimpaired at recognizing emotions (Calder et al., 2000b; Rives Bogart & Matsumoto, 2010) and interference results can be due to distraction. First, the interference manipulation could be distracting (see Rives Bogart & Matsumoto, 2010). Second, even when the manipulation is well controlled (e.g., Davis, Winkielman, & Coulson, 2017), disrupting an automatic process, namely mimicry, may be distracting in and of itself. This present research sought to test whether mimicry exhibited signs of being a computational mechanism that facilitated recognition without using an interference manipulation.

We did this by measuring facial EMG as participants categorized emotional expressions of joy, anger, and sadness that varied in visual emotion evidence. Visual emotion evidence was manipulated because different models of mimicry make different predictions about how people's faces will respond to expressions that are high or low in visual evidence. Experiment 1 (chapter 2) manipulated the visibility (normal, blurry) of expressions. Experiment 2 (chapter 3) manipulated their emotional intensity (high, low). Experiment 3 (chapter 4) showed participants only the top- or bottom- half of an expression at a time. The experiments were designed so that different outcomes would support different models of emotional mimicry. These models were the motor-matching model (Bargh & Chartrand, 1999, Hess & Fischer, 2013, 2014), the emotional mimicry in context model (Hess & Fischer, 2014), and the embodied computation model (motivated by Adolphs, 2006, Barsalou, 2013, and Barsalou et al., 2008). According to the motor-matching model, facial reactions should follow the perceptual information available in the stimuli: the more visual evidence, the more mimicry (see section 1.5.1.1). According to the emotional mimicry in context model, different emotional expressions signal different degrees of affiliation, and not all emotions are equally likely to be mimicked: joy is more likely to be mimicked than anger (see section 1.5.1.2). According to the embodied computation model, simulation facilitates recognition and mimicry is a product of simulation. Two potential simulation processes were tested (see section 1.5.1.3). The amplification hypothesis predicted that more mimicry should occur when expressions are low in emotion evidence and recognition is required (relative to when recognition is not required). The pattern-completion hypothesis predicted that mimicry should occur at muscle sites even when those muscle sites were not observed in the stimuli. In each case, the embodied computations are hypothesized to facilitate emotion recognition beyond the visual evidence.

5.2 Discussion of experimental manipulation results

Across each of the experiments, the behavioral and EMG data indicated that participants were actively engaging in the recognition task and attending to the stimuli. Participants were highly accurate at recognizing expressions of joy even when emotion information was reduced. Reducing emotion information reduced recognition accuracy for sadness and anger. This indicates that the manipulation made recognizing these expressions more difficult. Additional analyses could determine whether the errors were equally distributed across stimuli or if there were they particular items that were truly ambiguous according to both CERT and human judgments. If so, these could be pooled together into a negative affect condition and the data could be reanalyzed. In either case, the accuracy results indicated that participants were actively engaged in the categorization task. The EMG results indicate they were also attending to the stimuli in the passive viewing condition.

In each of the experiments we found mimicry of anger, joy and sadness. Experiments 1 and 2 (chapters 2 and 3) used a 3 (emotion) x 2 (visual emotion evidence) x 2 (task) repeated measures design and were set up to contrast the predictions of 3 models: the amplification hypothesis of the embodied computation model, the motor-matching model, and the emotional mimicry in context model. Neither task (categorization and passive viewing), nor visual evidence of the emotions influenced facial responses in a manner that was consistent with the predictions of the amplification hypothesis or the predictions of the motor matching model. Instead, they were better explained by the emotional mimicry in context model (Hess & Fischer, 2014).

According to emotional mimicry in context model, emotion recognition is an automatic process (Hess & Fischer, 2013), it should occur when passively viewing or actively categorizing expressions. Task did not significantly modulate responses within an emotion in either experiments 1 or 2, consistent with the position that emotion recognition is an automatic process. The emotional mimicry in context model also proposes that mimicry and facial reactions are based on the emotions that are inferred from expressions rather than the physical properties of the expressions themselves (Hess & Fischer, 2013, 2014; Hess, Houde, and Fischer, 2004). In experiment 1, participants mimicked expressions at a categorical level, whether the expressions were blurry or not—this is what would be expected if participants were mimicking the conceptual interpretation of an emotion rather than the low-level perceptual features. Another important claim of this model is that different emotional expressions signal different intentions. Mimicry is most likely to occur in response to expressions of joy because joy signals affiliation and mimicking it has little social cost. Mimicry of sadness is affiliative, but mimicry implies an implicit promise of concern, and thus is not as likely to be mimicked as joy. Anger signals aggression. When directed at an observer, it is the least likely expression to be mimicked since this can escalate aggression (for mimicry of specific emotions as a function of social meaning, see Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). In experiment two we found mimicry of joy and sadness. Participants also displayed congruent facial reactions to low intensity anger but not high intensity anger. For high intensity anger, participants responded with a relatively neutral expression. This makes sense from a social perspective—mimicking high intensity anger could increase aggression and be maladaptive. Displaying more mimicry to the low than the high intensity anger is the opposite of what the motor-matching model predicts. Although it is consistent with the predictions of the embodied computational model, we found that mimicry of anger did not mediate recognition of anger in this experiment, which argues against the computational interpretation. Additionally, this difference in facial responses to high and low intensity anger did not vary as a function of task, which also argues against the amplification hypothesis of the embodied computation model because engaging in simulation in order to recognize expressions was hypothesized to be task dependent—supplementing sparse visual information when recognition was required.

The task manipulation was dropped from experiment 3 because it had not made a meaningful difference in the mimicry of any given emotion in either experiment 1 or 2. Experiment 3 used a repeated-measures 3(emotion) x 2 (face half: top, bottom) design. This was used to test whether mimicry occurred at muscle sites that were not observed, a prediction of the embodied computation hypothesis and the emotional mimicry in context model (Hess, Houde, & Fischer, 2014). The motor-matching hypothesis made a different prediction, mimicry should follow the perceptual information and only occur in response to observed activity. According to this model, if a muscle was not observed, it should not be mimicked (See Hess & Fischer, 2013). The EMG results indicated that participants did mimic muscles that were not observed. The main effect at the zygomaticus (cheek) muscle site was consistent with both the embodied computation and the emotional mimicry in context models. The corrugator (brow) results revealed a main effect of emotion and a main effect of face-half. There were patterns of mimicry but there was greater overall activation when the corrugator was observed. There was significant corrugator relaxation to smiles, as predicted by both models. However, if it was the case that mimicry was merely a reflection of how expressions were interpreted, then whether the top or bottom half of an expression was observed should not influence mimicry. The emotional mimicry in context model cannot explain the finding that it did. The pattern completion hypothesis of the embodied computation model only predicts that pattern completion will occur.

While the majority of the experimental data was best described by the emotional mimicry in context model, the embodied computation model best explained the corrugator data for the face-half experiment. Overall, this suggests that the primary function of mimicry is social regulation, but embodied computations in the service of recognition also influence what occurs during mimicry.

5.3 Mediation discussion

In each experiment, mimicry (the emotion index) partially mediated between the visual evidence (CERT estimates) of some of the expressions and the way those expressions were categorized. This supports embodied computation. The effect, however, was small.

Since the effect was small and did not always occur, it supports the hypothesis that mimicry is not necessary for recognition. This interpretation is consistent with studies that have found that individuals with congenital facial paralysis, Möbius Syndrome, can recognize prototypical expressions as well as controls (Rives Bogart & Matsumoto, 2010). Mimicry's role in recognition is minor but not nonexistent. Perhaps this is why some individuals with Möbius Syndrome do show impairments (Gianni et al., 1984), particularly when recognizing subtle expressions (Calder et al., 2000b). The hypothesis that mimicry and simulation have subtle effects on emotion recognition and are most important when recognizing expressions that are relatively difficult to discriminate is consistent with other research that has interfered with mimicry as well (Davis, Winkielman & Coulson, 2017; Korb et al., 2015; Maringer et al., 2011; Neal & Chartrand, 2011; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Rychlowska et al., 2014; for a discussion of evidence, see Hess & Fischer, 2013).

Across the experiments, mimicry did not consistently mediate between visual emotion evidence and emotion recognition for all of the emotions. In experiment one, mimicry mediated between joy and anger. In experiment two, it was between joy and sadness. In experiment three, mimicry of joy mediated recognition of joy top- and bottom-half expressions, and mimicry of sadness mediated recognition for top expressions only.

This is a bit puzzling if one treats all emotions as equivalent stimuli that vary only in their morphological features. However, different expressions signal different emotions. This may influence simulation. Joy is affiliative expression, whereas sadness is less so, and anger less than that. The affiliative meaning of these signals influences their likelihood to be mimicked or returned with a congruent affective reaction (Hess & Fischer, 2013, 2014; Seibt, Mühlberger, Likowski, & Weyers, 2015). Our EMG data cannot discriminate between mimicry of a discrete emotion and a more general affective response. We would need to have recorded from many more muscle sites to do that. So, one possible explanation is that genuine mimicry was reliably occurring in response to joy and less reliably in response to the other emotions. If it was the case that mimicry but not emotional reactions mediated between vision and recognition, it would support simulation theories (e.g., Wood, Rychlowska, Korb & Niedenthal, 2016). Another possibility is that emotion recognition involves simulation in all cases but different emotions are simulated differently. It may be more advantageous socially to simulate and mimic joy through the face but keep the simulation relatively more concealed for expressions of anger. It is worth noting that MVPA of brain imaging (Kragel & LaBar, 2015) and autonomic activity (Kragel & LaBar, 2013) indicate that different emotions are represented differently. It could be that sensorimotor circuits are more important for the recognition of joy than other emotions. In line with this is research indicating that amygdala damage disrupts recognition of fear, anger, and surprise but not joy (Adolphs, Tranel, Damasio and Damasio, 1994). Insula damage selectively impairs recognition of disgust (Calder et al., 2000a). Although interference-based mimicry studies have found that impairing mimicry can impair recognition of different emotions, the most frequently published results demonstrate that interfering with a smile impairs recognition of joy. It would be worthwhile for future research to dig deeper into the topic of whether different emotions and expressions are simulated differently. It is also plausible that within a type of expression, e.g., smiles, there is variability in what is simulated and represented (for an in-depth examination of different types of smiles see Niedenthal, Mermillod, Maringer, & Hess, 2010).

Another question worth addressing is why any mediation occurred at all. For quite some time, mimicry has been hypothesized to induce emotional contagion, and through contagion it was hypothesized to facilitate empathy and recognition (e.g., Chartrand & Bargh, 1999). Yet not until recently was there empirical data that actually argued in favor of mimicry as an actual causal mechanism (Olszanowski, Wrobel, & Hess, 2019). The recognition benefit of mimicry could be due to either or both of these processes. The difference between the two is that in contagion, mimicry provides physiological feedback associated with an emotion, this feedback induces an emotional experience, and this felt sense facilitates understanding (e.g., Hatfield, Cacioppo & Rapson, 1993; Hatfield, Bensmen, Thornton, & Rapson, 2014; Neal & Chartrand, 2011). Mimicry causes the emotion which leads to understanding. Sensorimotor simulation on the other hand is an internal as-if mechanism that runs on embodied conceptual representations and functions to facilitate recognition—mimicry is a consequence of simulation (Wood, Rychlowska, Korb & Niedenthal, 2016). According to Adolphs (2002), the extended system involved in emotion recognition begins processing facial expression information after about 170ms but conceptual knowledge does not become activated until after 300ms. Mimicry is often not detectable until after 300-400ms (Dimberg & Thunberg, 1998). If contagion is a product of mimicry, it would need to occur after mimicry has begun. We did not collect data on when participants first recognized the expressions or whether they changed their minds as they watched the videos. We only collected their responses after the videos were complete. Disentangling what internal mechanism drove the mediation effects is a topic for future research. One way this could begin to be assessed would be to have participants make speeded categorization judgments and look at the time course of mimicry in relationship to that judgment.

5.4 A hybrid social-computational model

Most of the EMG data was best explained by the emotional mimicry in context model (Hess & Fischer, 2014) but the mediation data was not. The mediation data was better explained by simulation models of emotion recognition (e.g., Wood, Rychlowska, Korb & Niedenthal, 2016). This suggests that a hybrid model may be more accurate. Mimicry's primary function is affiliative (Chartrand & Bargh, 1999; Hess & Fischer, 2013, 2014) but it has a secondary function which is that it can facilitate recognition.

Experiment 3 was consistent with the pattern-completion hypothesis of the embodied computation model. Experiments 1 and 2 were not consistent with the predictions of the amplification hypothesis but a slight alteration of the model could make the data consistent. If we assume that emotion recognition is an automatic process, as the emotional mimicry in context model assumes (Hess & Fischer, 2013, 2014), then our passive viewing/categorization manipulation should not have made a difference. Since the high and low evidence stimuli elicited the same facial responses, it could be that participants simulate to a conceptual level of understanding and this is expressed in mimicry. There may be more mimicry than what was warranted by the low visual evidence stimuli and less than what was warranted by the high visual evidence stimuli. Testing this would require different types of task manipulations, perhaps manipulations that diverted attention from the emotional significance of the stimuli. By doing this, it would be possible to obtain a baseline measure of mimicry that was more representative of automatic, low-level processing.

Another possibility is that mimicry can facilitate motor simulation, but they are distinct and dissociable processes. Mimicry is often not a high-fidelity representation of the emotion that is observed (Hess & Fischer, 2013). For simulation to facilitate discriminate between subtleties in expressions, it would need to include relatively high-resolution details (for subtle differences between smiles and their meanings see Niedenthal, Mermillod, Maringer, & Hess, 2010). If they are distinct processes, then it may be the case that they are most likely to co-occur when variables such as the observed expression and the social relationship between the observer and the observed support affiliation, and when mimicking and recognizing the expression are most beneficial or rewarding. We found that mimicry influenced the recognition of emotions above and beyond the visual evidence most reliably when the emotion was joy. Mimicking and recognizing others' joy is mutually beneficial. Mimicry of joy promotes affiliation and has little social cost (Seibt, Mühlberger, Likowski, & Weyers, 2015). Simulating another's emotional state is a way to understand them. Understanding is a form of connection, further promoting affiliation. Smiles are socially rewarding (Seibt, Mühlberger, Likowski, & Weyers, 2015). Social rewards activate neural circuits involved in reward processing more generally (Bhanji & Delgado, 2013). Simulation is a means to obtain first-person experience of another person's emotional state (Adolphs, 2006). The first-person experience of joy also activates reward circuits (Kringelbach & Berridge, 2009). Sharing another person's happiness is intrinsically rewarding.

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Supplementary Materials

S1: Experiment 1 (Chapter 2)

We explored the data beyond what was warranted by the statistical analysis to see if there were trends that might be consistent with the embodied computation prediction that there should be an increase in mimicry related activity when the expressions were blurry rather than normal and the task required recognizing the emotions. We also wanted to check whether there were indications of mimicry at each muscle site. As a reminder, mimicry of joy is indicated by a decrease in corrugator and an increase in zygomaticus activity. Mimicry of sadness and anger are indexed by an increase in corrugator and a decrease in zygomaticus activity.

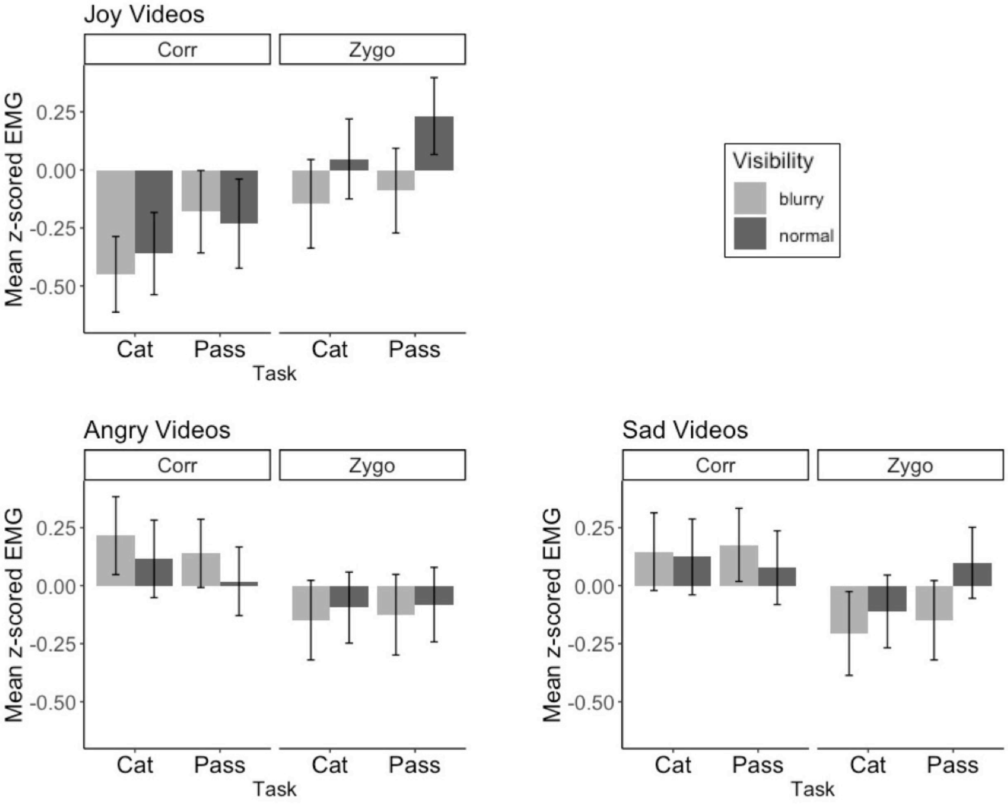

Figure S1 Experiment 1 EMG all conditions. Mean EMG values for each emotion video as a function of muscle site (Corr = corrugator, Zygo = zygomaticus), task (Cat = categorization, Pass = passive viewing), and visibility. The data do not support the hypothesis that reduced visibility increases mimicry as a function of task relevance. Error bars are 95% confidence intervals.

For joy, corrugator activity fit the pattern predicted for embodied computation, but it is clearly not a significant pattern. There were trends of more mimicry to blurry than normal videos when categorizing the expressions and just the opposite when passively viewing them. This pattern did not occur at the zygomaticus. Additionally, the zygomaticus response to the blurry videos was below baseline, indicating a lack of zygomaticus mimicry. This suggests the mimicry data should be interpreted with caution. However, corrugator relaxation is often a more reliable indicator of joy mimicry than increased zygomaticus response (Hess, 2009; Hess & Blairy 2001; Likowski et al, 2011a; Likowski et al, 2011b; Neufeld et al, 2016; Seibt, et al., 2013) and an emotion index contrast variable is arguably a more reliable indicator of mimicry than single muscle analysis (see Hess et al., 2017; Hess & Blairy, 2001; Olszanowski, Wróbel & Hess, 2019)).

EMG responses to videos expressing anger showed a trend of greater mimicry (at both the zygomaticus and corrugator sites) when participants viewed the blurry videos than the normal videos. If it was the case that participants were implicitly categorizing the expressions during the passive viewing task, this data would be consistent with embodied computation. It is possible that this was the case. Angry facial expressions automatically capture attention, even when presented to the neglected visual field in hemineglect patients (Vuilleumier & Schwartz, 2001). Facial expressions that signal a potential physical attack activate the amygdala to the same extent whether a face is or is not attended to (Anderson et al., 2003). Given that angry faces capture attention and are evaluated at a subcortical level, it is possible that the task did not matter and there was biological motivation to recognize the blurry expressions. Again though, the data is only trending in this direction. A similar trend of more mimicry in response to the blurry videos occurred for sadness expressions but the variability was very large and so once again, little can be made of this. Overall, there was no significant evidence of embodied computation, even if some of the data trended in the appropriate direction.

S2: Experiment 2 (Chapter 3)

We looked at the EMG data separately for each emotion as a function of EMG channel, task, and intensity (see Figure 3.6) to see if there were trends consistent with the embodied computation hypothesis—increased mimicry patterns to the low intensity stimuli when categorizing relative to passively viewing them (but no difference for high intensity stimuli). Although some data appeared to trend this direction it was not significant or consistent

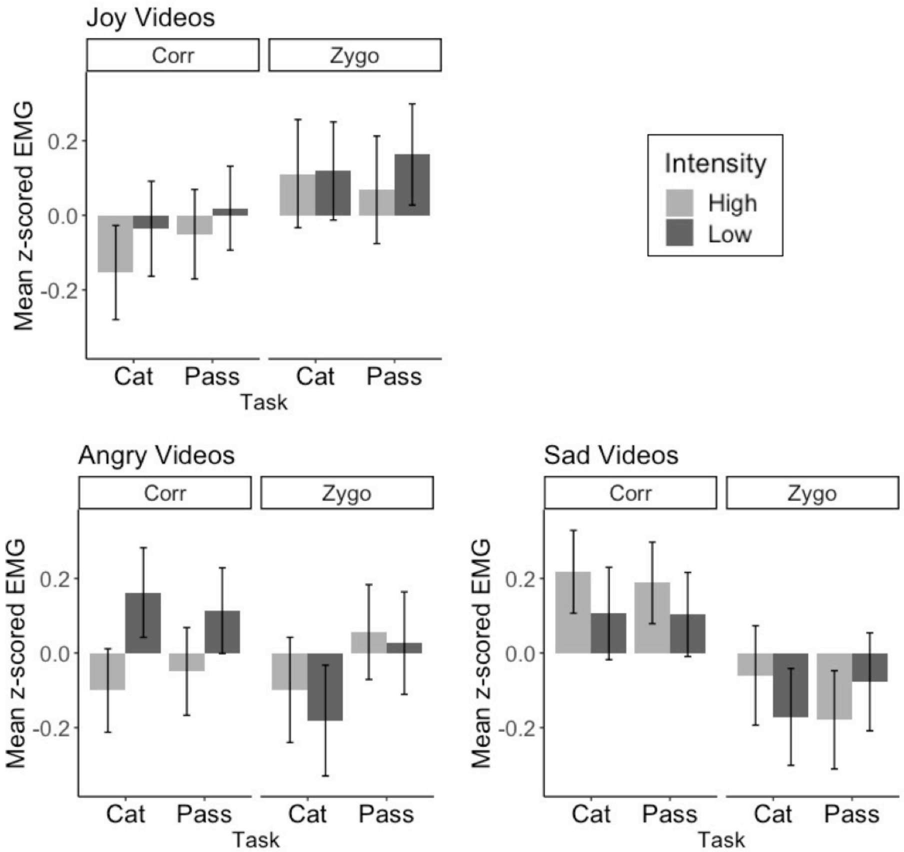

Figure S2 Experiment 2 EMG all conditions. EMG data for each type of emotion video as a function of EMG muscle site, task, and intensity. Corr = Corrugator; Zyg = Zygomaticus; Cat = categorization task; Pass = passive viewing task. Error bars reflect 95% confidence intervals.

S3: Experiment 3 (Chapter 4)

In this study we were interested in whether mimicry occurred at muscles sites that were not observed in the stimuli. As, such this data is presented by muscle site rather than emotion.

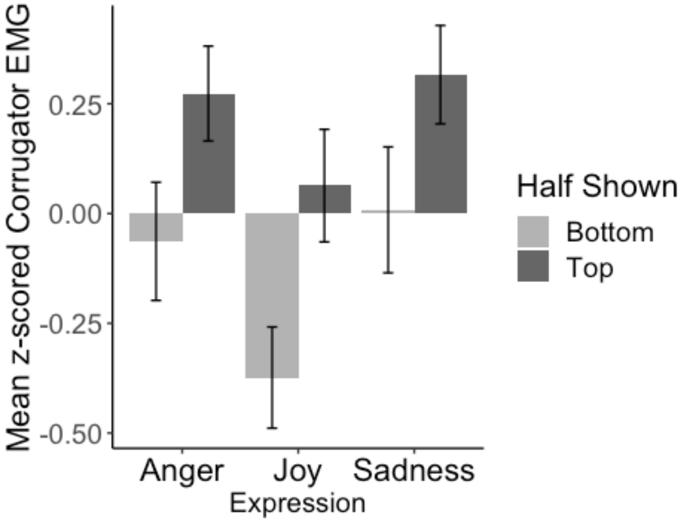

Figure S3.1 Experiment 3 corrugator all conditions. Error bars reflect 95% confidence intervals.

In the corrugator analysis, there was a main effect of face half and a main effect of emotion and no interaction. As can be observed in figure S3.1, the data is consistent with mimicry when looking only at the top half (more activity in response to anger and sadness than to joy). This is also true in the bottom half.

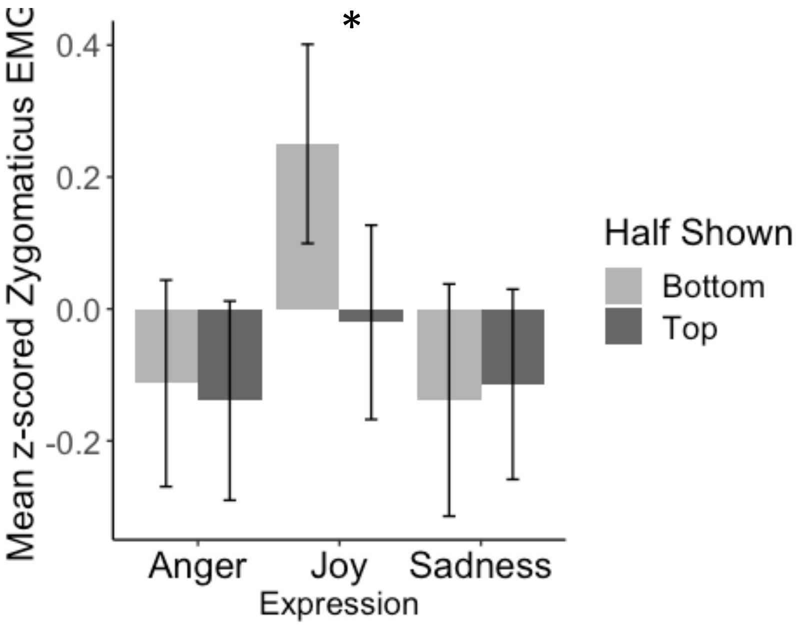

Figure S3.2 Zygomaticus EMG all conditions.

The analysis of the zygomaticus data revealed a main effect of emotion (p = 0.003). The interaction between emotion and face half was not significant (p = 0.12). However, looking at all of the data suggests that zygomaticus mimicry occurred when viewing the bottom half stimuli but not top half stimuli. There was more joy mimicry when observing the lower face expressions (smiles) than the top face expressions. This is somewhat consistent with research that has found adults display less zygomaticus mimicry when observing an infant with a pacifier in their mouth relative to an infant displaying a full expression. However, it is not entirely consistent. They included a condition in which a white box was placed on the images covering the same area as the pacifier but this did not reduce zygomaticus mimicry (Rychlowska et al., 2014). Given that but the means for top half zygomaticus activity are greater than the means for any of the anger or sadness expressions, they are not significantly greater, we suggest interpreting upper face mimicry at the zygomaticus with caution.