# Physically Emotional

## The Role of Embodied Emotions from Encoding to Memory

Candidate:

Jenny Charlotte Baumeister

Advisors:

Raffaella I. Rumiati & Francesco Foroni

Thesis submitted for the degree of Doctor of Philosophy in

Cognitive Neuroscience

Trieste, 2015

# Acknowledgments

I am deeply indebted to my advisers Raffaella Rumiati and Francesco Foroni for their fundamental role in my doctoral work. I thank them both for the great effort they put into training me in the scientific field. Raffaella gave me the freedom to develop my own research ideas, while at the same time continuing to contribute valuable feedback, advice, and encouragement. Francesco provided me with the guidance, expertise, and insights that I needed.

I am very grateful to Prof. Ursula Hess and Prof. Maria Paola Paladino for their time and valuable feedback on a preliminary version of this thesis. I also would like to thank Prof. Piotr Winkielman and his (former) lab-members, Galit Hofree, Liam Kavanagh, and Evan Carr for welcoming me as a member of their lab for several months and introducing me into the use of facial EMG. I would like to thank Tim Yu and Kaja Mitrenga for their many hours of help in testing participants, Dr. Markus Conrad for providing the stimuli for the L1/L2 project, Dr. Giovanni Papa for the help in recruiting participants for the project involving Botox users, and Alessio Isaja for the constant IT-support. I'd like to give a very special thanks to my colleagues Georgette Argiris and Sebastian Korb, who have been a tremendous support during the data collection and analysis of the EEG data. I also would like to express my deep gratitude to Ana Diez-Martini, Giovanni Novembre, and my sister Leonie Baumeister, who all spent hours on translating stimuli and questionnaires for me, and Laura Babcock for lots of useful advice and practical help in accomplishing the minor and major issues in writing a thesis. I would like to express my deep gratitude to Joe Bashe, who spent countless days and nights proofreading chapter after chapter, and who introduced me to the joys of pivot tables and programming. Finally, I would like to thank Prof. Ben Thompson, whose guidance and encouragement during my last year in university has been decisive for me to pursue a doctoral degree.

During the past years at SISSA I had the pleasure to meet many wonderful colleagues, who became my friends and a second family. I would like to thank all of them for being a constant source of knowledge, input, and inspiration.

# Table of Contents

**Chapter Title** **Page**

**Abstract** **7**

**Chapter 1 – Introduction** **11**

1.1 Embodied Cognition 11
1.2 Embodied Emotions 14
1.3 Facial Motor Resonance 16
1.4 The Function of Facial Motor Resonance 18
1.5 Emotional Memory - I embody and therefore I remember? 20

**Chapter 2 - The Role of Facial Muscle Resonance in Emotion Processing: Why emotional intensity matters** **22**

2.1 Introduction 22
2.2 Materials 26
*2.2.1 Participants* 26
*2.2.2 Stimuli* 27
2.3 Procedure 32
*2.3.1 Session 1* 32
*2.3.2 Session 2* 34
2.4 Results 34
*2.4.1 Control analysis for mood and affect* 35
*2.4.2 Rating of sentences task* 35
*2.4.3 Rating of facial expressions task* 39
*2.4.4 RT task* 43
2.5 Discussion 47

**Chapter Title** **Page**

**Chapter 3 - When the Mask Falls: The Role of Facial Motor Resonance in Memory for Emotional Language 53**

3.1 Introduction 53

3.2 Method 58

*3.2.1 Participants* 58

*3.2.2 Stimuli* 58

*3.2.3 Muscle-blocking strategy* 61

3.3. Procedure 62

3.4 Results 65

*3.4.1 Data preparation and data analyses approach* 65

*3.4.2 Encoding phase* 66

*4.4.3 Retrieval phase* 68

3.5 Discussion 74

**Chapter 4 - Embodiment and Emotional Memory in a Second Language 81**

4.1 Introduction 81

4.2 Method 84

*4.2.1 Participants* 84

*4.2.2 Stimuli* 85

4.3 Procedure 87

*4.3.1 Encoding phase* 87

*4.3.2 Retrieval phase* 88

*4.3.3 EMG/SC acquisition* 89

4.4. Results 89

*4.4.1 PANAS* 89

*4.4.2 EMG/ SC data preparation* 89

*4.4.3 Statistical analysis EMG data* 90

*4.4.4 Statistical analysis of the SC data* 93

*4.4.5 Behavioral results* 94

4.5 Discussion 99

**Chapter Title** **Page**

**Chapter 5 – Forget It If You Can - A Combined EMG/ERP Study of Directed Memory and Forgetting of Emotional Words** **105**
5.1 Introduction 105
5.2 Methods 116
*5.2.1 Participants* 116
*5.2.2 Stimulus material* 117
*5.2.3. Procedure* 118
*5.2.4 EEG data acquisition and preparation* 121
*5.2.5 EMG data acquisition and preparation* 123
5.3 Results 124
*5.3.1 Behavioral results* 124
*5.3.2 EMG results* 125
*5.3.3 EEG results* 132
*5.3.4 Correlation analyses* 139
5.4 Discussion 143

**Chapter 6 – General Discussion** **150**
6.1 Embodied Simulations and the Benefit of Doubt 151
6.2 Embodied Memories 154
6.3 Neuroscientific Perspectives on Facial Motor Resonance 157
6.4 Shortcomings and Limitations 160
6.5 Conclusion 161

**References** **163**

# Abstract

Theories of embodied cognition hold that the perception of an emotional stimulus can trigger a simulation of the correspondent state in the motor, somatosensory, and affective systems. Amongst other bodily reactions, it is thought that such embodied simulations are also reflected in facial expressions in accordance to the emotional connotation of the presented stimulus – a phenomenon also referred to as facial motor resonance. Chapter 1 reviews the theories of embodied cognition, in general, and facial motor resonance, in particular. The aim of the present thesis was to further define the function of embodied simulations, reconciling previous inconsistent results concerning the level at which embodied simulations affect the processing of emotional information, and to explore uncharted aspects of embodiment theories such as their role in memory for emotional information.

In Chapter 2, I investigated the hypothesis that embodied simulations play a key role in processing only emotional information (happy and sad sentences and faces), which is low in emotional intensity or difficult to encode. This hypothesis was tested in a behavioral experiment involving a group of participants undergoing subcutaneous cosmetic injections of Botulinum Toxin-A (Botox) compared with a matched control group. The results confirmed the hypothesis: participants in the Botox group, but not those in the control group, rated emotional sentences and faces as less emotional after the Botox treatment. Furthermore, they were slower at identifying sad faces as sad

after the treatment. The critical nuance of these findings was that only stimuli with moderate emotional intensity were affected.

Upon considering the findings of Chapter 2, the question arose as to whether facial motor resonance, in addition to playing a role in the initial processing and recognition of emotional content, also determines its retrieval. This topic was investigated in the study reported in Chapter 3, in which eighty participants underwent a memory task for emotional and neutral words. The task consisted of an encoding and a retrieval phase. Facial muscles were blocked by a hardening facial mask in one of four conditions: during encoding, during retrieval, during both encoding and retrieval, or never (control). The results showed that memory for emotional words decreased significantly if embodiment was blocked at either point in time during the experiment (during encoding, during retrieval, or during both), in contrast to the control condition. These results suggest that facial motor resonance is involved in the encoding and retrieval of emotional words.

In Chapter 4, this line of research was extended and applied to the processing of emotional content in a second language (L2). In a classical memory task involving an encoding and a retrieval phase, thirty-two Spanish/English late bilinguals were presented with emotional (happy and angry) and neutral words. Electromyographic (EMG) activity and skin conductance (SC) were recorded during the encoding phase. The results suggest that the emotionality of an L2 appears to be not only reduced as compared with a first language (L1), but also to be less embodied. This was suggested both by the absence of the Enhanced Emotional Memory (EEM) effect in L2 as well as by partially decreased and delayed EMG and SC activity in response to emotional words in L2 as compared with L1.

If facial motor resonance is involved in the recollection of emotional information, what is its role in forgetting emotional information? This question was pursued in the study reported in Chapter 5, employing the directed forgetting paradigm (DF), which involves the presentation of a stimulus (e.g. a word), followed by a cue to “remember” (R-cue) or to “forget” (F-cue). Twenty-one participants were instructed to remember or to intentionally forget neutral, negative, and positive words. EMG from the zygomaticus and corrugator muscle was simultaneously recorded with event related potentials (ERPs). The behavioral results showed that both neutral and emotional words were forgotten at equal rates. However, the type of word and cue instruction interactively modulated facial motor resonance, as measured by EMG. Upon R-cues, the muscle activation patterns for both negative and positive word types were significantly enhanced, in contrast to the facial motor resonance evoked by F-cues. It was speculated that the increase in facial motor resonance reflects active rehearsal, whereas the decrease is associated to active suppression mechanisms. This assumption was supported by the ERP data, indicating that the successful forgetting of affective words required more active suppression, as was indexed by enhanced frontal positivities. In contrast, intentional encoding of emotional words followed by R-cues seemed to be facilitated by an enhanced P3 and late positive potential (LPP) components emerging from centro-parietal areas. These components have been hypothesized to reflect rehearsal and memory consolidation processes.

Overall, the present results suggest that embodied simulations help with the processing of indefinite emotional information and assist with the formation of enduring representations of emotional stimuli. The implications of these findings for theories of embodied cognition, in general, and for emotion processing, in particular, are discussed in Chapter 6.

# Chapter 1

# Introduction

## 1.1 Embodied Cognition

A body can be defined as the physical structure of an organism that gives shape to its being. Yet, there is much more to it. It serves us as a home for our actions, feelings, and thoughts. But embodied theories propose that its role goes well beyond that of a passive instrument. They state that the body itself is able to guide our perception and behavior. Embodied theories became popular in the 1990s (see Barsalou, 2008, for a review), but they arose from early approaches at defining the relationship between the body and mind.

Nietzsche (1872) emphasized that embodied imitations of external stimuli are a fundamental process in human meaning making. In his words, “knowing is nothing but working with the favorite metaphors, and imitating which is no longer felt to be an imitation*” (p.50).* Only few years later, the James-Lange theory proposed that emotional experience occurs only in response to physiological changes (James, 1884; Lange 1912). In this view, emotions are only a secondary reaction to information received via the body's nervous system. For example, we experience sadness because we cry, rather than cry because we are sad. This view received a lot of criticism, as several studies on animals and humans demonstrated that emotion could be experienced even if physiological changes are not sensed (Cannon, 1927). However, the basic idea of a close relationship between the body and the mind was further pursued.

In the middle of the 20th century, the developmental psychologist and philosopher Jean Piaget (1952) argued that cognitive abilities emerge from sensorimotor abilities. This means that throughout development, the body accommodates and assimilates new environmental information. Hence, learning involves giving external stimuli a persistent representation within our physical structure. Later, in the 1980s, linguists followed up on the ideas previously formulated by Nietzsche as they began exploring the link between abstract linguistic concepts and metaphors for bodily, physical concepts (e.g., Lakoff & Johnson, 1980). For example, drooping shoulders are typically associated with gloom and sadness, but an upright posture is associated with a positive emotional state. Likewise, the polar opposites of *up* and *down* are also used in many languages to reference to something positive or negative. Accordingly, I might feel *down* because I encounter a problem, but my spirits may *rise* as soon as I find the solution. Finally, Damasio (1996) defined emotions in his famous Somatic Marker Hypothesis as occurring from physiological changes in the body, which, only in a second step, are relayed to the brain. The brain then makes sense of these somatic markers by associating an emotion with the stimulus that triggered them. This past emotional association to a stimulus then guides future behavior, helping us to make appropriate responses, even in the absence of any conscious awareness.

Nowadays, such approaches are summarized under the banner of theories of embodied cognition. They hold that knowledge of the outside world is grounded within our body, including the motor, somatosensory, affective, and reward systems. In that way, the perception of a stimulus evokes its multimodal representation within the body.

This, in turn, causes a re-activation of the perception, action, and emotional associations with it. For instance, upon the perception of a visual object (e.g. a cup), simulations of potential actions, such as appropriate grasping preparation, are triggered (Bub, Masson, & Cree, 2007; Tucker & Ellis, 1998, 2004). Findings like this suggest that humans automatically activate embodied knowledge about objects in terms of how they can be used and manipulated. It is thought that this embodied knowledge is accessed to make sense of the world around us.

Due to their fundamental nature, the theories of embodied cognition have immediate relevance to the full range of cognitive research fields (see also Barsalou, 2008, for a review), including action and perception (e.g. Bub et al., 2007; Tucker & Ellis, 1998, 2001), language comprehension (e.g. Intraub & Hoffman, 1992; Tucker & Ellis, 2004), social cognition (e.g. Dijksterhuis & Bargh, 2001; Nakamura, Ito, Honma, Mori, & Kawaguchi, 2014), and emotion processing (see Niedenthal, 2007). The present thesis will focus on the last, investigating the role of embodied knowledge in emotion processing, ranging from initial encoding to retrieval and forgetting of emotional information, over the course of four experimental studies. As outlined above, the controversial hypothesis of the James-Lange theory, stating that emotions only follow bodily reactions, is seen as a root for the embodied cognition view, in general, and for the view of *embodied emotions*, in particular. However, the modern theories of embodied cognition set a more moderate tone in their portrayal of the relationship between the body and emotions, as will be outlined in subsection 1.2.

## 1.2 Embodied Emotions

A human body can express emotions in various ways. For example, if you are afraid of snakes, you may express several bodily reactions upon seeing one on the wayside. You will probably display a scared facial expression, your pupils will constrict, you will start to sweat, and you will feel your heart beat accelerating. Interestingly, similar reactions can sometimes be evoked by a mere picture of a snake or by simply seeing the word *snake*.

These phenomena are explained by theories of embodied cognition as signs of a physical *simulation* and *re-enactment* of the original emotion associated with a stimulus (Niedenthal, Winkielman, Mondillon, & Vermeulen, 2009; Semin & Cacioppo, 2008; Niedenthal, 2007; Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). In other words, knowledge of an emotion concept is not simply reduced to an abstract linguistic description but is thought to engage simulations of previously experienced emotions associated to the concept. Thus, even though the word *snake* does not present a danger in itself, the embodied knowledge of the snake-concept is automatically activated, and with it, a fear response. This is thought to be mirrored in the activation of affective brain networks involved in the experience of the respective emotion in oneself. Support for this account comes from several neuroimaging studies demonstrating that the recognition of emotional expressions, as well as the processing of valenced words and pictures, activate brain structures, such as the prefrontal cortex (PFC), somatosensory cortices, and amygdala, which also have a key role in the experience of emotions in oneself (e.g. Adolphs, 2002; Kensinger and Schacter, 2006).

Since populations of neurons in the affective networks are vastly interconnected with other brain structures, the activation of a pattern of neurons in one system can, independent of modality, easily cascade across the brain. This allows a fast multimodal re-establishment of given emotional information, hereby also leading to a modulation of a perceiver's motoric and somatic state (Damasio, 1989). See Figure 1.1 for an illustration of this concept.

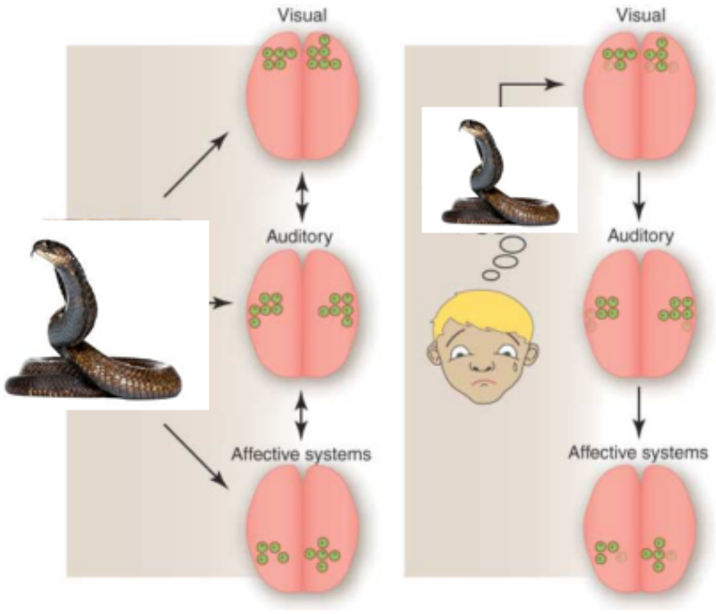


**Figure 1.1 (Left)** Upon perception of a snake, populations of neurons in the visual, auditory, and affective systems are activated. **(Right)** The same populations originally associated with the snake appearance can become reinstated when later remembering the snake, as for example when reading or hearing the word *snake*. (Figure adapted from Niedenthal, 2007)

Although these motoric and somatic simulations are thought to be often subtle and unconscious, they are nevertheless detectable by means of psychophysiological measurements. For example, heart rate has been shown to significantly change in response to emotional words, whether they were presented visually (Buchanan, Etzel, Adolphs, & Tranel, 2006) or aurally (Ilves & Surakka, 2012). Similarly, skin conductance (SC), which is a peripheral index of arousal and closely linked to sweat gland activity, has repeatedly been shown to increase upon the simple viewing of positive and negative pictures (e.g. Codispoti, Bradley, & Lang, 2001), or photos of emotional facial expressions (e.g. Merckelbach, Van Hout, Van den Hout, & Mersch, 1989). It could be argued that the viewing of strongly negative pictures powerful enough to induce startle reflexes (Codispoti et al., 2001) do not require simulations to be understood. It is therefore important to consider that also rather abstract stimuli, such as emotional words, increase SC (e.g. Gray, Hughes, & Schneider, 1982; McGinnies, 1949). However, our most intrinsic and specific way of showing emotions is the posing of facial expressions. They can be interpreted as affective subtitles of our action, perception, and thoughts. It is thus just consequential to assume that the embodiment of emotion concepts is also notably reflected in the activation of facial mimetic muscles.

## 1.3 Facial Motor Resonance

The human face can effectively communicate emotional states in the absence of spoken words. It does so by activating mimetic muscles that innervate directly to the facial skin. In this way, even tiny muscle contractions are sufficient to move the overlying skin, hereby creating distinctive facial expressions. Clearly, facial expressions are largely used to enforce the significance of our affective state to others. But theories of embodied cognition suggest that their role may go beyond that of a social tool and also occur in conditions in which the perceiver attributes emotional meaning to a stimulus at hand (Barsalou, 1999, 2003; Gallese, 2003; Niedenthal, 2007). Given that embodied motor processes are often referred to in the literature as *motor resonance* (e.g. Hogeveen & Obhi, 2012; Quené, Semin, & Foroni, 2012; Zwaan & Taylor, 2006), the term *facial motor resonance* will be used in the following to refer to the motor resonance of facial mimetic muscles in response to emotion-laden stimuli. The embodied responses of the mimetic muscles have been extensively studied using Electromyography (EMG) recordings. EMG measures electrical currents generated in muscles during contraction by means of passive electrodes placed over the muscles of interest. Two of the muscles, whose activity in response to emotional stimuli is often recorded in studies employing facial EMG, are the zygomaticus major and the corrugator supercilii muscles (e.g. Larsen, Norris, & Cacioppo, 2003). The former pulls the corner of the mouth upwards and is the primary muscle in smiling. The latter draws the eyebrows downward or medially and has a major role in facial expressions associated to negative emotions, such as sadness, anger, disgust, and fear.

In line with what theories of embodied cognition would suggest, EMG recordings have repeatedly shown facial motor resonance to be compatible with the emotional content of a stimulus. For example, matched facial muscle activation occurs in response to pictures of facial expressions (Dimberg, Thunberg, & Elmehed, 2000; Dimberg, Thunberg, & Grunedal, 2002), emotional words (Foroni & Semin, 2009; Niedenthal et al., 2009), and prosody (e.g., Hietanen, Surakka, & Linnankoski, 1998; Quené et al., 2012).

Facial motor resonance thus seems to be a rather stable phenomenon. This raises the question: What is the role of facial motor resonance?

## 1.4 The Function of Facial Motor Resonance

Theories of embodied cognition suggest that facial motor resonance is not an accessorial phenomenon, but instead it has a facilitative function in the comprehension and processing of emotional information by providing us with proprioceptive feedback (e.g., Foroni & Semin, 2009; Niedenthal et al., 2009; Zwaan, & Taylor, 2006). Evidence in line with this interpretation comes from studies in which facial muscles' activity was blocked by external manipulations. For example, by instructing participants to hold a pen laterally between their teeth, facial motor resonance can be prevented, impairing the recognition of emotional words and facial expressions (Niedenthal et al., 2009; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman, Winkielman, & Ramachandran, 2007). In a study by Havas and his colleagues (Havas, Glenberg, Gutowski, Lucarelli, & Davidson, 2010), participants were found to be slower at reading emotionally negative sentences after they had received Botulinum Toxin-A (BTX) injections into their corrugator supercilii. BTX is a strong neurotoxin that is used in the cosmetic industry to paralyze mimetic muscles for aesthetic purposes. It temporally leaves the injected muscles completely immobilized, allowing the investigation of how blocked mimetic muscles affect emotion processes. The authors argued that facial motor resonance is thus not only an accessorial phenomenon but is causally and selectively involved in emotion processing. Growing evidence supports the claim that the role of embodied simulations may go well beyond initial processing: they also seem to guide our behavior and judgments (e.g., Foroni & Semin, 2009; 2011; 2012; Winkielman, Berridge, & Wilbarger, 2005).

However, the link between facial motor resonance and the recognition and perception of emotions does not seem to be as clear-cut as could be assumed from these findings. For example, in a study by Davis et al. (2011), BTX-blocked mimetic muscles only altered the perception of slightly emotional stimuli but did not seem to interfere with the experience of strongly emotional ones. Others studies could not establish a relationship between facial motor resonance and emotion recognition at all (Blairy, Herrera, & Hess, 1999; Hess & Blairy, 2001; Fischer, Becker, & Veenstra, 2012). It thus seems that the facilitative effect of embodied processes on emotion processing is rather complex and possibly only mediated under certain conditions. I will follow up on this notion in **Chapter 2**, which is dedicated to testing the hypothesis that facial motor resonance has a particularly facilitative role in understanding and processing stimuli and situations whose emotion association is weak or difficult to recognize.

Another aspect that awaits investigation is the role that embodied simulations, in general, and facial motor resonance, in particular, plays in memory processes. If facial motor resonance has any role in the perception of emotional stimuli, it is conceivable that it will also affect their memory. Indeed, as discussed in section 1.5, memory processing is highly sensitive to emotions.

## 1.5 Emotional Memory - I embody and therefore I remember?

Emotionally arousing experiences, events, and stimuli tend to be well-remembered. Most of the time, they are significantly better remembered than everyday occurrences and neutral stimuli. This emotional persistence is often referred to as the emotional enhancement of memory effect (EEM, see Buchanan & Adolphs, 2002; Hamann, 2001; LaBar & Cabeza, 2006, for reviews). The EEM effect has been demonstrated using different types of stimuli, such as pictures (Chainay, Michael, Vert-Pré, Landré, & Plasson, 2012), words (Kensinger & Corkin, 2003), sentences (Laney, Campbell, Heuer, & Reisberg, 2004), and film-clips (Cahill et al., 1996).

Kensinger and Corkin (2004) proposed that EEM is caused by the arousal-aspect of emotional stimuli, which activates an amygdala-hippocampal network, whereas the processing of neutral stimuli depends on a prefrontal cortex-hippocampal network. This dual route is thought to facilitate the consolidation of emotional stimuli, as the amygdalar activation provides a salient and rather automatic processing. In contrast, the prefrontal cortex – hippocampal route is associated with controlled, elaborative encoding processes, making the consolidation of neutral information more effortful.

Because theories of embodied cognition claim that embodied simulations play a large part in the perception and recognition of emotional stimuli, one could assume that they also support the mechanisms that underlie their enhanced memory. And indeed, a recent finding demonstrated that mimetic muscle activation modulates amygdala activity (Hennenlotter et al., 2009). Whether this presumable link between embodied simulations and memory can also be established behaviorally is investigated in Chapters

3-5. **Chapter 3** is devoted to the general role of facial motor resonance in the encoding and retrieval of emotional stimuli. In a novel approach, the specific effects of embodied simulations are investigated at different stages of emotional memory processing (during encoding and/or retrieval). The tie between embodied cognition and emotional memory is further investigated in **Chapter 4.** In this chapter, I explore whether differences in embodied simulations in a first language (L1) vs. a second language (L2) are also reflected in an altered processing of emotional content. The focus is on the investigation of processes and embodied simulations associated with emotional memory. Finally, in **Chapter 5**, the topic is directed to the relationship between brain activation and facial motor resonance during intentional memory vs. intentional forgetting. If facial motor resonance helps us to remember, will it ultimately also not let us forget?

# Chapter 2

# The Role of Facial Muscle Resonance in Emotion Processing: Why Emotional Intensity Matters

## 2.1 Introduction

The relationship between embodiment and emotion processing is a complex one. On the one hand, several findings support the notion of a close link between emotion understanding and embodied processes, especially with facial motor resonance (Künecke, Hildebrandt, Recio, Sommer, & Wilhelm, 2014; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Oberman, et al., 2007; Zwaan, & Taylor, 2006). On the other hand, other findings could not confirm a facilitative function of facial motor resonance in the perception of emotion (Blairy, Herrera, & Hess, 1999; Fischer, Becker, & Veenstra 2012). These seemingly opposing results may be reconciled by defining the mediators that modulate the influence of facial motor resonance on our behavior and perception. One such mediating factor could be the emotional intensity and recognizability of the emotional information at hand, as recently suggested by Hess and Fischer (2013). They speculated that only nonprototypical facial expressions benefit from facial motor resonance during decoding. They supported this hypothesis with findings from Oberman et al. (2007), who showed that blocking muscles negatively affected the recognition of happiness. The critical detail is that Oberman et al. (2007) used stimuli adjusted to lower levels of happiness in order to avoid a ceiling effect in recognition accuracy. Similarly, another study that found an interference effect of blocked facial motor resonance on emotion recognition focused on subtle differences in facial expressions (Maringer, Krumhuber, Fischer, & Niedenthal, 2011). The findings by Davis and colleagues (2011) suggest that slightly emotional non-facial stimuli may also specifically benefit from facial motor resonance. Their study explored whether participants would rate positive and negative video clips differently after a BTX treatment (Davis, Senghas, Brandt, & Ochsner, 2011). In contrast to their original hypothesis, BTX-blocked mimetic muscles did not alter participants' perception of emotional video clips. Instead, they discovered that the missing facial feedback did weaken the participants' perception of slightly happy video clips, which had originally been introduced as control stimuli. In summary, there has been some support for the account that facial motor resonance is especially important when the evoked emotional impulse is low and the emotion-stimulus association is weak.

So far, only one study has explicitly investigated this idea (Hess & Blairy, 2001). In order to explore whether the decoding of slightly emotional stimuli would benefit from facial feedback, Hess and Blairy used dynamic facial expression stimuli that showed the affective expression in a moderate, natural-like manner. Surprisingly, the results revealed no correlation between mimetic muscle activity and emotion decoding accuracy. However, establishing a correlation between facial motor resonance and decoding accuracy may be especially difficult, considering the strong inter-individual differences in facial muscle activation to facial stimuli (Künecke et al., 2014). A general paralysis of the corrugator muscles, as can be achieved with BTX, could bypass the complex role of mimetic muscle activation in face perception. Furthermore, facial stimuli are rather complex because they also have strong social and affiliative components. It is therefore of interest to extend the range of stimuli to those that are less influenced by social aspects, such as written emotional language. As a consequence, it may be too early to abandon the idea that facial motor resonance has a particularly facilitative role in understanding and processing stimuli and situations whose emotion association is weak or difficult to recognize.

The present study further investigated this hypothesis by assessing the perception of slightly and very emotional stimuli in first time BTX users before and after their treatment of the corrugator supercilii and orbicularis oculi muscles. The former muscle pulls the eyebrows together to a frown in response to negative emotions and relaxes in response to positive emotions. The latter can squint the eyes, causing "laugh lines" lateral to the eyes, and is thus the major muscle to accompany honest smiles (Niedenthal, Mermillod, Meringer, & Hess, 2010). But it can also crinkle the eyes and is therefore also activated by negative emotions, such as sadness (Katsikitis, 2003). The emotional stimuli consisted of slightly and very happy and sad static facial expressions, and slightly and very happy and sad sentences describing a situation. This variety of stimuli allowed a comparison of effects across different stimuli types (facial expressions vs. emotional language). The choice for static rather than dynamic facial expressions was owed to a previous finding showing that static facial expressions evoke more motor cortex activity than dynamic facial expressions (Kilts, Egan, Gideon, Ely, & Hoffman, 2002). The authors claim that this may be due to the fact that the decoding of emotional content in static facial expressions requires more simulation of the expression to match the static percept to its dynamic mental representation. Thus, using static rather than dynamic facial expressions as stimuli may be more straightforward for the investigation of facial motor resonance. Two rating tasks were designed to access whether participants' perception of emotional sentences (Sentences rating task) and emotional facial expressions (Facial expressions rating task) would differ after the treatment. Since no link between facial motor resonance and comprehension of slightly emotional stimuli was found in the previous results (Hess & Blairy, 2001), I added a third task (RT Task) specifically designed to assess possible speed-differences in interpreting facial expressions after the BTX treatment. This task was meant to assess participant's reaction times (RTs) and accuracy in categorizing slightly and strongly emotional faces into either being *happy* or *sad*.

If facial motor resonance has a specifically supportive role in the processing and understanding of stimuli with a weak emotional connotation, then a decrease in emotionality ratings for slightly emotional stimuli would be expected when facial muscles are blocked. When categorizing facial expressions under time pressure, RTs should increase after BTX treatment for slightly emotional stimuli. The RTs in response to very emotional stimuli are expected to be not at all or less affected by the BTX treatment. Lastly, since the BTX-injected muscles (orbicularis oculis and corrugator supercilli) have a role in happy and sad expressions, I expect that any interference by the BTX treatment should occur for both happy and sad emotions. However, since another major smiling muscle, the zygomaticus major, was left untreated and because happy expressions are generally easier to decode (see Adolphs, Damasio, Tranel, & Damasio, 1996; Adolphs, Damasio, Tranel, Cooper, 2000; Oberman et al., 2007), I speculate that the effects for happy emotions will possibly be smaller than for sad emotions.

## 2.2 Materials

### *2.2.1 Participants*

Twenty-two healthy native Italian speaking female participants took part in the experiment. Eleven of them (mean age 52.3, range 35-66) received BTX injections for the first time for cosmetic purposes, and the other 11 served as a control group. The BTX patients were recruited and informed about the study by a collaborating plastic surgeon from the plastic surgery department of the local hospital. Participants in the BTX group received BTX injections into the corrugator supercilii muscles (involved in frowning) and into the orbicularis oculi (muscles lateral to the eyes involved in producing laugh lines). Two participants received injections into the corrugator supercilii, only. The eleven participants in the control group (mean age 50.3, range 34-60) had never received any BTX injections and served as controls. The control participants were recruited by announcements. All participants gave written informed consent according to the procedures approved by the local ethics committee and the Helsinki declaration. One participant from the BTX group was excluded from all analyses because she had been fully informed about the hypothesis of the study accidently by the hospital staff prior to session two. For two further participants, no data for the reaction time task were available.

### *2.2.2 Stimuli*

*Pilot:* All stimuli (sentences and pictures of facial expressions for the ratings tasks and pictures of facial expressions for the RT task) were piloted by a group of 14 healthy young participants (11 females, age range 22-32). During the pilot, the stimuli for each of the three tasks were presented in separate blocks. Participants were asked to rate the emotional connotation and intensity of the given stimulus. More precisely, for the facial expression stimuli (both for the rating and for the RT task), the instruction was to rate how the person in the picture feels. For the sentences, participants were asked to rate the emotional response they evoked. Each stimulus was presented one at a time on a computer screen with a visual analogue scale (VAS) shown below it. The VAS ranged from 0 (*very sad*) – 100 (*very happy*), and a short vertical line divided the VAS to indicate a neutral position. The scale was labeled with "very sad" on the left, "neutral" below the middle vertical line, and "very happy" on the right. No numbers were displayed. Participants were instructed to move the cursor with the computer mouse along the scale and click to make the rating. Ratings closer to the midline of the VAS indicated less emotionality, and ratings placed closer towards the end of each side of the scale represented a stronger intensity of the respective emotion. Participants were encouraged to make use of the full scale and to rate stimuli as neutral when they appeared as such.

*Stimuli for sentences rating task:* Sentences were all formulated in present tense, directly addressing the reader (see Table 2.1 for examples). 140 Sentences (28 Neutral, 28 slightly happy, 28 very happy, 28 slightly sad, and 28 very sad sentences) were selected from an initial pool of 250 emotion-laden (happy and sad) and neutral Italian sentences after the pilot (described above). Ratings for each stimulus that were more than 2.5 SD away from the mean rating of that stimulus were not considered as a valid rating for that stimulus. This cleaning affected 5 % of all data points. A sentence was included as a stimulus if its rating was most representative of one of the five emotion conditions (neutral, slightly happy, slightly sad, very happy, or very sad). In other words, stimuli with ratings near the extrema of either side of the scale were selected as very emotional stimuli. To be selected as a slightly emotional stimulus, the rating had to be low, meaning close to the middle of the scale. Ratings within the range of ± 5 to 50 were considered to be neutral. An one-way ANOVA confirmed that ratings differed across emotion categories $F(4,1218) = 2135$, $p < .001$, and post-hoc comparisons verified that this was also true when comparing directly all emotion categories to each other (all *p*s <.001). Corresponding ratings for each emotional category are given in Table 2.1. Next, stimuli were evenly assigned to one of two sets, making different sets of sentences for session one and session two available. Five one-way ANOVAs comparing the two sets in terms of their emotionality rating separately within each emotion (neutral, slightly happy, slightly sad, very happy, or very sad) verified that each emotion category received comparable emotionality ratings across sets (all *F*s < 1.5, *p*s > .22).

*Stimuli for facial expression rating task:* Sixteen different female and male face identities were selected from Ekman and Friesen (1976), and the NimStim set (Tottenham et al., 2009). For each face identity, a black and white photo of a neutral, a very happy, and a very sad facial expression was available. In order to create additional slightly emotional facial expressions, I morphed the neutral expressions and either the happy or angry expression of the same face identity with *Abrosoft FantaMorph*™. In this way, for each facial identity, five facial expressions were obtained: neutral, slightly happy, slightly sad, very happy, and very sad. The final set was composed of 80 stimuli, with 16 for each emotion category. Ratings that were more than 2.5 SD away from the stimulus mean were discarded, affecting 1% of all data points. An one-way ANOVA confirmed that the ratings differed significantly between the five emotion categories $F(4, 79) = 241.65$, $p < .001$. This was also true when comparing all emotion categories to each other by means of post-hoc comparisons (all *p*s < .001, Bonferroni corrected). See Table 2.1 for more information on the ratings and for example stimuli.

*Stimuli for RT task:* Fifteen different male and female identities were selected from the Warsaw Set of Emotional Facial Expression. For each face identity, a color photo of a neutral, a very happy, and a very sad facial expression was available. In order to obtain additionally slightly happy and sad facial expression, the strongly emotional expressions were morphed with the neutral expression as outlined above. The photos of the neutral facial expressions were only used for the morphing procedure but were not used as stimuli. Hence, the final set of photos used as stimuli was composed of 20 slightly happy, 20 slightly sad, 20 very happy, and 20 very sad facial expressions. To ensure that distracting features such as the model's hairstyle did not influence RTs, I applied a black oval layer mask surrounding the face using Adobe Photoshop. This left only the face from the hairline to the chin visible. Ratings more than 2.5 SD away from the stimulus mean were not considered as a valid rating. This cleaning affected 4% of all data points. An one-way ANOVA confirmed that the ratings of the pilot differed significantly between the four emotion categories $F(3, 779) = 745$, $p < .001$. Comparing all emotion categories (slightly happy vs. slightly sad vs. very happy vs. very sad) to each other post-hoc verified that ratings differed significantly between them (all *p*s < .001, Bonferroni corrected). See Table 2.1 for example stimuli and documentation of the average ratings for each emotion category.

|  | Sentences |  |  | Faces for rating |  |  | Faces for categorization |  |  |
|---|---|---|---|---|---|---|---|---|---|
| Example | "Your friend is diagnosed with a fatal disease"<br>" You realize that you cannot cheer up your friend"<br>"You push the button for the elevator"<br>"you arrive in time for the next train"<br>"No matter what you do, you know you succeed" |  |  |  |  |  |  |  |  |
| Emotion | Mean Rating | Range | SD | Mean Rating | Range | SD | Mean Rating | Range | SD |
| very sad | 4.99 | 0 - 17 | 5.81 | 23.12 | 2 - 27 | 6.42 | 23.7 | 8 - 30 | 8.49 |
| slightly sad | 33.25 | 26 - 43 | 5.45 | 35.21 | 29 - 45 | 4.79 | 38.76 | 32 - 47 | 5.03 |
| neutral | 50.11 | 49 - 51 | 0.54 | 48.79 | 46 - 54 | 2.46 |  |  |  |
| slightly happy | 63.3 | 57 - 68 | 4.4 | 59.47 | 55 - 66 | 3.11 | 57.44 | 54 - 62 | 2.68 |
| very happy | 87.59 | 81 - 100 | 6.02 | 84.27 | 67 - 96 | 8.82 | 86.81 | 76 - 98 | 6.33 |

**Table 2.1** Example and results of the pilot for each task separately. The mean ratings, range, and SD are based on a 0 (very sad) – 100 (very happy) VAS scale, as is described under 2.2.2. The sentences examples show a very sad, a slightly sad, a neutral, a slightly happy, and a very happy stimulus (from top to bottom). The sentences shown here are translated from the original Italian sentences used in the study. The examples of facial expressions for the rating task represent a very sad, a slightly sad, a neutral, a slightly happy, and a very happy facial expression (from left to right). The examples given for the pictures for the categorization task characterize a very sad, a slightly sad, a slightly happy, and a very happy stimulus (from left to right).

## 2.3 Procedure

Participants from both groups were informed that the aim of the study was to explore the effects of general anesthesia on cognitive and emotional processing and that they served as a control group for patients receiving general anesthesia. A second session, approximately two weeks after the first, was explained by our particular interest in whether any effects could be found up to two or three weeks following treatment. This cover story resembled the one used by Davis et al. (2011). Testing of the BTX patients took place in a quiet room at the local hospital on the day of the BTX treatment. The control group was tested in a quiet room at the SISSA institute.

### *2.3.1 Session 1*

Upon arrival, participants read and signed the informed consent before filling in the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988). The experimental procedure included three tasks. Task order was pseudo-randomized across participants, with the condition that the RTs task was always conducted after the facial expression rating task, to ensure that participants had received equal training in identifying facial expressions prior to categorizing facial expressions under time pressure. Task instructions and stimuli were presented on a computer screen using E-Prime software (Psychology Software Tools, Inc., Pittsburgh, PA).

*Sentences rating task:* Upon the presentation of each stimulus, participants were asked to rate the emotion that was evoked by it. For this, participants clicked a point along a VAS scale as previously used during the pilot. The scale ranged from 0 –

100, but those numbers were not shown to the participant. Instead, the scale contained emotion labels to indicate “very sad” at the very left end and “very happy” at the very right end. A vertical line in the middle of the scale was labeled as “neutral”. Participants' task was to judge how the person in the picture felt, by sliding the cursor across the scale and clicking in order to confirm the choice. Participants were encouraged to give a spontaneous yet precise response reflecting best their personal judgment of the stimulus at hand. There was no time limit. Stimuli were presented in random order and were alternated randomly with an easy arithmetic or logic problem. This served to reduce any possible carryover effects and to lead participants to believe that the study pertained to cognitive processing in general. Before the actual task, participants had a short practice session consisting of four trials in order to familiarize themselves with the task.

*Facial expressions rating task:* The procedure was the same as that outlined above for the rating of the emotional sentences, with the only difference being that participants were instructed to assess and rate the emotion that the person in the picture expressed.

*RT task:* Participants were instructed to categorize facial expressions as quickly and accurately as possible into either being *sad* or *happy*. Participants were informed that the intensity of the facial expression varies across stimuli but that all of them expressed either a sad or happy emotion. Stimuli were presented one by one in random order. Responses were given by pressing one of two assigned keys on the keyboard. Labels with the Italian words for *sad* and *happy* were attached to the left and right sides of the computer screen, respectively, to remind participants of the button-assignment during the task.

Session 1 was concluded with the completion of the Beck Depression Inventory-ll (BDI-II; Beck, Steer, & Brown, 1996). After the first session, participants in the BTX group received the BTX treatment of their choice.

### *2.3.2 Session 2*

Session 2 took place 13 - 17 days later, and the procedure was identical to session one. The only difference was that participants were now presented with the other set of sentences. The order of presentation of the sets of sentences was counterbalanced across participants. The facial stimuli used for the Facial Expressions Rating and RTs Task were the same as were used during session one.

Before participants were finally thanked and informed about the actual purpose of the study, participants in the BTX group were questioned about their thoughts and opinion regarding the study. This ensured that none of the BTX participants had guessed that the study actually aimed at assessing the impact of BTX injections on emotion processing.

## 2.4 Results

### *2.4.1 Control analysis for mood and affect*

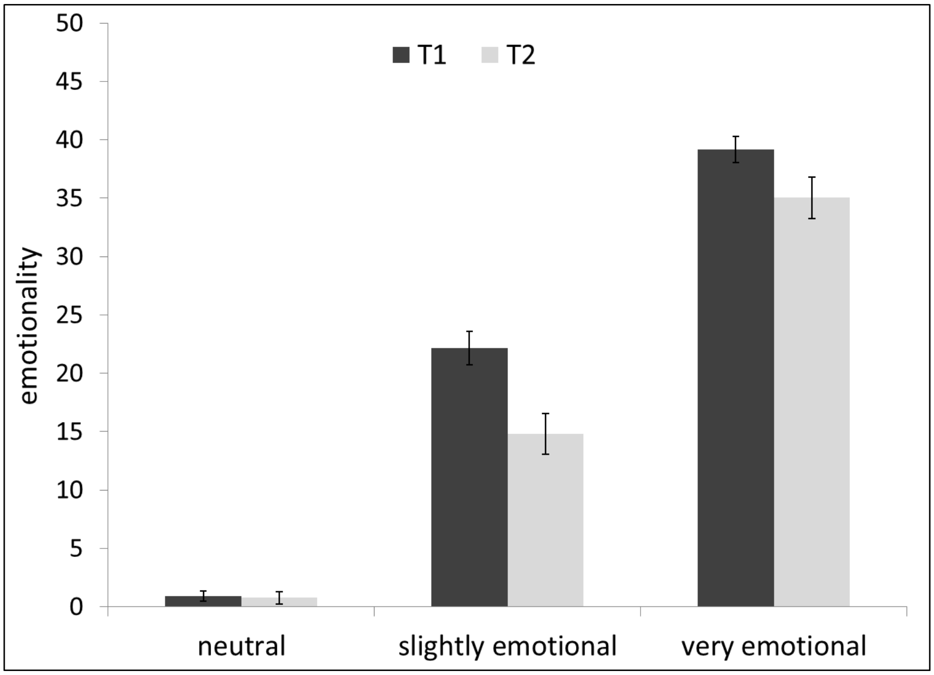
In order exclude possible confounding factors, the two groups were compared on several dimensions in regard to mood and affect, in order to ensure that possible differences in these known influencing factors were not responsible for the reported results. To verify that the BTX and control groups did not differ at any time point in terms of positive and negative affect, I ran a mixed-measures 2(affect: positive vs. negative) X 2(time point: T1 vs. T2) X 2 (group: BTX vs. control) ANOVA, with the first two factors being within subject factors, and the last being between subject factors. This resulted in an obvious main effect of affect only (*F*s(1,18) = 198, *p* < .001), caused by more positive affect (*M* = 33.53, *SD* = .91) compared with negative affect (*M* = 14.01, *SD* = 1.03) across participants and time-point. Next, I compared the results on the depression scale (BDI) at T1 and T2 between groups with a 2 (time point: T1 vs. T2) X 2 (group: BTX vs. control) mixed measures ANOVA, which resulted in no significant effects (all *F*s < 2.60, *p* >.12).

### *2.4.2 Rating of sentences task*

In order to reduce the possible impact of extreme data points, any rating for a given stimulus that was greater than 2.5 SD from the average rating for that stimulus was removed from the analysis. This cleaning was done within group and within session, and led to a loss of 1.4 % of all rating scores within the BTX group and 2.2% within the control group. Subsequently, the original ratings ranging from 0 (very sad) – 100 (very happy) were recoded to create a general scale of emotional intensity. The new scale did not make a differentiation between sad and happy emotions but expressed the rated intensity of the emotion (from 0 - low intensity to 50 - high intensity) by subtracting 50 from each rating score and calculating its absolute value. This scaling allowed better comparability of the hypothesized general effect across emotions.

Then, separately for each time point (T1 & T2), the averaged ratings were calculated for both slightly happy and slightly sad stimuli (slightly emotional score; Cronbach's alpha at T1 = 0.96) and for both very happy and very sad stimuli (very emotional category, Cronbach's alpha at T1 = 0.92). These values were analyzed by a 2(group: BTX vs. Control) X 2(time point: T1 vs. T2) X 3(emotion category: neutral vs. slightly emotional vs. very emotional) mixed-measures ANOVA, with the first factor being between-subjects and the last two within-subjects. This revealed a significant main effect of emotion ($F(2,38) = 269.83$, $p < .001$), a main effect of time point ($F(1,19) = 9.09$, $p < .01$), and a significant interaction of time point by emotion ($F(2,38) = 4.41$, $p = .02$). Finally, and most importantly, the interaction between emotion, time point, and group ($F(2,38) = 4.62$, $p = .02$, $\eta^2_p = .20$) was also significant. To further investigate the 3-way interaction, two repeated measures ANOVAs 2(time point: T1 vs. T2) X 3(emotion: neutral vs. slightly emotional vs. very emotional) were run separately for each group (BTX and control). Within the BTX group, this resulted in a significant main effect of emotion ($F(2,18) = 225.51$, $p < .001$), a significant main effect of time point ($F(1,9) = 10.93$, $p <.01$), and in a significant interaction between emotion and time point ($F(2,18) = 7.04$, $p < .01$; $\eta^2_p = .44$, see Figure 2.1, panel a). In contrast, the control group showed only an effect of emotion ($F(2,20) = 101.46$, $p < .001$) and no other effects (all $F$s < 1.4, all $p$s > .26; see Figure 2.1 panel b).

**a) BTX group**



**b) Control group**

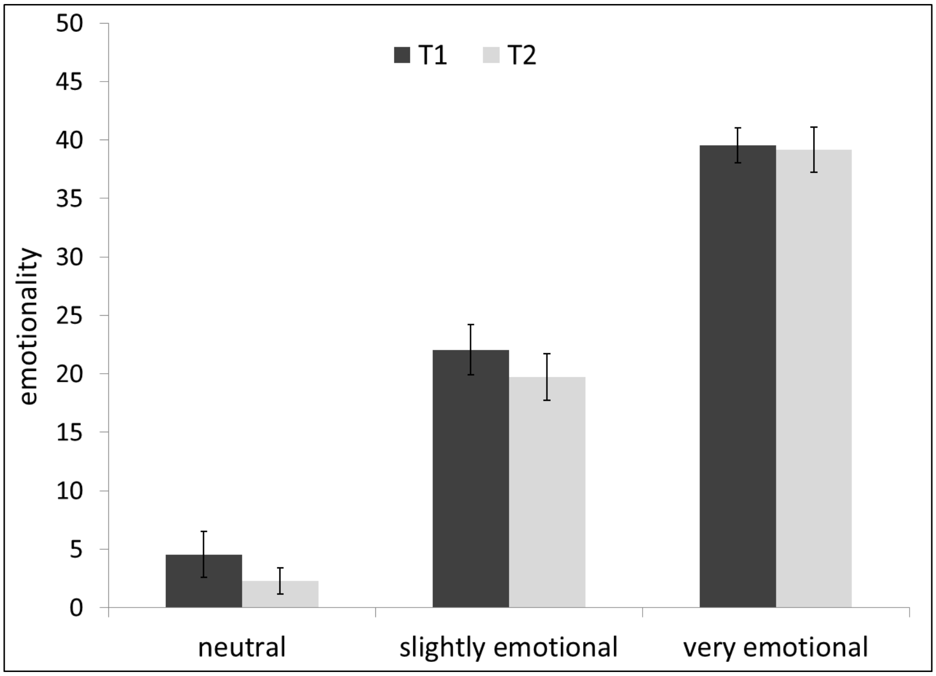


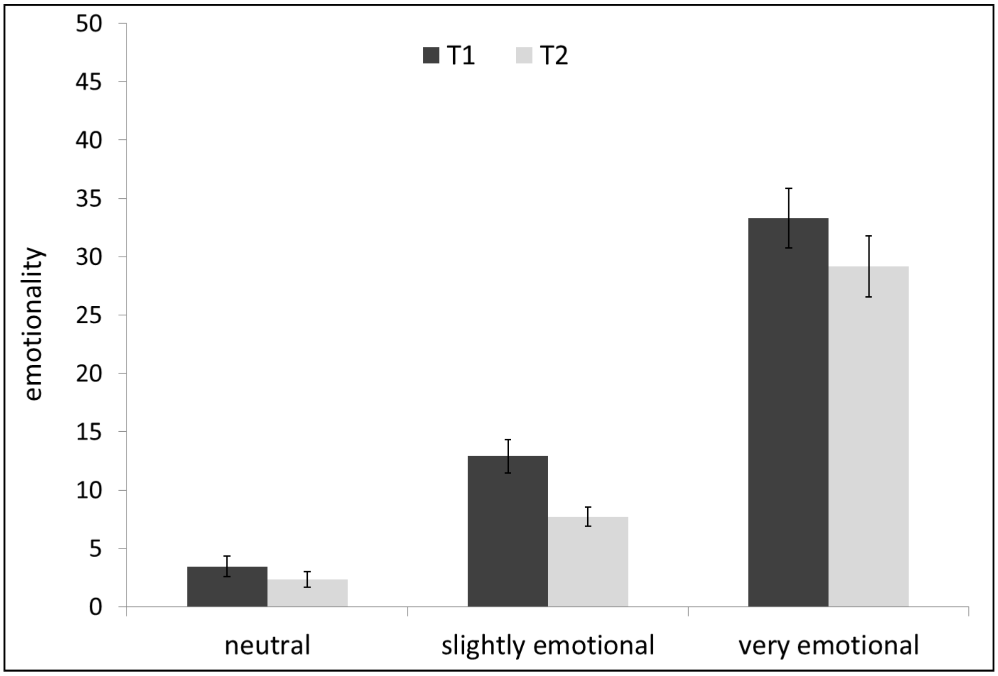
**Figure 2.1.** Emotionality ratings of sentences as function of emotional intensity (neutral vs. slightly emotional vs. very emotional) and time point (T1 vs. T2). Panel (a) shows the RTs of the BTX group. Panel (b) shows the results for control group. Error bars represent standard error of means (SE).

Next, it was investigated whether the interaction within the BTX group was driven by a drop in the perceived emotionality of the slightly emotional stimuli from T1 to T2. I ran three paired-samples tests, comparing the ratings at T1 with ratings at T2 for each emotion-intensity separately (neutral, slightly emotional, and very emotional). This did not reveal any significant changes for the neutral sentences ($t(9) = 1.33$, $p = .21$) from T1 ($M = .89$; $SD = 1.41$) to T2 ($M = .77$; $SD = 1.64$). In contrast, the slightly emotional sentences showed a significant drop in emotionality ratings from T1 ($M = 22.14$, $SD = 5.17$) to T2 ($M = 14.80$, $SD = 7.47$; $t(9) = 3.97$, $p < .01$), revealing a large effect size (Cohen's $d = 1.26$). However, the strongly emotional stimuli also showed a marginal decrease of emotionality after the BTX treatment (T1: $M = 39.16$, $SD = 3.83$; T2: $M = 35.02$, $SD = 7.17$; $t(9) = 1.98$, $p = .08$), revealing a smaller but still medium-sized effect (Cohen's $d = .63$). To confirm that the drop observed for the slightly emotional sentences was indeed more pronounced than the marginal decline observed for the strongly emotional sentences, I calculated the proportional difference between T1 and T2 for each emotion category (slightly emotional and strongly emotional separately) by using this formula: [(Rating at T2 – Rating at T1] / ((Rating at T1 + Rating at T2)/2)]. Those proportional-difference values were submitted to a paired-samples t-test, which demonstrated that the drop in perceived emotionality of slightly emotional sentences ($M = .50$, $SD = .27$) was significantly stronger ($t(9) = 3.51$, $p < .01$) than the decrease observed within the very emotional sentences ($M = .18$, $SD = .16$). Cohen's effect size value ($d = 1.11$) suggested a high practicability of this result. Finally, it was investigated whether this effect within slightly emotional stimuli was present for both emotions (happy and sad). Two pairwise t-tests compared the ratings between T1 vs. T2 for each emotion (slightly happy and slightly sad) separately. This revealed a significant effect for slightly happy stimuli (*t*(9) = 5.21, *p* <.01, 2-tailed, Cohen's *d* = 1.64) and for slightly sad stimuli (*t*(9) = 2.01, *p* = .04, 1-tailed, *d* = 0.65; *p*-values are Holm-Bonferroni corrected). Since the effect sizes suggested a stronger decrease in emotionality ratings for slightly happy sentences as compared with slightly sad sentences, an additional pairwise comparison of the proportional difference scores of slightly happy and slightly sad stimuli was conducted to investigate whether this observed difference was significant. This was, however, not the case (*t*(9) = .91, *p* = .39).

### *2.4.3 Rating of facial expressions task*

Data preparation followed the same procedure as described above for task 1. The cleaning removed 2.5% of all data points within the BTX group and 1.9% within the control group. Additionally, I disregarded data associated to six of the very emotional stimuli from all analyses because, despite their pilot, their emotionality ratings at T1 were too low to be considered very emotional (average for both groups was < 25). Next, the average values for slightly emotional (slightly happy and slightly sad; Cronbach's alpha = .91 at T1 for both groups) and very emotional (very happy and very sad; Cronbach's alpha = .92 at T1 for both groups) stimuli were analyzed together with the average rating for the neutral stimuli (Cronbach's alpha = .80 at T1 for both groups) in a 2(group: BTX vs. Control) X 2 (time point: T1 vs. T2) X 3(emotion: neutral vs. slightly emotional vs. very emotional) mixed-measures ANOVA, with the first factor being between-subjects and the last two within-subjects. This revealed a significant main effect of emotion (*F*(1,20) = 183.56, *p* < .001, Greenhouse-Geisser corrected) and a significant interaction between time point and group (*F*(1,19) = 7.63, *p* = .01). However, the interaction between time point, emotion, and group did not reach significance (*F*(2,38) = 16.91, *p* = .13, $\eta^2_p$ = .10). Due to my a priori interest in the effects of BTX injections on emotion across time, I subsequently ran two separate 2(time point: T1 vs. T2) X 3(emotion: neutral vs. slightly emotional vs. very emotional) repeated measures ANOVA for each group (BTX and control). Within the BTX group, this revealed a significant main effect of emotion (*F*(1,10) = 83.04, *p* < .001), a significant main effect of time point (*F*(1,9) = 10.73, *p* =.01), and a marginal interaction between them (*F*(2,18) = 3.00, *p* = .08, $\eta^2_p$ = .25; see Figure 2.2, panel a). The control group showed only an effect of emotion (*F*(1,12) = 100.45, *p* < .001) and no other effects (all *F*s < .40, all *p*s > .53; see Figure 2.2 panel b).

**a) BTX group**



**b) Control group**

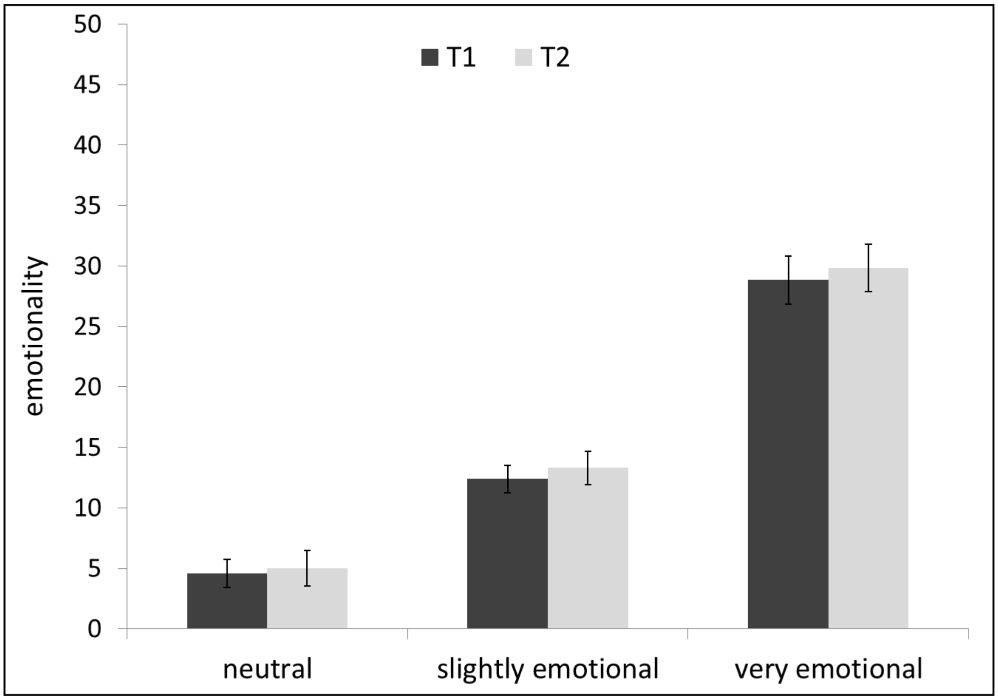


**Figure 2.2** Emotionality ratings of facial expressions as function of emotion (neutral vs. slightly emotional vs. very emotional) and time point (T1 vs. T2). Panel (a) shows the RTs of the BTX group. Panel (b) shows the results for control group. Error bars represent standard error of means (SE).

Next, I investigated whether this marginal interaction within the BTX group was driven by a drop of perceived emotionality of the slightly emotional stimuli from T1 to T2. Therefore, I ran three paired-samples tests, comparing the ratings at T1 with ratings at T2 for each emotion-intensity separately (neutral, slightly emotional & very emotional). This revealed no changes from T1 (*M* = 3.31, *SD* = 2.90) to T2 (*M* = 2.34, *SD* = 2.22) for the neutral facial expressions (*t*(9) = 1.39, *p* = .20). In contrast, the slightly emotional stimuli showed a large and statistically significant drop in emotionality ratings after the BTX treatment (T1: *M* = 13.30, *SD* = 5.82; T2: *M* = 7.80, *SD* = 2.65; *t*(9) = 3.27, *p* = .01, Cohen's *d* = 1.03). However, the ratings for the strongly emotional stimuli also decreased marginally after the BTX treatment, yet with a smaller but still medium sized effect (T1: *M* = 33.05, *SD* = 10.36; T2: *M* = 29.01, *SD* = 9.98; *t*(9) = 2.1, *p* = .06, Cohen's *d* = .67). To confirm that the drop observed for the slightly emotional sentences was indeed more pronounced than the marginal decline observed for the very emotional sentences, I calculated the proportional difference between T1 and T2 as described above. Those proportional difference values were then compared in a paired-samples t-test, which demonstrated that the drop in perceived emotionality of slightly emotional sentences (*M* = .53, *SD* = .34) was significantly stronger (*t*(9) = 3.2, *p* = .01) than the decrease observed within the strongly emotional sentences (*M* = .22, *SD* = .14). Finally, I was interested in whether this effect within slightly emotional stimuli was present for both emotions (happy and sad). Two pairwise t-tests comparing the ratings between T1 vs. T2 for each emotion (slightly happy and slightly sad) revealed a significant effect for slightly happy stimuli (*t*(9) = 2.56, *p* =.03, Cohen's *d* = 1.54) as well as for slightly sad stimuli (*t*(9) = 3.25, *p* = .02, Cohen's *d* = 1.33; *p*-values are 2-tailed and Holm-Bonferroni corrected). Since the effect seemed slightly stronger for the slightly happy stimuli, an additional comparison of the proportional differences between slightly happy vs. slightly sad stimuli was conducted. This revealed no differences in effects (*t*(9) = .14, *p* = .53), suggesting that the emotionality ratings of slightly happy and slightly sad stimuli were equally affected by the BTX treatment.

### *2.4.4 RT task*

For the RTs analysis of the categorization task, I considered only trials in which the categorization was done correctly. This left 90% of the data for the BTX group and 92% of the data for the control group to be included. In a second step, RTs were cleaned to exclude extreme values by removing trials with an RT greater than 2.5 SD away from the mean within each emotion condition (slightly happy, slightly sad, very happy, and very sad) and a given time point (T1, T2). This was done for each participant separately, and affected 5.6% of the data from the BTX patients and 4.5% of the data from the controls. Furthermore, the method employed to clean and down-select data led to no valid RTs for one participant in one emotional condition in session 1. This missing RT value was instead calculated by interpolating the RTs of all other participants for this condition during session 1.

Log-transformed RTs were analyzed with a 2 (group: BTX vs. Control) X 2 (time point: T1 vs. T2) X 2 (emotion: slightly emotional vs. very emotional) mixed-measures ANOVA, with the first factor being between-subjects and the last two within-subjects.

This ANOVA revealed a main effect of emotion ($F(1,17) = 63.88$, $p < .001$), driven by general faster categorization of very emotional stimuli ($M = 2.84$, $SE = .02$) in comparison with slightly emotional stimuli ($M = 2.97$, $SE = .03$). Furthermore, a significant interaction between time point and group ($F(1,17) = 12.26$, $p < .01$) and an interaction between time point and emotion ($F(1,17) = 6.08$, $p = .03$) were present. The interaction between time point, emotion, and group showed only a slight trend ($F(1,17) = 2.00$, $p = .14$, $\eta^2 = .10$). To further investigate the difference between the two groups over time, and due to the a priori interest in the effect of time on emotional intensity, the two groups were analyzed separately with a 2(time point: T1 vs. T2) X 2(emotion: slightly emotional vs. very emotional) repeated measures ANOVA. The analysis of the BTX group revealed a main effect of emotion ($F(1,7) = 56.62$, $p < .001$), a main effect of time point ($F(1,7) = 19.83$, $p < .01$), and an interaction between them ($F(1,7) = 13.90$, $p < .01$, $\eta^2_p = .67$). In contrast, the analysis of the control group resulted in a main effect of emotion ($F(1,10) = 30.18$, p < .001) but no other effects (all $F$s < 2.00, $p$s > .18). See Figure 2.3 for the corresponding graphs.

**a) BTX group**

**b) Control group**

**Figure 2.3** RTs in response to facial expressions as function of emotion (slightly emotional vs. very emotional) and time point (T1 vs. T2). Panel (a) shows the RTs of the BTX group. Panel (b) shows the results for control group Error bars represent standard error of means (SE).

Afterwards, I investigated whether the effects within the BTX group were specifically due to a slowdown in categorizing the slightly emotional facial expressions. RTs at T1 were compared with RTs at T2 within each emotionality category (slightly emotional & very emotional). This revealed a significant effect in the slowing of RTs at T2 in comparison with T1 for both slightly ($t(7) = 4.66$, $p < .01$) and very emotional stimuli ($t(7) = 3.46$, $p = .011$). The calculation of the effects' sizes suggested that this effect was larger for the slightly emotional stimuli (Cohen's $d = 1.63$) as compared with the very emotional stimuli (Cohen's $d = 1.20$). To investigate whether this difference in effect size was significant, the proportional difference scores were calculated [(RTs at T2 – RTs at T1] / ((RTs at T1 + RTs at T2)/2)], indicating their change in RTs over time for the slightly and strongly emotional stimuli. A paired-sampled t-test comparing the proportional RTs difference of slightly emotional stimuli with the proportional RTs differences of very emotional stimuli confirmed that the slowing effect from T1 to T2 was more pronounced for slightly ($M = .04$; $SD = .02$) than for very emotional stimuli ($M = .02$, SD = .01; $t(7) = 3.76$, $p < .01$). Finally, I investigated whether this slowing in RTs was present for both emotions (happy and sad). Pairwise t-tests comparing RTs at T1 vs. T2 for each emotion (slightly happy and slightly sad) revealed that this effect was mainly driven by a slowing of RTs in response to slightly sad facial expressions ($t(7) = 4.25$, $p < .01$; 2-tailed). Slightly happy stimuli showed a marginal significant reduction in speed at T2 ($t(7) = 2.04$, $p = .08$; 1-tailed; $p$-values are Holm-Bonferroni corrected).

*Accuracy*

As before, accuracy was analyzed with a 2 (group: BTX vs. Control) X 2 (time point: T1 vs. T2) X 2 (emotion: slightly emotional vs. very emotional) mixed-measures ANOVA, with the first factor being between-subjects and the last two within-subjects. This ANOVA revealed a main effect of emotion ($F(1,17) = 18.29$, $p < .001$) and no other effects. Further inspection of this main effect suggested that it was driven by a higher accuracy in categorizing very emotional facial expressions ($M = .97$, $SE = .01$) in comparison with slightly emotional stimuli ($M = .84$, $SE = .03$), regardless of time point. These results seem to suggest that accuracy was unaffected by the BTX treatment. However, since the very high accuracy rates in categorizing very emotional faces indicate a ceiling effect, the informative value of this finding is limited.

## 2.5 Discussion

The present study hypothesized and later confirmed that the processing of slightly emotional stimuli benefits more from the presence of facial motor resonance than the processing of very emotional stimuli. It was first demonstrated that the prevention of facial motor resonance by means of BTX led to a drop in emotionality ratings for happy and sad sentences and that this decrease was significantly stronger when the sentences were slightly emotional as opposed to very emotional. Similar patterns were observed when participants rated the emotionality conveyed by happy and sad facial expressions. Again, happy and sad facial expressions were perceived as less emotional after the BTX treatment, and this effect was significantly pronounced if the facial expression was low in intensity as compared with when the stimuli were very emotional. These results were, however, weaker than those obtained for the sentences-rating task and partially reached only marginal significance (see subsection 2.4.3). Finally, the analysis of a third task demonstrated that participants in the experimental group became slower in categorizing slightly emotional facial expressions as *happy* or *sad* after having received the BTX injections. The very emotional facial expressions were, however, not completely unaffected by the BTX injections and also showed a slight increase in RTs. Importantly though, the present results indicate that the effects for the very emotional stimuli were significantly weaker across all three tasks than the pronounced effects observed for the slightly emotional stimuli. Finally, while both happy and sad stimuli were affected by the BTX treatment in the rating tasks, the RT task revealed an effect for sad facial expressions and only a marginal effect for happy facial expressions.

Overall, the present results suggest that facial motor resonance is of particular importance when the stimulus is less extreme and thus more ambiguous. However, some inconsistencies remain with the original hypotheses that need to be addressed. First, while the results for the sentences rating task were clear, the results for the facial expressions rating task and RTs task were weaker, and the expected three-way interactions reached only marginal significance in both cases. A possible explanation for such variance in results across tasks may lie in the choice of stimuli, which were well matched within tasks but poorly matched across tasks. This led to larger differences in emotionality ratings between the slightly and very emotional sentences in comparison with the less extreme ratings for slightly and very emotional facial stimuli (see Table

2.1). This clearer differentiability between slightly and very emotional sentences might have eventually caused the strong effect for the sentences rating task. Likewise, the smaller differentiability of the slightly and very emotional facial expressions for the rating and RTs task might have reduced such an effect, leaving it at marginal significance levels. A second finding worth discussing is the fact that after the BTX treatment, participants became particularly slow at categorizing slightly sad facial expressions and that this effect reached only marginal significance for the slightly happy facial expressions. This could have been caused by the BTX-untreated zygomaticus muscle (smiling muscle), which continued to provide facial feedback in response to happy stimuli, hereby attenuating the effect of the BTX treatment. It is, however, unclear why this weaker effect for slightly happy stimuli was only observed in the RTs task but not within the rating tasks. Such variance may be related to the small sample size in the present study, which was particularly low in the RTs task due to the missing data of two participants (see subsection 2.2.1).

Generally, the results corroborate with previous findings in which blocking facial muscles decreased participants' positivity ratings of slightly positive sentences (Davis et al., 2010) or interfered with the recognition of slightly emotional facial expressions (Oberman et al., 2007). On the other hand, they seem to contradict the findings by Hess and Blairy (2001), who reported no facilitative role for facial motor resonance on recognition of slightly emotional facial expressions. However, these apparently conflicting results can be resolved. First, while Hess and Blairy's (2001) major interest was to explore the effects of facial motor resonance on natural-like dynamic expressions, the current study employed static pictures in order to evoke stronger motor simulation (Kilts et al., 2002). Consequently, static facial expressions may be more vulnerable to modulations of facial motor resonance than dynamic expressions. Second, Hess and Blairy (2001) assessed the correlation between the intensity of facial motor resonance and emotion recognition accuracy. In contrast, the present study did not assess the intensity of mimetic muscle activation but instead blocked it. Third, the dependent variables in the current study were perceived emotional intensity and RTs, as opposed to the recognition accuracy assessed by Hess and Blairy (2001). In fact, the speeding categorization task (RT task) of the current study did not indicate hampered recognition accuracy but only a slowdown in recognizing facial expressions after the BTX treatment. However, this task was specifically designed to assess possible differences in RTs, and, due to its limited difficulty, it may have been less sensitive to changes in accuracy. Finally, it is unlikely that the current results were due to BTX-induced changes in mood and affect, as both happy and sad emotions were influenced by the manipulation.

The present study takes an important step into determining the mediators that cause facial motor resonance to affect our perception and behavior. The current results suggest that one such mediating factor is the emotional intensity of the stimulus to be processed. A possible reason for this might be that motor resonance functions primarily as an ancillary information resource, providing additional information. Under clear-cut conditions, the information provided by facial feedback may be superseded by explicit knowledge of the emotional information at hand, diminishing its influence on our percept and behavior. However, if emotional intensity is low, the processing of emotional stimuli becomes more difficult. It is therefore conceivable that the impact of facial motor resonance accordingly increases, as it can help to process emotional information if explicit knowledge and logical reasoning leave us in doubt. Likewise, if facial motor resonance is absent, this may be reflected in flattened emotional perception and increased RTs, particularly in response to slightly emotional stimuli, equivalent to what was observed in the current study.

A possible objection to this interpretation of the results is that participants may not have engaged simulations, as facial muscle resonance was not assessed in the control group. This would clearly challenge the claim that facial muscle resonance has a causal role in emotion interpretation. Note that several findings demonstrated that people recruit relevant physical resources when the task requires the understanding of noun phrases (Wu & Barsalou, 2009) or emotion concepts (Niedenthal et al., 2009). Considering these previous findings and the current task designs, which explicitly required the evaluation of emotion concepts, it seems safe to conclude that facial motor resonance was recruited by the tasks employed here. Finally, the assumption that the blocking of facial motor resonance caused the present results conforms to the finding that impairing the use of facial muscles leads to a selective deficit in emotion recognition, demonstrated previously (Oberman et al., 2007).

The interpretation of the results is also in line with the fact that BTX attenuates activation of the amygdala as a consequence of missing facial feedback (Hennenlotter et al., 2009). The amygdala greatly contributes to the salient processing of emotional stimuli, giving them a processing advantage over neutral stimuli that reaches from initial perception to long-term memory (e.g. Kensinger & Schacter, 2006). It is therefore also referred to as "the gateway to the emotions" (Aggleton & Mishkin, 1986). Thus, if the activity of the amygdala is attenuated by means of BTX, then the processing of emotional information possibly depends on stronger cortical activation, similar to the processing of neutral stimuli (Kensinger & Schacter, 2006). Since it is thought that this cortical activation is associated with more effort, it is plausible to believe that the processing of an ambiguous emotional stimulus in the absence of facilitative amygdala activity requires more effortful cortical activation than a highly emotional stimulus, whose interpretation is easier. More research is needed to test this hypothesis.

In summary, the present study replicated previous findings, which showed that facial motor resonance has a role in the perception and understanding of emotional stimuli. It further extended those findings by defining an important mediator for these effects, namely emotional intensity. Slightly emotional stimuli are more dependent on facial motor resonance than highly emotional stimuli. This is possibly because the interpretation of highly emotional content is resilient to the influence of facial feedback while the interpretation of slightly emotional stimuli is more easily influenced. These findings don't make the relationship between facial motor resonance and emotion processing any less complex, but they do establish an important boundary condition to this complex interdependence.

# Chapter 3

# When the Mask Falls: The Role of Facial Motor Resonance in Memory for Emotional Language

## 3.1 Introduction

In the previous chapter, facial motor resonance was linked to the understanding and perception of emotional information. Sometimes, however, "an impression may be so exciting emotionally as almost to leave a scar upon the cerebral tissue." This observation by William James (1890, p. 670) describes what is nowadays known as the enhancement effect for emotional information (EEM). The EEM summarizes the general observation that memory for emotional content is usually superior to memory for neutral stimuli (see Buchanan & Adolphs, 2002; Hamann, 2001; LaBar & Cabeza, 2006, for reviews). It has been demonstrated for a wide range of emotional stimuli, such as narratives (Laney, Campbell, Heuer, & Reisberg, 2004), words (Kensinger & Corkin, 2003) and pictures (Chainay, Michael, Vert-pré, Landré, & Plasson, 2012). Since the previous chapter (Chapter 2) suggested that the decoding of emotional information is enhanced in the presence of facial motor resonance, one may wonder whether the presence of facial motor resonance can also be linked to enhancements of emotional information in memory – as would be reflected in the EEM effect.

So far, embodiment research has mainly concentrated on investigating mood-congruent or context- and state-dependency memory effects. According to some studies, memory for emotional stimuli is facilitated if a stimulus's affective tone is congruent with the participant's mood during retrieval (Cloitre & Liebowitz, 1991; Liu, Wang, Zhao, Ning, & Chan, 2012; Fitzgerald et al., 2011). For example, people are usually more likely to recall negative words such as *kill* as opposed to positive words such as *kiss* if they were in a bad mood during encoding (Rinck, Glowalia, & Schneider, 1992). This improvement of memory when affect at encoding or retrieval matches the valence of emotional stimuli is referred to as mood-congruent memory (Blaney, 1986). A related but distinct phenomenon is that memory can be improved by the reinstatement of the learning environment at retrieval (see Smith & Vela, 2001, for a review). This context- or state-dependent memory effect can be established by any meaningful contextual cue, such as ambient odor (Herz, 1997), music (Mead & Ball, 2007), or internal mood states (see Eich, 1995, for a review). For example, mismatching participants' internal mood states during encoding and retrieval leads to impaired memory for words (Lang, Craske, Brown, & Ghaneian, 2001) as well as for symbols and photographs (Robinson & Rollings, 2011). But do embodied simulations play any role in these mood-congruent and context-dependent memory effects, or are these effects simply produced by better integration of information due to external cues and context? Concrete attempts to study the effects of body movements on emotion retrieval were conducted by Casasanto and Dijkstra (2010), and Förster and Strack (1996). Both studies led to conceptually similar results. Motor movements schematically associated with *positivity*, such as moving marbles upward or shaking one's head vertically, and movements schematically associated with *negativity*, such as moving marbles downward or shaking one’s head horizontally, influenced retrieval of autobiographical memory and recognition of positive and negative words, respectively. Förster and Strack (1996) concluded that performing incompatible motoric and conceptual tasks (e.g. shaking the head horizontally while encoding positive words) requires more cognitive capacity than performing compatible motoric conceptual tasks (e.g. shaking the head vertically while encoding positive words). This additional demand in attentional resources eventually resulted in decreased performance during incompatible conditions. Although these studies provide evidence for a motor-to-meaning congruency effect on memory, they did not aim to investigate the role of embodiment in memory retrieval. Since Casasanto and Dijkstra (2010) did not control for mood, it is possible that the active body movements (moving marbles upwards or downwards) induced a positive or negative emotional state similar to the emotional state under which the information had been originally encoded, hereby causing improved memory by means of a state-dependency effect. A more concrete approach to study the role of embodiment in object recognition was recently employed by Decloe & Obhi (2013), who applied single-pulse transcranial magnetic stimulation (TMS) over the motor cortex during the observation of a model thumb typing on a cell phone. Their findings suggest that embodied simulations are linked to the recognition of objects of action, but their results are restricted to embodied actions and non-emotional objects. Thus, the general role of facial motor resonance and embodied processes in emotional memory remains speculative.

Given this information, the present study seeks to investigate the putative role of embodiment in memory processes for emotional information during encoding and retrieval of emotional language. It was expected that the role of facial motor resonance goes beyond the initial processing and recognition of emotional stimuli (Havas et al., 2010; Niedenthal, et al., 2001; Niedenthal et al., 2009) and also affects memory for emotional information. To test this prediction, participants performed a memory task involving the encoding and retrieval of emotional and neutral words. Depending on the experimental condition, facial muscles were blocked by a hardening facial mask either during encoding, during retrieval, during both encoding and retrieval, or never (control). In contrast to the blocking methods used in previous studies (e.g., Havas et al., 2010; Niedenthal et al., 2001; Niedenthal et al., 2009; Oberman et al., 2007; Foroni & Semin, 2009; 2011; 2012), I implemented a new method involving the application of a hardening cosmetic mask in order to block all relevant muscles at once, allowing us to investigate the effects of blocked facial muscles on the encoding and retrieval in a wider range of emotional words. By testing the effect of blocking facial muscles on memory for both positive and negative emotional content, I was also able to avoid the possible confounding of mood-congruency (see Casasanto & Dijkstra, 2010; Havas et al., 2010). For the encoding phase, I used a categorization task (following Niedenthal et al., 2009) that involved the categorization of words as being either related or unrelated to emotion. This type of task, requiring the active processing of emotion concepts, had previously been shown to elicit facial motor resonance (Niedenthal et al., 2009). This is important, considering that the masks used in the current study did not allow for an explicit assessment of facial motor resonance via EMG. Unlike the categorization task employed in the study discussed in Chapter 2, the abstract phrasing of the present task instruction was specifically designed to increase its difficulty and thus be a sensitive measure for accuracy. I predicted that if the blocking manipulation successfully interfered with facial motor resonance, performance on the categorization task should be impaired for words from all emotion types, as previously shown by Niedenthal and colleagues implementing a different blocking manipulation.

My primary hypothesis was related to the performance on the memory task. I expected that in comparison with the condition where facial muscle action is free (control), memory for emotional but not for neutral words would be impaired if facial muscles are blocked during encoding, during retrieval, or during both. Specifically, I was interested in whether blocking facial motor resonance during encoding or retrieval only produces similar effects, or whether the effects are specifiable. If facial motor resonance supports the initial identification and processing of emotional information and its later recognition and retrieval, then blocking facial muscles during encoding or during retrieval should interfere with the memory of emotional words. In these two conditions, the encoding and retrieval phases also provided no contextual cues: during the blocking condition, a hardening dry mask interfered with facial muscle activity, while in the free conditions, a soft, creamy control mask ensured free muscle activity. In the memory literature, it is reported that similarity between encoding and retrieval context may help memory performance. Thus, the predictions regarding the inhibition of facial resonance during both encoding and retrieval were less definitive: on the one hand, it is possible that blocking during both encoding and retrieval leads to even stronger interference with memory of emotional content; on the other hand, it is possible that a contextual effect might compensate for any additional interference that such double blocking may cause.

## 3.2 Method

### *3.2.1 Participants*

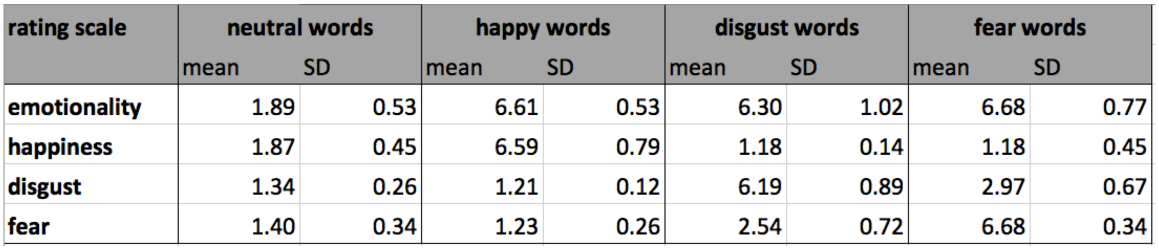
Eighty young healthy Italian native speakers (49 females; mean age: 23.7 ± 3.8) participated in the experiment. Participants were randomly assigned to one of four possible conditions. Depending on the assigned condition, participants' facial expressions were either: a) blocked during encoding, but not during retrieval, b) not blocked during encoding, but blocked during retrieval, c) blocked during both encoding and retrieval, or d) blocked neither during encoding nor retrieval (control group).

### *3.2.2 Stimuli*

Stimulus material consisted of 144 Italian words. Seventy-two words were strongly related to one of the three emotional concepts (24 words for each emotion): disgust (e.g., *Bacteria, Vomit*), happiness (e.g., *Joy, Sweets*), and fear (e.g., *Panic, Danger*). Those emotional categories were meant to provide maximal diversity in the possible facial motor resonance they would trigger, in order to allow generalizability. The remaining 72 words were neutral (e.g., *Code, Subject*). The words used for the study were selected based on the result of pre-test conducted with an independent sample of

13 Italian native speakers (eight females, mean age: 24.2 ± 3.4) from an initial pool of 318 words (selected on the basis of a word list used by Niedenthal et al., 2009 and from different written sources of Italian language, such as newspapers). During piloting, participants judged the degree of association of each word to disgust, happiness, and fear, using a scale from 1-9 (1 being *not at all associated* and 9 being *highly associated* with a given emotion). The ratings relative to each emotion were done in different blocks separated by short breaks. In addition to the ratings for the three specific emotions, each word was rated a fourth time on the degree of its general association to emotion using again a scale from 1 (*not associated with emotion*) - 9 (*highly associated with emotion*). These ratings were similar to those performed by Niedenthal et al. (2009) and were used to determine whether a given word was considered neutral with respect to any emotional content, including those emotions that were not explicitly rated.

To be selected as an *emotional word*, a word had to qualify under the following criteria: it had to be judged as highly associated with one of the three emotions considered (rating > 5); it had to be associated with emotional content in general (rating > 3); and finally, it could not be associated with the other emotions considered (rating < 3.5). Words were considered neutral when they were rated below 3, both on the general and the three specific emotionality scales. The stimulus material was selected from words that matched these criteria. Words were grouped into four categories: neutral, happiness, disgust, and fear. Univariate Analysis of Variance (ANOVA) confirmed that the four word types differed significantly from each other in their ratings on the general emotion association scale ($F(3,140) = 419.30$, $p < .001$) and that this effect was due to the neutral words being rated significantly lower on emotionality in comparison to each of the three emotion categories, $p$s < .001 (Bonferroni-corrected). Furthermore, ANOVA for the ratings on the specific emotion scales indicated that emotional word types differed significantly on the ratings for each scale: $F(3,140) = 779.14$, $p < .001$ (happiness scale); $F(3,140) = 647.57$, $p > .001$ (disgust scale); $F(3,140) = 767.91$, $p < .001$ (fear scale). See Table 3.1 for corresponding means and SDs. Specifically, post-hoc comparisons showed that words categorized as happy were more strongly associated with happiness than fear and disgust words ($p$s < .001, Bonferroni-corrected); words categorized as disgusting were more strongly associated with disgust than happiness and fear words ($p$s < .001, Bonferroni-corrected); and, finally, words categorized as fearful were more strongly associated to fear than happiness and disgust words ($p$s < .001, Bonferroni-corrected).



| **rating scale** | **neutral words** | | **happy words** | | **disgust words** | | **fear words** | |
|---|---|---|---|---|---|---|---|---|
| | mean | SD | mean | SD | mean | SD | mean | SD |
| **emotionality** | 1.89 | 0.53 | 6.61 | 0.53 | 6.30 | 1.02 | 6.68 | 0.77 |
| **happiness** | 1.87 | 0.45 | 6.59 | 0.79 | 1.18 | 0.14 | 1.18 | 0.45 |
| **disgust** | 1.34 | 0.26 | 1.21 | 0.12 | 6.19 | 0.89 | 2.97 | 0.67 |
| **fear** | 1.40 | 0.34 | 1.23 | 0.26 | 2.54 | 0.72 | 6.68 | 0.34 |

Table 3.1 Overview of the means and SD for each word type on each of the emotion scales. Ratings were done on each scale from 1-9. See subsection 3.2.2 for further information on the scales and corresponding statistics.

The final list of words (total *N* = 144) was divided into two separate sets of 72 words each. Each set included 12 words for each of the three emotions (36 emotional words) and 36 neutral words. A list of words used as one of the sets can be found in the Appendix. The two sets were designated not to differ in word frequency (*t*(142) = 0.17, *p* = .86) or word length (*t*(142) = 0.41, *p* = .96). Moreover, neutral words and emotional words of Set 1 were compared with the respectively neutral and emotional words of Set 2 to assure that they did not perform differently on their emotionality ratings. As expected, the emotionality rating for both emotional words (*t*(70) = 0.18, *p* = .45) and neutral words (*t*(70) = 1.30, *p* = .26) did not differ from Set 1 to Set 2. These two sets were necessary for the memory test, as one set served as the target and was presented during the encoding and retrieval phase, and the second set served as distractor during the retrieval phase. The presentation of one set as target or distractor was counterbalanced across participants.

### *3.2.3 Muscle-blocking strategy*

In order to test the effect of motor resonance on memory, I implemented a novel blocking procedure. Facial muscles were blocked by a mask containing pure green algae (*Green Clay Paste, Argiletz Laboratoire*), which solidifies into a hard shell that clings to the face after approximately 10 minutes. Because facial muscles, unlike other skeletal muscles, attach either to other muscles or directly to the skin, the hardening mask left the facial area largely immobile. This is in contrast to the study by Neal and Chartrand (2011), which used a gel that turns into a thin skin-like film. By application of the gel, Neal and Chartrand aimed at creating a subjective feeling of resistance in order to increase muscle activity and hence proprioceptive feedback. However, importantly, the gel was meant to preserve the initiation of muscle movements and, unlike the mask used in the present study, it was not meant to block them at any point. In order to compare the blocking condition with the no-block condition in a way that differed only in the blocking of the muscle, the participants assigned to the no-blocking condition received a non-hardening cosmetic cream with a similar thickness (*Burro di Karite, Erboristica*).

## 3.3 Procedure

The experimental session was carried out in a soundproof chamber where participants were seated approximately 50 cm away from a computer screen (Samsung; resolution 1280 x 1024 pixels). Instructions were presented on the screen describing the experiment as an investigation of the effect of altered skin conductance on word processing, and that the experiment would be performed in two separate sessions. Participants were not informed about the hypothesis related to the blocking of muscles and about the subsequent memory test. Instead, they were told that in order to restore skin conductance levels, an hour-long break was required before the second session.

The experiment involved an encoding phase and a retrieval phase, separated by a 1-hour break, in which participants were free to make use of the institute's library and garden, with the restriction that they could not consume any caffeine. During the *encoding phase*, participants performed a classification task. The procedure for this task followed exactly that outlined by Niedenthal et al. (2009). Words (size 27 in Arial font) were presented electronically, one at a time, after a fixation point (500ms.), in random order using E-Prime software (Psychology Software Tools, Pittsburgh, PA). Participants' task was to categorize each word as being "associated with emotion" or "not associated with emotion" by pressing one of two pre-instructed buttons on the keyboard. Two signs next to each side of the computer helped participants to remember the key-assignment during the task. Key-assignment was counterbalanced across participants and responses were not time-limited. After the response the next trial started. Before the task, participants had a short practice session to familiarize themselves with the task (five trials). After the practice trials, participants' questions were answered, and the first mask was applied to their faces. According to the participant's experimental group, the mask either blocked facial movements (blocking mask) or allowed movements (control mask). In both cases, however, the experimenter waited 10 minutes after applying the mask. At the end of the encoding phase, participants washed off the mask and filled in the Italian version of the Positive Affect and Negative Affect Schedule (PANAS; Terracciano, McCrae, & Costa, 2003), requiring participants to self-report their current state in relation to 20 given negative/positive mood states (e.g., *attentive*, *interested, nervous, jittery*) on a scale from 1 - 5.

After the 1-hour break, participants returned to the laboratory and took part in the *retrieval phase*. To begin, the second mask was applied (either the blocking mask or the control mask according to participant's condition). After another 10 minutes of waiting time, participants were presented with an unexpected memory task. In this task, the words from both Set 1 and Set 2 were presented one at a time in random order on a computer screen. Participants were asked to indicate for each word whether it had been presented during the first (encoding) phase (*old*), or it had not been presented before during the experiment (*new*). They were instructed to give a spontaneous but accurate answer by pressing one of two pre-instructed buttons. Just as during the encoding phase, there was no time limit to the responses and key-assignment was counterbalanced across participants and cued by 2 signs on each side of the computer.

Again, at the end of the task, participants washed off their mask and filled in the PANAS for a second time. In an additional questionnaire, they were asked to rate on a scale from 1 - 10 the (a) difficulty of the tasks, (b) the discomfort they felt because of the masks separately in encoding and retrieval phase, and (c) how stressful the experiment was in general. Before participants were finally thanked and informed about the actual purpose of the study, they were asked about their thoughts and opinion regarding the study and about the masks. If participants speculated that the masks were not meant to change skin conductance the experimenter asked additional questions such as, "What do you think was the real purpose of the masks?" and, "In what way do you think the masks have influenced your behavior?" This was done to ensure that none of the participants had guessed the relationship between the masks and their facial motor activity.

## 3.4 Results

### *3.4.1 Data preparation and data analyses approach*

In line with the procedure applied by Niedenthal et al (2009), I only considered words that were categorized with high agreement by participants. A word was considered neutral (or emotional) and included in the analyses if during encoding at least 75% of the participants in the non-blocked condition agreed on its classification. This criterion left 93% of all words for analyses.

RTS data were prepared by eliminating trials with response times below 300 ms or above 3 SD of participant's individual mean (total excluded trials: 2% and 4% for the categorization task and for the subsequent memory task, respectively). All RTs were log transformed before being analyzed. One participant's data were discarded from the analysis when the debriefing interview revealed that he had understood that the purpose of the hardening mask was to interfere with muscle activity. The final sample was composed of 79 participants (free in encoding & retrieval (control): *N* = 20; blocked in encoding: *N* = 19; blocked in retrieval: *N* = 20; blocked in encoding & retrieval: *N* = 20).

I first present the results relative to the categorization task (i.e., manipulation check), supporting the success of our blocking manipulation (blocking mask) in interfering with the processing of emotional content as expected by a blocking manipulation. Subsequently, I present the data relative to the memory task, analyzing the impact of the blocking manipulation during encoding and retrieval.

### *3.4.2 Encoding phase*

*Manipulation check:* The dependent variable was the index of sensitivity *d'* (Green & Swets, 1966)[1], discriminating emotional words from neutral words. An independent-samples t-test showed that participants whose muscles were free during encoding were significantly more accurate at categorizing emotional and neutral words (*d'* = 3.85, *SD* = .54) than those whose muscles were blocked during encoding (*d'* = 3.07, *SD* = .75), *t*(77) = 5.35, *p* < .001. To investigate the specific effect that the blocking manipulation might have on the single emotional word-types, I also computed an index of sensitivity (*d')* for each individual emotion (disgust, happiness, fear). For each word-type, the *d*' value was independently computed on the basis of false alarm rates of 12 randomly chosen neutral words from the neutral word set. The individual indexes were analyzed by a mixed-measures analysis of variance with condition (free at encoding vs. blocked at encoding) as the between-subjects factor and word-type (disgust vs. happiness vs. fear) as the within-subjects factor. Degrees of freedom were corrected when necessary using Greenhouse-Geisser correction for violation of sphericity. Because the self-ratings of the PANAS revealed a significant difference in negative affect between participants whose muscles were free (*M* = 1.2) during encoding and participants whose muscles were blocked (*M* = 1.4) during encoding (*t*(77) = 2.3, *p* = .03), I used the negative affect scores at encoding time as a covariate. Analysis revealed a main effect of condition (*F*(1,76) = 8.0, *p* < .001) but not for word-type (*F*(2,111) = 2.7, *p* = .13), and no significant interaction (*F(*2,152) = .53, *p* = .59). In general, blocking facial muscles impaired the ability to discriminate between emotional words and neutral words. Pair-wise comparisons for all three types of emotional words are presented in Figure 3.1. This effect was present for each emotion.

*Control variables*: Participants who were blocked during encoding rated the categorization task as more difficult (*M* = 3.7, *SD* = 2.1) than those whose muscles were free during encoding (*M* = 2.8, *SD* = 1.1), *t*(77) = 2.5, *p* = .016. They also gave higher ratings to feelings of exhaustion (*M* = 2.8, *SD* = 1.9) after the experiment than participants whose muscles had been free during encoding (*M* = 1.9, *SD* = 1.3; *t*(77) = 2.5, *p* = 0.16). None of the other ratings regarding the discomfort caused by the masks or the positive affect differed between the encoding conditions, (*t*(77) = 1.07, *p* = .29 and *t*(77) = 1.01, *p* = .32), respectively.

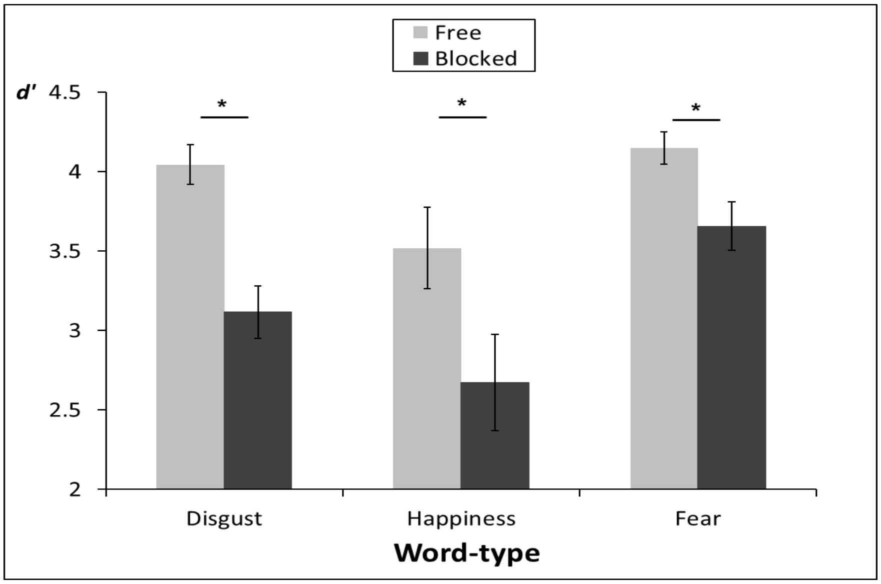


**Figure 3.1**. Classification Task. Accuracy of word classification expressed in *d'* as a function of word-type (disgust vs. happiness vs. fear) and encoding condition (free vs. blocked). Error bars represent ± 1SE. * $p < .05$

*RTs:* Reaction times were analyzed with a 2 (condition: free at encoding vs. blocked at encoding) X 2 (word-type: neutral vs. emotional) mixed-measures ANOVA with the first factor being between-subjects and the last one within-subjects. This ANOVA showed no significant effects of word-type (*F*(1,77) = .28, *p* = .60) or condition (*F*(1,77) = .69, *p* = .31), and no interaction (*F*(1,77) = .44, *p* = .51).

### *3.4.3 Retrieval phase*

*Retrieval accuracy:* The main hypothesis of the present experiment was that blocking facial muscles during encoding and/or retrieval would impair the memory of emotional words, but not neutral words. The dependent variable for the memory performance was *d',* which represents a measure of performance in discriminating between words presented during encoding (*old words*) and words not presented during encoding (*new words*). This *d'* index was computed separately for neutral and emotional words, and submitted to a mixed-measures 2 (word-type: emotional vs. neutral) X 4 (condition: free in encoding & retrieval vs. blocked during encoding vs. blocked in retrieval vs. blocked in encoding & retrieval) ANOVA, with the former factor being within-subjects and the latter being between-subjects. This revealed a significant interaction of the factors word-type and condition, *F*(3, 75) = 3.23, *p* = .027. Consequently, I ran two one-way ANOVAS, comparing the retrieval performance of the four conditions for neutral and emotional words separately. As expected, this analysis revealed a significant effect for emotional words *F*(3, 75) = 2.9, *p* = .042 but did not reveal any differences between conditions for the retrieval of neutral words (*p* > .05). I performed planned pairwise comparisons in order to explore whether the difference between the conditions in the retrieval of emotional words was, as expected, driven by better performance of the group whose muscles were free at all time during the experiment in comparison with the three experimental groups (see Figure 3.2). The results suggest that blocking embodied simulations impairs memory for emotional content irrespectively to when it occurs (in encoding, retrieval, or both). Additional post-hoc comparisons meant to test whether any differences occurred between the blocked conditions revealed no significant results (all *t*s < 1, all *p*s > .33), suggesting that blocking facial muscles at encoding, at retrieval, or both had comparable impeding effects on the retrieval of emotional words.

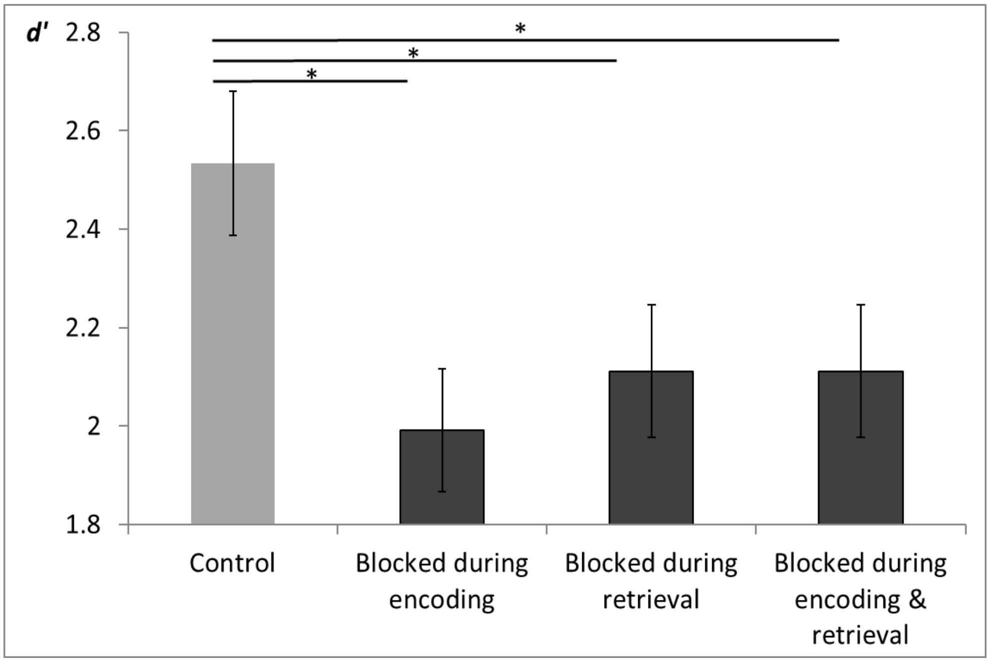


**Figure 3.2.** Memory accuracy for all emotional words expressed in *d'* as a function of condition (free condition in light grey; blocked conditions in dark grey). Error bars represent ± 1SE. * $p < .05$

To further investigate whether this assumption is true for each of the specific emotional word-types used in the present study (disgust, happiness, and fear), I computed memory performance expressed in *d'* values separately for each of the three emotional word-types. These *d'* values were submitted to a 2 (condition: free vs. blocked) X 3 (word-type: disgust vs. happiness vs. fear) mixed-measures ANOVA, with the first factor being between-subjects and the last one being within-subjects. The between-subjects factor compared any participant that had his or her muscles blocked either during encoding, retrieval, or both (*N* = 59), compared with the control participants, whose muscles were free during the complete experiment (*N* = 20). This analysis revealed a significant effect of word-type (*F*(2,154) = 3.6, *p* = .03) and condition (*F*(1,77) = 5.9, *p* = .018), but no interaction (*F*(2, 154) = .26, *p* >.05). In order to test whether each emotion showed an effect, three independent t-tests were computed, and results are reported in Figure 3.3. Blocking the muscles (as opposed to leaving muscles free during the experiment) significantly impaired memory for the word-types happiness (*t*(77) = 2.0, *p* = .045) and fear (*t*(77) = 1.9, *p* = .028, one-tailed), but not significantly for disgust *t*(77) = 1.1, *p* = .26) which, however, showed a similar pattern of means.

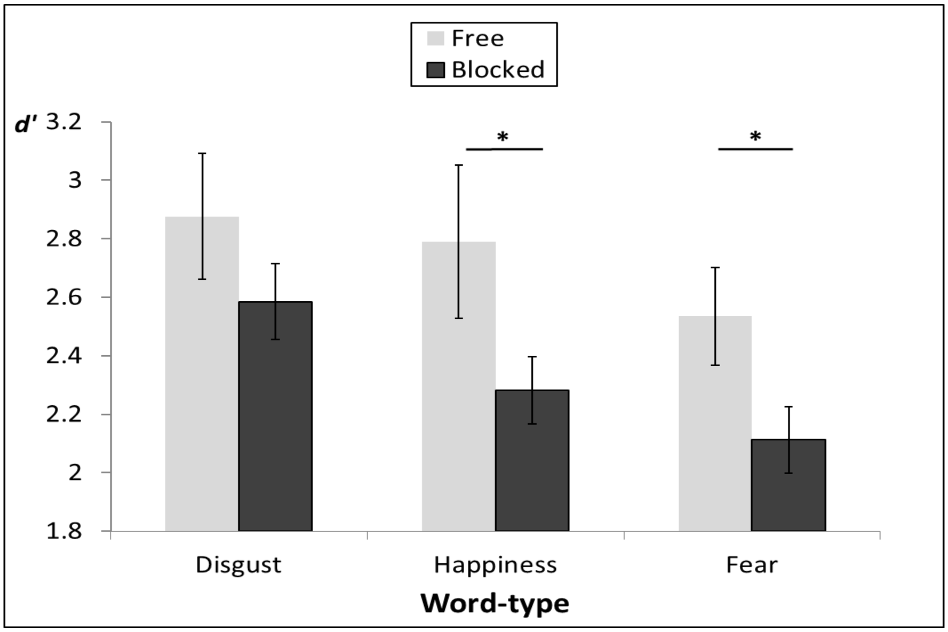


**Figure 3.3**. Memory accuracy for emotional words expressed in *d'* as a function of word-type (disgust vs. happiness vs. fear) and condition (free vs. blocked). Error bars represent ± 1SE. *p < .05 (one-tailed).

In order to test for the presence of an EEM in participants whose muscles were blocked at least once during the experiment against those participants whose muscles were never blocked, I ran two paired-samples t-tests (for the free and blocked conditions separately), comparing retrieval for emotional words vs. neutral words. The results revealed that participants with free muscles tended to remember emotional words (*d'* = 2.54, *SD* = .66) slightly better than neutral words (*d'* = 2.35, *SD* = .66). This pattern was, however, only marginal *t*(19) = 1.5, *p* = .07 (one-tailed). Further inspection showed that there was a tendency for the enhanced memory of all emotional word-types in comparison with neutral words. Significance was reached for words related to disgust and happiness, but not for words related to fear (see Figure 3.4.), supporting the claim of the presence of a memory advantage for emotional words over neutral (significantly in two of the three emotion categories). However, this trend for an EEM effect was absent when participants had been blocked at least once during the experiment. In this case, emotional (*d′* = 2.1, *SD* = .58) and neutral words (*d′* = 2.1, *SD* = .67) were equally well remembered, *t*(58) = .21 , *p* = .84.

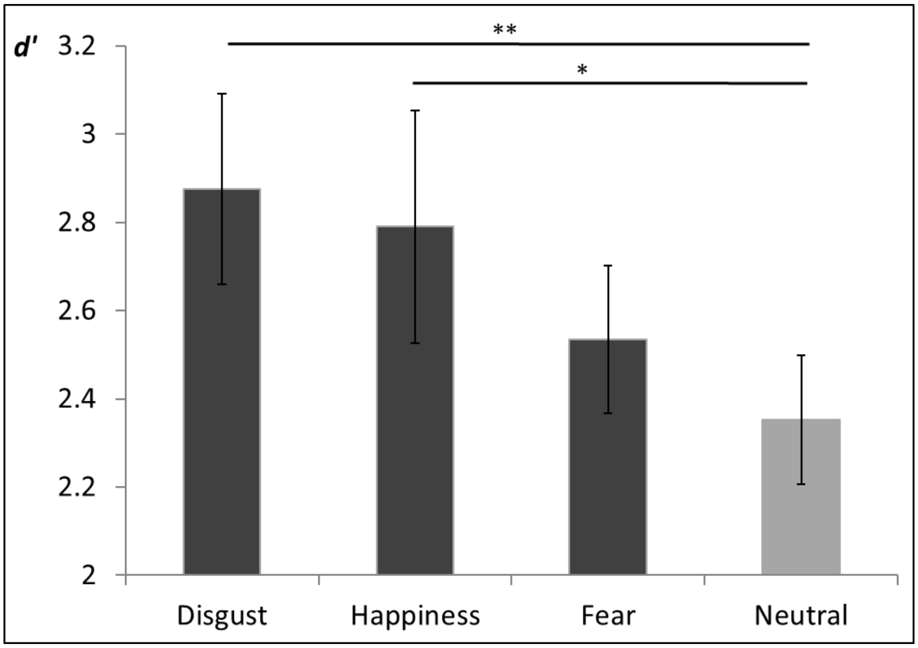


**Figure 3.4** EEM effect. Memory accuracy for each emotional word type expressed in *d′* in comparison to neutral words for participants in the free condition. Error bars represent standard error of means (SE). ** *p* < .05 (two-tailed), * *p* < .05 (one-tailed).

The different masks might have caused different effects on memory by providing either congruent or incongruent contextual cues. Therefore, I tested for the presence of a context-dependency effect. Since such an effect should modulate emotional and neutral words equally, I ran an independent samples t-test comparing the general memory performance *d′* for all words, regardless of word-type, between participants who had received the same mask during encoding and retrieval (congruent conditions) and those who had received different masks during encoding and retrieval (incongruent conditions). This comparison revealed no significant result (*t*(77) = .36, *p* = .60), suggesting that participants in the congruent mask conditions did not show better memory (*d'* = 2.23, *SD* = .60) in comparison with those in the incongruent conditions (*d'* = 2.18, *SD* = .52).

*Control variables:* To ensure that affective states did not differ between participants in the four conditions, the positive and negative affect ratings were submitted to two separate mixed-measures ANOVAs with the within-subjects factor time (after the encoding phase vs. after the retrieval phase) and the between-subjects factor condition (free in encoding & retrieval vs. blocked in encoding vs. blocked in retrieval vs. blocked in encoding & retrieval). Both ANOVAs revealed a main effect of time (positive affect: *F*(1,75) = 6.85, *p* = .011; for negative affect: *F* (1,75) = 6.86, *p* = .011). This result was due to a decrease over time of positive and negative affect across all conditions. Importantly though, the between-subjects factor condition neither revealed any significant main effects nor any interaction effects with the factor time (all *p*s > .05). Thus, participants assigned to the different conditions did not differ in their self-reported positive and negative states. Due to the discussed difference in negative affect ratings during encoding between participants in blocking condition and those that had been free, I re-ran the ANOVA analyses described above, taking negative affect during encoding as a covariate. This did not change the results. The covariate did not show any effect, and no significant interactions with retrieval performance were detected (all *p*s >.05). It is thus very unlikely that the presented results were driven by differences in affect, rather than by the hypothesized blocking manipulation. Regarding the stress-levels experienced during the experiment, a one-way between-subjects ANOVA demonstrated that also here, participants did not differ between conditions (*F*(3,78) = 2.2, *p* = .10).

*RTs:* Reaction time data were cleaned as was done for the RTs in the categorization task. The dependent measure was the log-transformed mean RT, and the design was a 4 (condition: free in encoding & retrieval vs. blocked in encoding vs. blocked in retrieval vs. blocked in encoding & retrieval) X 2 (word-type: neutral vs. emotional) mixed-measures ANOVA with the first factor being between-subjects and the last one within-subjects. There was no main effect for word-type (*F*(1,75) = 1.65, *p* = .20) or condition (*F*(1,75) = 0.11, *p* = .98) and no interaction between them (*F*(3,75) = 2.2, *p* = .10.

## 3.5 Discussion

In the present investigation, I examined whether facial motor resonance supports the encoding and retrieval of emotional words. The results confirmed this hypothesis: participants who had their facial muscles blocked during encoding, during retrieval, or during both remembered fewer emotional words than participants whose facial muscles were left free to resonate. This effect was specific for emotional words and was not found for neutral words. To my knowledge, this is the first study to show that embodied simulations support the encoding and later retrieval of emotional content. The data are aligned with theories of embodied cognition (see e.g., Barsalou 2008; Semin & Cacioppo, 2008; Niedenthal, 2007; Niedenthal et al., 2005), which predict that embodied processes are involved in the processing of emotional content and should do so both during encoding and during retrieval.

Previous research has demonstrated that the processing of emotional stimuli relies on facial motor resonance. The present results add to these findings by showing for the first time that blocking facial muscles interferes with the recollection of the emotional information. Further analyses revealed that the impairment of emotional words was mainly driven by a significantly reduced recall of fear and happiness words. The disgust words showed a decrease in memory accuracy in the blocking conditions, but failed to reach standard significance. This weaker impairment displayed by disgust words could be explained by the fact that disgust words also contained taboo words, such as *Anus* and *Pee* (e.g., Arnell, Killman, & Fijavz, 2007). Taboo words are generally better remembered than emotional non-taboo words (e.g., Kensinger & Corkin, 2003; Jay, Caldwell-Harris, & King, 2008). This is probably caused by the extreme arousal levels that they evoke (e.g., Kensinger & Corkin, 2003; Sharot & Phelps, 2004), as arousal has frequently been shown to modulate memory (e.g., Cahill & McGaugh, 1995; Kensinger & Corkin, 2004; McGaugh, 2004; Sharot & Phelps, 2004). Based on this evidence, one may expect that taboo words continue to be successfully remembered because of their salience even in the blocking condition, which may have led to the smaller effect shown in the present experiment. In other words, the processing of taboo words might be so facile and automatic that their processing remains relatively robust despite a lack of facial feedback. This is also in line with the previously discussed hypothesis that highly emotional stimuli, whose emotional connotation is clear-cut and easy to process, depend less on feedback from facial motor resonance and are thus less vulnerable to blocked facial muscles (see Chapter 2).

My results also extend previous research on the EEM. A marginal overall EEM effect was present, suggesting that the control group had the tendency to remember emotional words better in comparison to neutral words. Split by emotional word-type, the EEM effect was statistically significant for the words related to disgust and happiness. Fear words showed the same pattern, but in this case it was not significant. This may indicate that the emotional connotation of fear words is less accessible and meaningful in a neutral lab environment, potentially due to a decrease in imageability associated to them. However, when facial muscles were blocked at either time point during the experiment, this pattern vanished. This pattern cannot be explained by a contextual effect provided by the masks, as participants in the double blocking condition did not show an enhanced memory effect in comparison to participants who received two different masks during encoding and retrieval (see also Figure 3.2.), nor can it be explained by mood congruency or state-dependency effects (as in other research: e.g., Casasanto & Dijkstra, 2010), as both negative and positive emotions were affected. These findings suggest that embodied simulations play a role in the enhancement of emotional content. Since EEM has been shown to be correlated to amygdala activity (see Hamann, 2001; McGaugh, 2004, for reviews), the reported pattern is in accordance with the assumption that blocking facial motor resonance interferes with amygdala activity as suggested by Hennenlotter and colleagues (2009). Still, further studies are needed to explore this putative interaction between embodied simulations, amygdala activity, and EEM.

Another relevant aspect of my study is the use of a novel facial blocking manipulation (green algae mask). Blocking strategies implemented thus far tend to interfere with the activity of specific muscles (e.g., corrugator supercilii using BTX injections; or zygomaticus major using specific pen-holding manipulations). My goal was to block multiple facial muscles at the same time. In order to test the blocking effects of my blocking mask, I chose three categories of emotional words (disgust, happiness, and fear) meant to evoke motor resonance in different facial muscles (see Ekman & Friesen, 1978). Confirming my expectations, the blocking mask manipulation successfully interfered with the ability to discriminate neutral words from emotional words, irrespectively of their emotional content. This is important for future research because even when emotional facial expressions predominantly involve one muscle, many facial expressions result in the activation of multiple muscles. The facial resonance to sad stimuli, for instance, involves an increased activation of the corrugator supercilii, orbicularis oculi, and of the depressor anguli oris (Schwartz, Fair, Salt, Mandel, & Klerman, 1976). The possibility of blocking all muscles provides flexibility allowing, for instance, the testing of the role of facial simulations in more complex situations where multiple emotions may be at play. Furthermore, the control mask seemed to have successfully provided a similar context, as my analysis did not reveal any differences in disliking or distraction of the two masks, nor did I find a context-dependency effect.

Some interpretive objections remain, however. One could argue that the present results do not evidence the role of facial muscle resonance in memory for emotional stimuli but instead may be caused by an interference of the hardening mask with subvocalizational mechanisms known to improve the comprehension and retention of complex material (Dooley & George, 1988). There are three reasons why this interpretation is unlikely. First, interference with subvocalization should impede the processing of any word, but the present results demonstrated a specific effect for emotional word types and not for neutral words. Second, if people subvocalize, their reading speed slows down (see Dooley & George, 1998). Thus, if participants in the blocked conditions were hindered from subvocalization, their reading time should have decreased in comparison to those participants who were free. This was not found in the analysis of RTs (see subsections 3.4.2 & 3.4.3). Finally, considering that the present encoding task has previously been demonstrated to elicit facial motor resonance via EMG recordings, and considering that the hardening mask employed in the present study led to comparable effects with previously used blocking manipulations (Niedenthal et al., 2009), the best explanation for the present results is that they were caused by an inhibition of facial motor resonance.

My study intended to establish a link between previous research on embodiment and earlier research on memory. The results are in line with embodied theories of cognition and extend them by showing that embodied simulations play a role in memory for emotional information both at the encoding and retrieval stage. This interpretation does not exclude the possibility that the contribution of embodied simulations is restricted to the semantic activation of a word's affective content, which in turn may serve as an online cue for memory. Indeed, the way by which the blocking of facial motor resonance affects the normal recruitment of neural substrates associated with memory is an important question for future research. As discussed above, Decloe and Obhi (2013) found that embodied simulations of thumb movements have a causative role in the retrieval of action objects. Whether this link can also be established between facial motor resonance and retrieval of emotional content remains speculative at this point. Furthermore, the encoding and retrieval of emotional words in the blocking conditions may not only depend on the creation of a motor representation but also on attenuated activity of the amygdala (e.g., Adolphs et al., 1997; Brierley et al., 2004; Cahill et al., 1995; Markowitsch et al., 1994), because blocking facial muscles seems to interfere with neural activity in the amygdala (Hennenlotter et al., 2009). However, previous findings are limited to amygdala activation during active imitation of facial expressions, and thus they do not necessarily apply to the case of encoding and retrieval of emotional stimuli in general. Hence, future studies should explore whether the observed decrease in memory for emotional words reported here may be ascribed to an interference of the blocking manipulation with motor cortex and/or amygdala activation.

In summary, I showed that blocking facial muscles interferes with the encoding and retrieval of words with emotional content. Hence, I suggest that facial motor resonance plays a role and supports the processes involved in emotional memory when facial muscles are free. Facial motor resonance might not only elicit a smile when reading an emotional word, but might also help to remember it later on.

# Chapter 4

# Embodiment and Emotional Memory in a Second Language

## 4.1 Introduction

Language and emotions are closely linked. In the previous two chapters, I outlined how this link is supported by facial motor resonance during initial perception and later retrieval of emotional language. In light of these findings, the question arises as to whether the frequently reported phenomenon of diminished affective processing in a second language (L2) learned late in life may be associated to or even explained by reduced facial motor resonance in response to an L2.

Introspective reports, surveys, interviews, and clinical observations suggest that people remain emotionally distant from an L2 if it was not learned during early childhood[1], (e.g. Bond & Lai, 1986; Santiago-Rivera & Altarriba, 2002; Schwanberg, 2010). The behavioral effects of this emotional distance to an L2 have been well documented: for example, a recent study suggested that decision-making biases were reduced when using L2 (Keysar, Hayakawa, & An, 2012). Also, taboo words presented in L2 elicited less interference than taboo words in L1, thereby providing a processing advantage in a Rapid Search Visual Presentation task (Colbeck & Bowers, 2012). A third

---

[1] This study only reviews, discusses, and draws conclusions from studies in which participants acquired their second language in late childhood, meaning after the age of 8. Whenever I use the term L2 within this study, I refer to a L2 that was learned after the age of 8.

study showed that the usually observed enhanced memory for emotional stimuli over neutral stimuli (EEM effect; see Hamann, 2001, for a review) was only present in L1 but not in L2 (Anooshian & Hertel, 1994). The last result is especially interesting when considering that I found memory for emotional content to be closely linked to facial motor resonance, as was discussed in the previous chapter. One thus has to wonder whether the absence of an EEM effect in L2 may indeed be tied to a disembodiment of L2.

The differential degree of embodied responses to L2 vs. L1 has recently become a topic of interest. The focus has hereby been on the effects of L2 processing on SC. SC is a sensitive measurement of physiological arousal because it increases involuntarily in response to emotional stimuli, including words (see Dawson, Schell, & Filion, 2007, for a review). Eilola and Havelka (2010) showed that L1 speakers reacted with higher SC to negative and taboo words compared with neutral and positive words while performing an emotional Stroop task. No such pattern was observed for L2 speakers. In line with this, other studies have demonstrated higher SC responses in late bilinguals when they listened to or rated emotional words, phrases, or reprimands in L1 but not in L2 (Caldwell-Harris & Ayçiçeği-Dinn, 2009; Harris, 2004; Harris, Ayçiçeği, & Gleason, 2003). Considering the reduced levels in SC responses to emotional information in L2, one may wonder whether the processing of emotional information in L2 is also associated to lower levels in facial motor resonance.

If facial motor resonance occurring in response to emotion-laden words is moderated in L2, then this could explain the lack of EEM effect in L2 found by Anooshian and Hertel (1994). However, the absence of an EEM effect in L2 is not a consistent phenomenon. Ayçiçeği and Harris (2004) found that both L1 and L2 displayed an EEM effect, and the effect was even stronger in L2. In a follow-up to their research, the authors modulated the incidental study task to control how deeply participants processed the emotional connotation of the stimuli. This time, the results revealed an EEM effect for L1 but not for L2, provided that the study phase required deep encoding (Ayçiçeği-Dinn & Caldwell-Harris, 2009). A possible explanation for these differing results may be that encoding of L2 is more effortful than encoding of L1. When L1 and L2 words are mixed during encoding, as was the case in the procedures employed by Ayçiçeği-Dinn and Caldwell-Harris (2004, 2009), the elaborative processes and novelty effects associated with L2 may interfere with the processing of words presented in L1. However, if processing is deep and elaborative by task instruction, then the distractive effects of the L2 words may be cancelled out. In order to avoid such carry-over effects and distractive task switching, it may thus be more straightforward to present words in separate blocks for each language. This has been taken into consideration for the experimental set-up of the present study.

In order to investigate the putative role of embodiment and specifically the role of facial motor resonance on memory processes for emotional words in L2 vs. L1, a group of late Spanish/English bilinguals underwent a classical memory task involving encoding and retrieval of both emotionally charged and neutral words. Facial muscle EMG activity and SC responses were obtained during the encoding phase, in which participants performed a categorization task which required them to categorize words into “associated to emotion” or “not associated to emotion”. I predicted that the processing of emotional L2 words would elicit less facial motor resonance and reduced SC responses in comparison to the processing of emotional L1 words. Furthermore, I hypothesized that this absence or reduction of embodied simulations in L2 might have similar effects on emotion processing as the external blocking of mimic muscles, discussed in the previous chapters. In regard to the encoding phase, this means that accuracy for categorizing words should be reduced in L2. In regard to the memory performance, this raises the expectation that the EEM would be present in L1 but absent or reduced in L2.

## 4.2 Method

### *4.2.1 Participants*

32 young healthy late bilinguals (17 females; mean age: 26.4 ± 5.2) recruited in Southern California and bordering areas of Mexico participated in the experiment. Participant’s native language was either English or Spanish, and they spoke their second language (Spanish or English, respectively) at a very advanced level. Participants self-assessed their levels of speaking, reading, and understanding of L2 on a scale from 1 (*very poor*) - 10 (*perfect*) as being on average *very good* (speaking: *M* = 8.5. *SD* = 1.1; reading: *M* = 8.8, *SD* = 1.1; understanding *M* = 8.9, *SD* = 1.1; ratings ranged from 7 (*good*) – 10 (*perfect*)). Participants reached fluency in their L2 at a mean age of 15 (*SD* = 6.3; age range from 8 – 32 years). In a classical 1-minute letter fluency task, participants produced on average 11 words in L1 (*SD* = 3.1) and 9 words in L2 (*SD* = 3.2). A paired-

samples t-test showed that this difference was significant *t*(28) = 2.5, *p* = .02. Three participants were excluded from all analyses, two because of insufficient fluency in L2 and one due to self-judged onset of fluency in L2 earlier than age 8. Technical malfunctioning led to a loss of data of three further participants, leaving data of 26 participants for the analyses.

### *4.2.2 Stimuli*

*Pilot:* All final stimuli were selected from a large pool of words composed mainly by word pairs (English-Spanish translations) from an affective database for English and Spanish words (Conrad et al., N.D.), and some emotional words used in a previous research project. A total pool of 345 word pairs was selected for piloting. Words were pre-selected to be associated to the concepts of *Happiness* or *Anger* or to appear neutral according to the previous ratings they had received. To allow comparability, all words were rated again in both languages by 24 native speakers (14 English; 14 Spanish speakers) in an online survey. Not all participants completed all blocks of the pilot, but all words received ratings by at least 10 participants. Ratings were done in regard to their association to the concepts of anger, happiness, and overall emotion on a scale from 1 (*not at all associated to*) - 9 (*very much associated to*). Further ratings were done in regard to imageability and arousal, again on scales from 1 - 9.

*Final word-selection:* In order to be selected as a stimulus, the happy and angry word-pairs were required to be rated > 3.5 on the respective emotion scale, to be associated to emotional content in general (rating > 3), and to not be associated to the other emotion considered (rating < 2.5) across both languages. Word-pairs were considered as neutral when they were rated below 3.3 both on the general and the specific emotionality scales in both languages. In this way, 320 word-pairs were selected. Descriptive statistics confirmed that happy words were rated higher on the happiness scale ($M$ = 6.8, $SD$ = 1.1) than angry ($M$ = 1.1, $SD$ = .13) and neutral words ($M$ = 1.7, $SD$ = .52), and angry words were rated higher on the anger scale ($M$ = 6.2, $SD$ = 1.5) in comparison with happy ($M$ = 1.5 $SD$ = .60) and neutral words ($M$ = 1.5, $SD$ = .24). Furthermore, neutral words were rated lowest on overall emotionality ($M$ = 1.6, $SD$ = .60) in comparison with both happy ($M$ = 5.7, $SD$ = 1.6) and angry words ($M$ = 6.0, $SD$ = 1.5). All words were divided into 8 wordlists (4 English wordlists and 4 Spanish wordlists). Each wordlist was composed of 20 happy words (e.g., *Joy, Sweets*), 20 angry words (e.g., *Murderer, Harassment*), and 40 neutral words (e.g., *Code, Subject*). These wordlists were assembled to form four word-sets, each including one English and one Spanish wordlist. An English word and its Spanish translation were never assigned to the same set. The four word-sets were designed to not differ in word frequency, word length, imageability, and arousal within the English ($F$s(3,319) < 2.0, $p$s > .12) and Spanish words ($F$s(3,319) < 1.4, $p$s > .26). Furthermore, English and Spanish emotion-laden words (angry and happy) were separately matched across all four sets in terms of their ratings on the respective emotion-scale (anger- and happiness-scale), whereas neutral words were matched for their average overall emotionality ratings (all $F$s(3,156) < .34, all $p$s > .80). Finally, it was ensured that within each set, words differed significantly on happiness, anger, and overall emotionality ratings (all *F*s(2,159) > 247, all *p*s <.001).

## 4.3 Procedure

The experiment involved an encoding phase and a surprise retrieval phase on two consecutive days. Instructions were presented in the participant's native language and described the experiment as investigating the effect of SC on word processing in a native and second language. Participants were not informed about the hypothesis related to facial muscle activity and the subsequent memory test.

### *4.3.1 Encoding phase*

Upon arrival on the first session, participants read and signed a consent form before completing the Language Experience And Proficiency Questionnaire (LEAP-Q; Marian, Blumfeld, & Kaushanskaya, 2007) to assess their language ability in L1 and L2. Potential baseline differences in daily affect and mood were controlled by the Positive and Negative Affect Schedules (PANAS; Watson et al., 1988), presented in the respective L1 (for the Spanish version see Sandín et al., 1999). To lower skin impedance for better EMG signals, the skin areas above the zygomaticus major and corrugator supercilii were prepared with cotton pads and abrasive lotion. Residue of the abrasive lotion was removed with cotton pads soaked in alcohol. Bipolar 4-mm EMG electrodes were attached to the corrugator supercilii and the zygomaticus major on the left side of the face. Skin conductance was recorded with gold-plated electrodes on the index and middle fingers of the non-dominant hand.

During the first session, participants performed a classification task, requiring them to categorize words into “associated to emotion” or “not associated to emotion” by pressing one of two buttons on a keyboard. Labels to the left and right of the computer monitor served as reminders of the button-assignment throughout the experiment. The English and Spanish word lists of one of the four sets were presented in separate blocks on a computer screen, divided by a short break (5 minutes). The order of word-lists (English word list vs. Spanish word list) within each set and the set presentation itself were randomized across participants. Each trial started with a fixation-cross presented for 2 seconds. This was followed by the randomly ordered display of the word stimulus for 3 seconds and was concluded with the display of a question mark (E-Prime software; Psychology Software Tools, Pittsburgh, PA). Participants were instructed to wait for the question mark to give their response in order to avoid movement interference with the EMG recordings. After the response the next trial started. Every participant started with a short practice session (6 trials).

### *4.3.2 Retrieval phase*

The second session took place 24h later and started with participants filling in the PANAS for a second time. This was followed by a surprise memory task. Words from the old and the new set were mixed and randomly presented within a Spanish and English block, providing an equal number of old and new words. Each word was presented individually on a computer screen. Participants' task was to indicate whether the word had been presented during the encoding phase (*old*) or whether it was new (*new*) by pressing one of two buttons. Signs left and right of the computer screen indicated the button-assignment and served as reminders.

### *4.3.3 EMG/SC acquisition*

EMG and SC Signals were recorded using BIOPAC MP150 modules (BIOPAC Systems, Inc., Goleta, CA) set at a sample rate of 2,000 samples per second with gain set to 100. The signals were filtered using a bandpass from 20 to 400 Hz and a notch filter at 60Hz. The acquisition of the EMG signals was controlled by BIOPAC's AcqKnowledge software Version 3.0.21 (Mindware Technologies LTD., Gahanna, OH).

## 4.4 Results

### *4.4.1. PANAS*

The self-ratings of the PANAS revealed no significant differences between the first and second session of the experiment (*p*s > .25), and were thus disregarded in further analyses.

### *4.4.2 EMG/ SC data preparation*

Offline processing of the EMG data was performed with software from *Mindware Corporation*. EMG signals were rectified, integrated, and averaged for a period of 2500 ms in chunks of 500 ms after stimulus onset. Data were cleaned for each participant and each muscle individually, removing data points above or below three *SD* of participant's mean. The baseline (recorded during the presentation of the fixation cross, 500 ms before the target) was subtracted from the mean activity. The baseline-corrected score was used as the dependent variable. The same cleaning was applied to the SC data, with the only difference that due their later onset, SC signals were averaged in chunks of 500 ms for a time period from 1500 – 3000 ms after stimulus onset. All EMG and SC data associated to trials in which the word presented was incorrectly categorized during the encoding phase were excluded from the analyses (8%). For the SC, the root mean square was calculated and all data were standardized.

### *4.4.3 Statistical analysis EMG data*

To examine the relationship between EMG data, language, and word type, I ran two separate repeated measures ANOVAs for each muscle (zygomaticus and corrugator; see Figure 4.1). The within-subjects factors were language (L1 vs. L2), word type (happy vs. angry vs. neutral), and time point (500ms, 1000ms, 1500ms, 2000ms, 2500ms). The Greenhouse-Geisser epsilon correction was applied to adjust the degrees of freedom of the *F*-ratios when necessary. For the zygomaticus muscle, this analysis revealed a strong effect of word type ($F(2,40) = 5.80$, $p < .01$, $\eta^2_p = .19$) and a strong interaction of word type and time point ($F(3,67) = 5.32$, $p < .001$, $\eta^2_p = .18$). The expected interactions between language and word type ($F(2,50) = .15$, $\eta^2_p = .006$) or between language, word type, and time point ($F(4,97) = .94$, $\eta^2_p = .04$) revealed, however, no significant effects ($p = .87$ and $p = .49$, respectively). For the corrugator muscle, a marginal interaction between language and word type was present ($F(2,47) = 2.47$, $p = .09$, $\eta^2_p = .09$). The expected main effect of word type remained, despite a medium sized effect, insignificant ($F(2,39) = 1.29$, $p = .28$, $\eta^2_p = .05$). Also the interaction between language, word type, and time point remained insignificant ($F(8,200) = .90$, $p = .52$, $\eta^2_p = .04$).

Despite the absence of the expected interactions, the visual inspection of the data (see Figure 4.1) suggested that the zygomaticus and the corrugator muscle are differently activated by L1 and L2, particularly in later time windows. I therefore decided to conduct further analyses with the intention to explore facial muscle reactivity in response to emotional words in L1 and L2 at each time point. In a series of pairwise comparisons, EMG activity in response to happy vs. angry words was compared over the five time intervals. Hereby, the activity over zygomaticus and corrugator muscles was analyzed separately.

*Zygomaticus:* Significant differences in response to happy vs. angry words in L1 were recorded in the time window 1500 ms - 3000 ms after word onset. In comparison, the zygomaticus activity for happy vs. angry words in L2, differentiated only in the time window 2000 ms - 2500 ms after word onset. This result indicates a later onset and shorter duration of specifiable zygomaticus activity in response to happy vs. angry words in L2 compared with L1 (see Figure 4.1). A direct comparison of the averaged differential activity of the zygomaticus in response to happy vs. angry words in L1 vs. L2 did not reach significance ($t(25) = 1.02$, $p = .11$, one-tailed, Cohen's $d = .26$)

*Corrugator:* Exploring the specifiable activity of the corrugator in response to angry vs. happy words across time revealed significant results only within L1. Corrugator activity was stronger in response to angry words vs. happy words in L1, starting from 2000 ms after stimulus onset. No significant differences of corrugator activity in response to angry vs. happy words were observed in L2 (see Figure 4.1). A direct comparison of the averaged differential activity of the corrugator in response to angry vs. happy words in L1 vs. L2 confirmed that the corrugator activity evoked by L2 words was significantly lower than in L1 ($t(25) = 1.25$, $p = .03$, one-tailed, Cohen's $d = .39$).

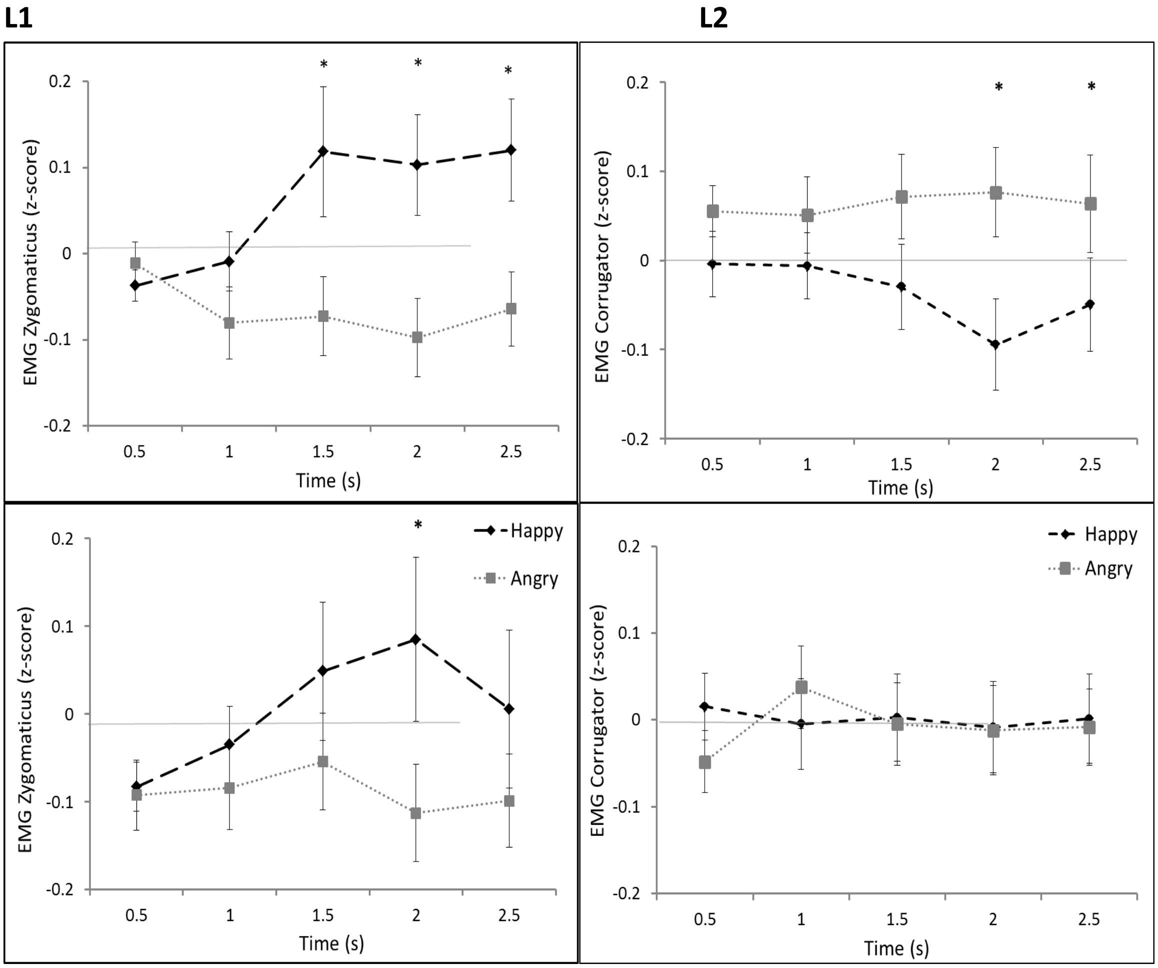


**Figure 4.1.** Mean zygomaticus (upper panel) and corrugator activity (lower panel) by time as a function of word type and language. Figures show EMG activity in response to happy words (black) vs. angry words (grey) in L1 (left panel) and in L2 (right panel). Error bars represent ± 1 SEM. * *p* ≤ .05 (two tailed).

### *4.4.4 Statistical analysis of SC data*

The Skin Conductance Response (SCR) was averaged separately for emotional (happy and angry together) and neutral words over the time window 2000 ms - 3000 ms after stimuli onset. This time window was chosen as the skin conductance response is usually delayed by around 1-3 sec after cue onset (see Dawson, Schell, & Filion, 2007). SCR-scores were submitted to a repeated measures ANOVA with language (L1 vs. L2) and word type (emotional vs. neutral) as within-subjects factors. The analysis resulted in a significant interaction *F*(1,25) = 4.5, *p* = .05. Pairwise comparisons revealed that this interaction was driven by a significantly stronger SCR to emotional words in L1 (*M* = .03, *SD* = .10) in comparison with L2 (*M* = -.01, *SD* = .11), *t*(25) = 2.2, *p* = .04. No differences between L1 (*M* = .02) and L2 (*M* = .01) were present for the neutral words *t*(25) = .43, *p* = .67.

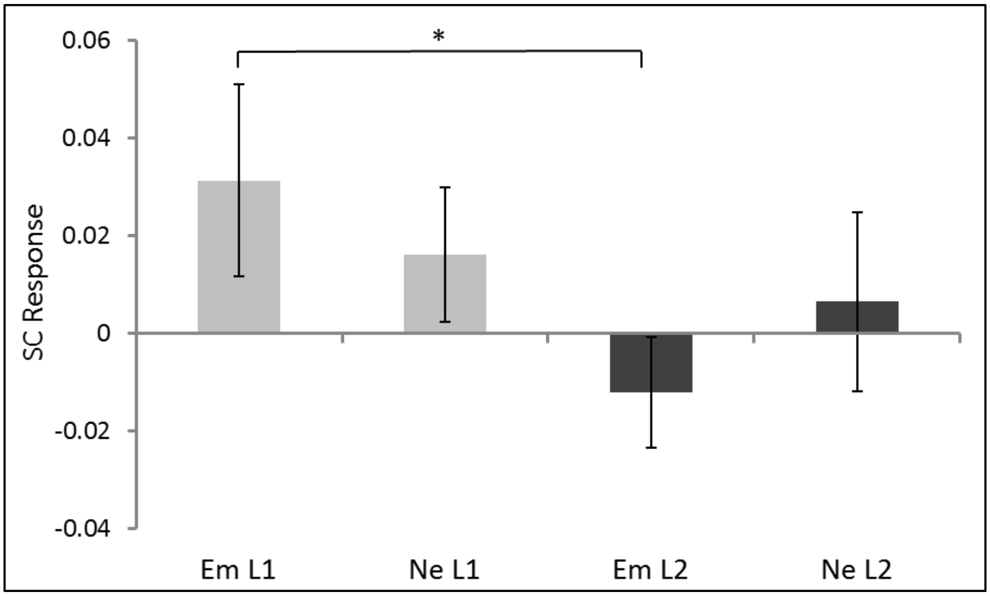


**Figure 4.2** SC in response to emotional (happy & angry) and neutral words presented in L1 vs. L2 averaged for the period from 2 – 3 sec after stimulus onset. Error bars represent ± 1 SEM. * $p \leq .05$.

### *4.4.5 Behavioral results*

*Encoding phase:* The dependent variable was the accuracy in discriminating emotional words from neutral words, expressed by the sensitivity index *d'* (Green & Swets, 1966). A paired-samples t-test showed that performance was significantly better in L1 than in

L2 (t(28) = .05, Cohen's *d* = .38). Since it could be argued that this was simply due to lower proficiency rather than reduced emotionality in L2, two paired samples t-tests compared the accuracy in percent for emotional words and accuracy for neutral words separately across languages. As expected, this revealed no significant difference between L1 (*M* = .85, *SD* = .08) and L2 (*M* = .82, *SD* = .11) for neutral words (*t*(27) = 1.6, *p* = .12); however, surprisingly, it also revealed no effect for emotional words (L1: *M* = .84, *SD* = .12; L2: *M* = .80, *SD* = .16; *t*(27) = 1.3, *p* = .20). In both cases, L1 showed a tendency for higher accuracy compared with L2, which would support the alternative hypothesis that the difference in *d'* is a matter of fluency. An alternative explanation could be that the present study used emotional stimuli with different emotional intensity. This raises the question of whether a specific impairment in encoding of emotional L2 words was possibly overshadowed by emotional L2 words with stronger emotional intensity. In Chapter 2, it was demonstrated that facial motor resonance particularly supports the encoding of slightly emotional stimuli and only to a lesser extent the encoding of highly emotional stimuli. To test whether the same mechanism underlies L2 processing, I categorized the emotional words into slightly and highly emotional. Note that the original categorization criteria for the emotional words (described in 4.2.2) accepted a large scale in emotionality ratings, including words with only moderate emotionality ratings. Thus, in order to obtain a better understanding of the impact that this broad scale in emotionality ratings for the emotional words might have had, any words with ratings between 3.0 - 6.5 on the overall emotionality scale ranging from 1 - 9 during the pilot (see section 4.2.2 for more information on the pilot and scales) were considered to be slightly emotional. Any words with ratings above 7.5 on the same scale were considered to be highly emotional. To test the prediction that specifically the categorization of slightly emotional L2 words was impaired, a 2(emotionality: high vs. low) X 2(language: L1 vs. L2) repeated measures analysis was conducted, with both factors being within-subjects. This revealed a significant effect of emotionality ($F(1,27) = 35$, $p < .001$) and a marginal interaction between emotionality and language ($F(1,27) = 3.31$, $p = .08$). Pairwise comparisons confirmed that participants performed equally well at categorizing highly emotional words in L1 and L2. In contrast, they exhibited a strong bias to incorrectly categorize slightly emotional L2 words as neutral, while this tendency was significantly less pronounced in L1 (see Figure 4.3).

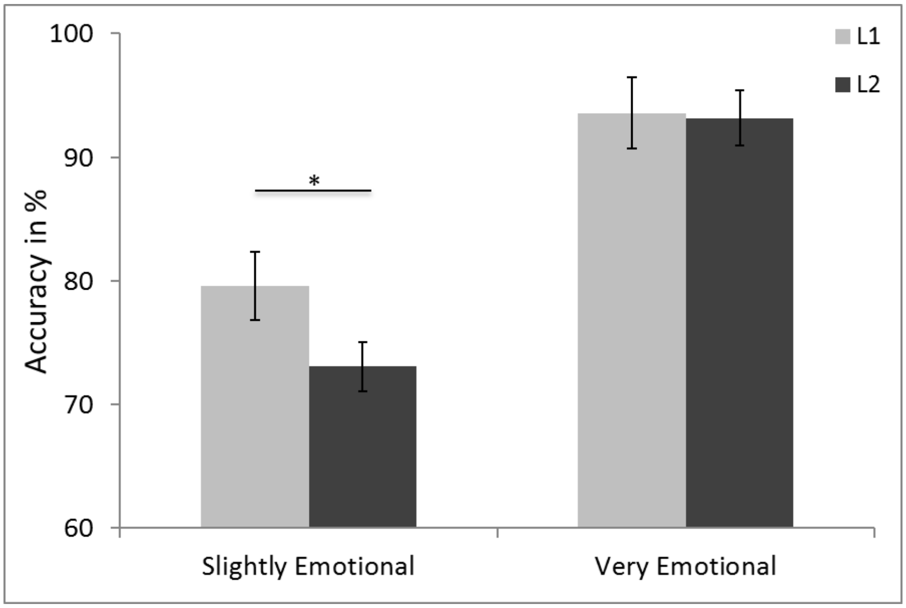


**Figure 4.3**. Accuracy (%) in identifying emotional words as *associated to emotion* during the encoding phase as a function of emotionality (slightly emotional vs. very emotional) and language (L1 vs. L2). Error bars represent ± 1 SEM. * $p \leq .05$ (two-tailed).

*Retrieval Phase:* Since I was interested in the memory of emotional words vs. neutral words, I controlled for individual differences in emotion perception across participants by excluding words that had been incorrectly classified during the encoding phase. This was done for each participant individually and guaranteed that our analysis of the memory task for emotional and neutral words was run only on words that had been perceived according to their piloted emotional category. The dependent variable was the memory performance indexed by *d',* which measures the performance in discriminating between *old* and *new* words. This *d'* index was computed separately for neutral and emotional words, and submitted to a repeated measures ANOVA with the within-subjects factors language (L1 vs. L2) and word type (emotional vs. neutral). The analysis did not result in any main effects or in an interaction (all *F*s < 2.0, *p*s > .18). However, because of the a priori interest in the comparison of the EEM effect within L1 and L2, pre-planned pairwise comparisons of emotional vs. neutral words in L1 and L2 were conducted. As expected, participants showed enhanced memory for emotional words (*d'* = 1.46, *SD* = .49) in contrast to neutral words (*d'* = 1.26, *SD* = .55) in L1 (*t*(25) = 2.20, *p* = .04). Calculation of the effect size (Cohen's *d* = .44) suggested a medium sized effect in L1. Importantly, the EEM effect was absent in L2 (*t*(25) = .10, *p* = .93), for which participants' memory for emotional words (*d'* = 1.44, *SD* = .65) versus neutral words (*d'* = 1.43, *SD* = .59) did not differ (Cohen's *d* = .02). Since the visual inspection of the EEM effects (Figure 4.4) suggested that the reported difference in the EEM effects in L1 and L2 was mainly driven by enhanced memory of neutral words in L2 as compared with L1, a paired sample t-test investigated whether this difference was significant. This was, however, not the case (*t*(25) = 1.40, p = .17). Finally, two pairwise comparisons showed that the EEM in L1 was driven by a better retrieval of angry and happy words (angry vs. neutral: *t*(25) = 1.80, *p* = .04 (one-tailed); happy vs. neutral: *t*(25) = 2.50, *p* = .02 (two-tailed; *p*-values are Holm-Bonferroni corrected; see Figure 4.4.).

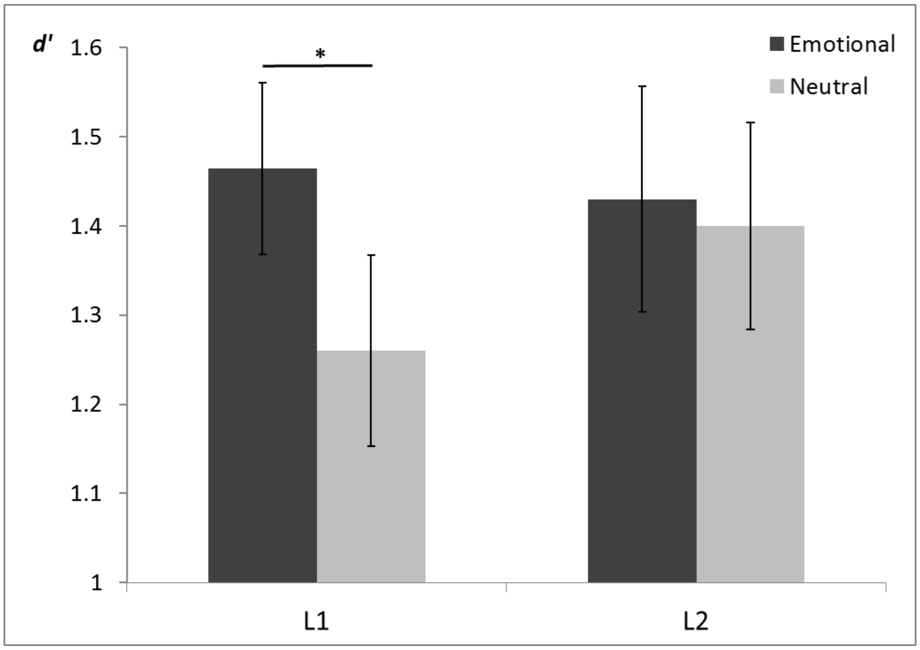


Figure 4.4. Memory accuracy expressed in *d'* for neutral and emotional (angry & happy) words. Error bars represent ± 1 SEM. * *p* ≤ .05 (two-tailed).

Since the encoding phase revealed that processing in L2 specifically affected the perception of slightly emotional stimuli, I was interested in whether a similar mechanism could be found for the retrieval of slightly emotional stimuli in L2. For this, the memory accuracy scores associated to highly emotional stimuli (above 7.5 on the overall emotionality scale), and those associated to slightly emotional stimuli (below 6.5), were submitted to a 2(emotionality: slightly emotional vs. very emotional) X

2(language: L1. vs. L2) repeated measures ANOVA with both factors being within-subjects. This revealed only a marginal main effect of emotionality ($F(1,24) = 3.06$, $p = .09$, $\eta^2_p = .11$) caused by a slightly better memory of highly emotional stimuli in comparison with slightly emotional stimuli. No other effects were observed (both *F*s < 1.42, both *p*s >.24).

## 4.5. Discussion

The goal of the present study was to associate embodied cognition with memory processes for emotional language in L1 and L2. First, the hypothesis that the processing of emotional words in L2 would evoke a lesser degree of embodied simulations compared with L1 was investigated. The results were relatively weak and only partially confirmed the hypothesis. In a second step, the hypothesis that L2 processing would interfere with both the categorization and later retrieval of emotional words was tested. Again, the results were weak but suggested that only L1 but not L2 evokes an EEM effect.

The overall results of the EMG and SC recordings suggested some reductions and differences in embodied simulations of emotional L2 words in comparison with emotional L1 words. Even though the expected two-way interaction of language and word type was absent for the analysis of zygomaticus activity and only marginal for the corrugator, some interesting results emerged. For example, whereas pairwise comparisons across time indicated that the activation of the zygomaticus showed typical activity in response to emotional L1 words, these patterns in activation seemed truncated and delayed in response to emotional L2 words (see Figure 4.1). The difference between L1 and L2 processing became particularly observable in the corrugator muscle, which showed typical response patterns to emotional L1 words but no recordable responses to emotional L2 words. Similarly, the SC also displayed no significant reactions to emotional words presented in L2 while still showing typical patterns of responsiveness in L1. The direct comparisons of facial muscle responsiveness to L1 vs. L2 revealed a significant difference only for the corrugator muscle but not for the zygomaticus muscles. However, despite not being significant, the zygomaticus showed a similar pattern of decreased responsiveness in L2. An explanation for this difference between zygomaticus and corrugator muscle activation in L2 could lie in the emotional content, which activates the respective muscle. Whereas the zygomaticus reacts to positive stimuli, the corrugator muscle reacts to negative stimuli. As was recently shown by Conrad, Recio, & Jacobs (2011), negative L2 words are less likely than positive L2 words to elicit differential brain activity in speakers currently living in their L2 country. They argued that this potentially reflects a predominant positivity bias for L2 processing. Given that most of the participants in the present study lived in their L2 country, such a positivity bias could also explain the current findings.

Overall, the results of the EMG and SC recordings give some indications that the processing of emotional L2 words is less grounded in embodied simulations than the processing of L1 words. This aligns with previous reports of decreased SC (Caldwell-Harris & Ayçiçeği-Dinn, 2009; Eilola & Havelka, 2010; Harris, 2004; Harris, Ayçiçeği, &

Gleason, 2003) and agrees with studies, which have shown reduced behavioral responsiveness to emotional language in L2 (Colbeck & Bowers, 2012; Keysar et al., 2012). Such results may indicate that L2 learning in adulthood does not necessarily involve the same affective linguistic grounding as L1 learning in childhood. When conceptual and emotion regulation systems have already reached a relatively stable state, the affective grounding of abstract symbols, such as words, may remain shallow.

The secondary hypothesis, which states that differences in embodied simulations between L1 and L2 would additionally be associated to performance differences during the encoding and retrieval phase, also could only be partially supported. During the encoding phase, participants were more accurate at categorizing L1 vs. L2 words. In contrast to the expectation, this effect was caused by an interference with categorizing both emotional and neutral L2 words. This finding opposes the expected difficulty in categorizing specifically emotional words in L2 and could be an indicator of participant's general lower fluency in their L2 (see also subsection 4.2.1). Further investigation and post-hoc analysis of this unexpected effect, however, suggested a specific difficulty at identifying slightly but not strongly emotional stimuli in L2, which would speak against a general proficiency effect. This finding is in line with the assumption that the encoding of slightly emotional stimuli particularly depends on the presence of facial motor resonance. However, given the post-hoc nature of this analysis, its result should be interpreted with caution. For example, although stimuli were carefully matched across languages and emotions, the slightly and strongly emotional stimuli were not comparable in terms of concreteness and frequency. Therefore, the interpretation that the difference in proficiency between L1 and L2 caused the differences in categorizing performance cannot be ruled out. In regard to memory performance, the expected interaction between language and word type did not appear. Yet, the comparison of effect sizes supported the initial hypothesis, suggesting the presence of an EEM effect in L1 but not in L2.

Even though the results of the memory task were relatively weak, they align with previous findings reporting no EEM effect in L2 (Anooshian & Hertel, 1994). However, they are in opposition to reports of an equal or even stronger EEM effect for L2 (Ayçiçeği & Harris; 2004; Ayçiçeği-Dinn & Caldwell-Harris, 2009). Two reasons could be responsible for these differences in results for emotional memory in L2. First, it is possible that these differences are owed to dissimilar experimental procedures. Second, they may be mediated by the distinct circumstances in which participants acquired L2. For example, while both the present study and the study by Anooshian and Hertel presented L1 and L2 words in different blocks, the two studies by Ayçiçeği-Dinn and Caldwell-Harris (2004; 2009) presented L1 and L2 stimuli intermixed. This may have caused a novelty effect for L2, which may in turn have inhibited normal processing of L1 words. The Turkish participants in the studies by Ayçiçeği-Dinn and Caldwell-Harris (2004; 2009) acquired their second language (English) in the classroom and/or in self-instruction and were generally less fluent in L2. Because of this, they may have been more likely to mentally translate L2 words into L1, which may have accounted for the EEM effect in L2. In contrast, most participants in the present study and in the study by Anooshian and Hertel (1994) were exposed to their L2 via emigration in late childhood and spoke their L2 with high fluency on a daily basis. It is, however, noteworthy that the current study also encountered large behavioral variances across subjects (see Figure 4.4), which corroborates the assumption that the processing of L2 is determined by many more factors besides proficiency.

The reported absence of an EEM effect in L2 is similar to the interference effect observed in the previous study (Chapter 3), in which blocked motor resonance specifically inhibited retrieval of emotional words. Those results suggested that facial motor resonance has a crucial role in the processing of emotional content and contributes to the presence of an EEM effect. It is thus of particular interest that the current results gave some indications that facial motor resonance could be reduced when processing L2 words. This suggests that the external blocking of facial motor resonance and the reduction of facial motor resonance by means of processing in L2 are both associated to the absence of an EEM effects. Clearly, this does not mean that processing in L2 affects human cognition in the same way that the forceful blocking of facial muscles does. After all, the reported effects on the categorization task differed between the present study and the study described in Chapter 3. Furthermore, facial motor resonance was not completely absent in L2. However, the observation that the absence or reduction of facial motor resonance was in both cases associated to the absence of an EEM effect could lead one to conclude that facial motor resonance is linked to emotional memory in L1 and L2. It would therefore be interesting to investigate in future studies whether the embodied grounding of an L2 would predict the appearance of an EEM.

Another subject that awaits investigation is the determination of the mechanism underlying such reduced affective processing in L2. Lamendella (1977) proposed that implicit linguistic competence, unlike explicit or semantic knowledge, is integrated within the limbic system, involving the striatum and amygdala. This is especially interesting because the amygdala, a structure known to be involved in both experiencing and processing emotional stimuli, shows attenuated activity if facial muscles are blocked by an external force (Hennenlotter et al., 2009). In line with this and the current results, a recent study (Hsu, Jacobs, & Conrad, 2014) demonstrated that emotional content in L2 evokes less amygdala activity than it does in L1. Those findings indicate a general interdependence between affective processes, embodied responses, and the recruitment of limbic structures in emotional language processing.

Overall, the results suggest that reading emotional words in a native language provides a deep and embodied emotional experience, which may subsequently also support their salient encoding and retrieval. In contrast, cognitive processes associated with L2 encoding and retrieval seem to be less associated to embodied processes. This could also explain the lack of enhanced emotional memory observed in the present study, reinforcing the idea of Chapter 3, that embodied cognition and emotional memory are linked.

# Chapter 5

# Forget It If You Can - A Combined EMG/ERP Study of Directed Memory and Forgetting of Emotional Words

## 5.1 Introduction

With the prior two chapters, I hope to have shed some light on the relationship between embodied processes and enhanced incidental memory for emotional stimuli. Extending this line of research, the present chapter links embodied processes to intentional emotional memory and forgetting. While successfully recalling information is often considered desirable, forgetting is explained as the failure of a limited memory system. However, it can also be a useful ability. Sometimes we prefer to forget, be it because we want to ease our cognitive load, or that we want to rid ourselves of an unpleasant event or fact. But intentional forgetting is not always easy and forgetting emotional stimuli may be particularly hard. Some studies suggest that the general processing advantage associated to emotional stimuli may become a disadvantage when we try to inhibit their enhanced processing, because more effort is required to suppress them from recollection (e.g. Nowicka, Marchewka, Jednorog, Tacikowski, & Brechmann, 2011; Yang et al., 2012). In contrast, when intentionally memorizing emotional stimuli, their processing advantage could be particularly helpful.

Considering that the results of the previous two chapters suggested that embodied simulations are associated to enhanced memory of *incidentally* encoded emotional words, the question arises as to whether the *intention* to consolidate or suppress emotional words may consequently modulate the degree to which they are simulated at encoding. In fact, it has been demonstrated that the intentional consolidation and forgetting of emotional stimuli can lead to very distinctive brain activations and memory performance (e.g., Hauswald, Schulz, Iordanov, & Kissler, 2011; Nowicka et al., 2011; Yang et al., 2012), which may in turn also be reflected in differences in facial motor resonance. The present study thus aims to investigate intentional memory and intentional forgetting of emotional stimuli by using a threefold approach, combining the assessment of behavioral data, EMG recordings, and event related potentials (ERP).

The human capacity for intentional forgetting has frequently been documented using the directed forgetting (DF) paradigm, developed by Bjork, LaBerge, and LeGrand (1968). There are two versions of this paradigm: the item-method and the list-method. The present research employed the item-method, in which participants are presented with a series of stimuli (e.g. words or pictures), each followed by a cue to either "remember" (R-cue) or to "forget" (F-cue) the preceding word. In contrast, in the list-method, the cue to remember or to forget is only presented after a complete set of study items. Regardless of which version is employed, participants are falsely informed that their memory will be tested for the to-be-remembered-items (TBR) only. However, the subsequent memory phase assesses their memory for both TBR and to be-forgotten-items (TBF). This method usually leads to improved recognition of TBR items compared with the TBF items. The difference in retrieval between TBR and TBF items is also known as the DF effect (see MacLeod, 1998, for a review). The DF effect has predominantly been studied using verbal stimuli (e.g. Van Hooff & Ford, 2011), but geometric figures (Williams & Woodman, 2012), abstract symbols (Hourihan, Ozubko, & MacLeod, 2009), and faces (Metzger, 2011) have also been showing the DF effect.

Whether stimuli conveying emotional information also show a DF effect has been the topic of several studies. While studies using pictures largely agree that at least medium to highly arousing emotional pictures are less likely to be forgotten than neutral ones (Hauswald et al., 2011; Nowicka et al., 2011; Payne & Corrigan, 2007), the results in regard to words are mixed (Bailey & Chapman, 2012, Brandt, Nielsen, & Holmes, 2013; Marx, Marshall & Castro, 2008; Wessel & Merckelbach, 2006). Some studies employing word stimuli showed that intentional forgetting leads to a DF effect regardless of the word's emotional content (Wessel & Merckelbach, 2006), or even to a stronger DF effect for negative words compared with neutral words (Brandt et al., 2013). Conversely, Marx et al. (2008) observed a strong DF effect for highly arousing, pleasant words and minimally arousing negative words, but no DF effect for low to medium arousing positive and medium to highly arousing negative words, proposing differential mechanisms underlying the forgetting of positive vs. negative words. Finally, Bailey and Chapman (2012) found a reduced DF effect for both positive and negative words, suggesting that emotional words are relatively resistant to intentional forgetting, regardless of their valence.

It can only be speculated as to why such a discrepancy between results occurred, but the inconsistency in the experimental methods may have largely contributed to them. While, for example, Wessel & Merckelbach (2006) employed the list-method of the DF paradigm, Marx et al. (2008) used a memory suppression task based on cued recall, and Bailey & Chapman (2012) adapted the item-version of the DF paradigm, presenting both stimulus and cue simultaneously by means of color-coding. Such variations from the item-version of the DF paradigm (as was employed by Brandt et al., 2013), which includes a delay between word and cue, might have led to distinct recruitment processes reducing the comparability of effects across studies.

Another possibly related contributing factor to the mixed findings might be the depth of encoding. It has been theorized that the readily accessible emotional information of pictorial stimuli allows privileged access of their affective information, while the processing of words is thought to be affected by the required level of analysis of linguistic information (De Houwer & Hermans, 1992; Hinojosa, Carretié, Valcárcel, Méndez-Bértolo, & Pozo, 2009; Hinojosa, Méndez-Bértolo, & Pozo, 2010). It is thus possible that word stimuli allow for more attentional control than pictorial stimuli, making it easier to not attend their emotional connotation and instead process them at first on a shallow level until a cue to remember is given. This assumption is also in line with findings that during the pre-cue encoding phase within the item-method of the DF paradigm, that emotional pictorial stimuli evoke more pronounced and prolonged brain activations associated with emotion processing (Hauswald et al., 2011; Yang et al., 2012) than emotional lexical stimuli do (Brandt et al., 2013). Hence, adapting the DF paradigm so that participants are required to actively attend to the emotional connotation of a given verbal stimulus before any cue is given may make emotional stimuli harder to forget. Throughout the previous chapters, participants' attention was directed to the emotional connotation of the stimuli by either rating or categorizing their emotionality. Such an approach may also help in the current study to understand whether intentional forgetting indeed distinguishes between lexical and pictorial emotional information, or whether this is mediated by differences in emotion processing. Therefore, the current study employed an adapted version of the DF paradigm, which reinforced the deep encoding of the words' emotional information by having participants rate the valence of a given word on a 1-9 scale from very negative to very positive.

Another beneficial feature of reinforcing the deep encoding of emotional information within the DF paradigm is that it is expected to encourage the generation of embodied simulations, which are thought to be situated, task-dependent processes (Barsalou, 2008; Niedenthal et al., 2009). In Chapters 3 and 4, embodied simulations, and in particular facial motor resonance, have been associated to enhanced emotional memory. The findings of Chapter 3 suggested that blocking facial motor resonance in either encoding or retrieval of emotional stimuli interferes with their recollection. Chapter 4 extended this line of research by demonstrating that the absence of enhanced processing of emotional stimuli in a second language is also reflected in reduced facial motor resonance. The close tie between facial motor resonance and emotional memory discussed in the previous two chapters raises the question of whether such a link can also be drawn between facial motor resonance and emotional forgetting. While facial motor resonance has repeatedly been shown to be congruent to the emotional connotation of a given stimulus, the embodied responses to the mere instruction to remember or forget this stimulus once it is out of sight remain unexplored.

However, it is conceivable that not only the emotional stimulus itself, but also an attempt to remember or forget it afterwards, modulates facial motor resonance. In regard to R-cues, embodied cognition would predict that remembering a previously seen word and actually seeing the word should evoke similar levels of facial motor resonance. After all, it's not the chain of letters forming a word that causes embodied simulations, but the emotional concept presented by the word that becomes reinstated (see also subsection 1.2 and Figure 1.1). In this sense, both reading a word and thinking of a word should mediate access to the original emotion concept it represents. In fact, the instruction to actively remember words may lead to intensified simulations, elicited by their motivated processing. In contrast, the predictions regarding embodied simulations evoked by F-cues are not contemplated by the theories of embodied cognition and were thus less definite. On the one hand, F-cues may interfere with embodied simulations, possibly leading to reduced or absent facial motor resonance. After all, the original DF paradigm (Bjork et al., 1968) assumes that participants can be instructed to exert a degree of voluntary control over their mental activity. This may consequently also modulate embodied simulations. On the other hand, and as outlined above, the extent to which this cognitive control can also be applied to emotional stimuli has led to some inconsistent behavioral results. If participants fail to control their memory for emotional words, then they may consequently also not show any suppression of embodied simulations. However, the assessment of behavior and EMG data allows only limited conclusions about the mental operations associated to any possible modulations in facial motor resonance. Therefore, the current study was designed to also assess event related potentials (ERPs), a technique that has previously been employed in the DF research and revealed some valuable insights into the mechanisms associated to intentional memory and intentional forgetting (e.g. Van Hooff & Ford, 2011; Paz-Caballero, Menor & Jiménez, 2004).

For example, the motivated encoding of TBR items has been associated to active attention and rehearsal mechanisms. These mechanisms are thought to be indexed by the P3 component and the late positive potentials (LPP) emerging from centro-parietal regions, as those have repeatedly been observed to increase in response to R-cues as in comparison to F-cues (Hauswald et al., 2011; Paz-Caballero et al., 2004, Paller, 1990). It has been argued that the LPP reflects active rehearsal and the attempt to remember a given stimulus (Mangels, Picton & Craik, 2001). This interpretation is in line with the general assumption that the P3 mirrors initial allocation of both perceptual and central resources which are then sustained by the LPP based on the intrinsic relevance of the presented stimulus, thus signaling motivated attention (Bradley & Lang, 2007; Codispoti, Ferrari, De Cesarei, & Cardinale, 2006; Hillyard et al., 1973, Kok, 1997). DF Studies employing emotional stimuli expanded upon this observation by showing that the P3 and LPP were further enhanced if the R-cue had been preceded by an emotional word as opposed to a neutral one (Brandt et al., 2013; Hauswald et al. 2011; Yang et al., 2012), suggesting that motivated encoding is preferentially engaged by emotional stimuli.

In contrast to the active and effortful encoding of TBR items, TBF items have been thought to not only interrupt encoding mechanisms but also to evoke additional cognitively controlled inhibition. This assumption is based on both ERP and functional magnetic resonance imaging (fMRI) studies showing that F-cues, in contrast to R-cues, elicit augmented frontal activations. Considering that frontal areas are crucial to executive control over overt behavior (e.g. Overtoom et al. 2002; Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003; Rieger, Gauggel, & Burmeister, 2003), enhanced frontal activation in response to F-cues has concordantly been interpreted as the effortful attempt to suppress TBF items from entering long-term memory. This has recently led some researchers to investigate whether these F-cue associated inhibitory mechanisms would be modulated by the emotionality of the items to be forgotten. In fact, one may wonder whether more effort is needed to forget emotional stimuli than to forget neutral stimuli, even if it may not manifest in any behavioral differences in memory accuracy. Along this line of inquiry, two recent studies observed an augmented frontal activation between 200-400 ms (Yang et al., 2012) and between 450 -660 ms (Hauswald et al., 2011) after F-cue onset, when it had been preceded by an emotional item as opposed to a neutral item. The authors suggested that this frontal activation indicates a higher need for cognitive control to hinder emotional stimuli from entering long-term memory as compared with the level of activation needed for neutral items (Hauswald, 2011; Yang et al., 2012). However, two other ERP studies could not confirm these findings, as their results indicated that frontal activation evoked by F-cues was not enhanced by emotional stimuli compared with neutral ones (Bailey & Chapman, 2012; Brandt et al., 2013). As discussed previously, Brandt et al. (2013) also found that negative words were not resistant to forgetting but that they instead showed an enhanced DF effect in comparison to neutral words. Therefore, they concluded that emotional TBF items do not only not evoke more cognitively controlled inhibition than neutral TBF items but that instead emotional TBR items solely evoke stronger selective attention and rehearsal mechanisms, such as the P3 and LPP components. Since they also demonstrated an enhanced LPP when participants passively viewed emotional words during the pre-cue phase, the authors argued that emotional words had been saliently encoded before cue-onset, even though this effect was less enhanced than in previous studies using pictorial stimuli (Hauswald et al., 2011; Yang et al., 2012).

That the LPP may not necessarily correlate with the efficiency of emotional word processing has been argued in a recent study (Brown, Steenbergen, Band, de Rover, & Nieuwenhuis, 2012), which suggested that its function rather reflects “a global inhibition of activity in visual cortex, resulting in the selective survival of activity associated with the processing of the emotional stimulus”. Instead of the LPP, the authors suspect earlier ERPs, such as the early posterior negativity (EPN) to be associated with improved perception of emotional stimuli. Distinct from the P3 and LPP, which are thought to index higher-order stages of stimulus processing, the early posterior negativity (EPN) emerging from temporo-occipital areas in a time window between 200-300 ms post onset, is thought to reflect early sensory-based selective encoding (Schupp, Junghöfer, Weike, & Hamm, 2003). It is thus surprising that the EPN has received only little attention so far in the emotional forgetting research. One would expect the EPN to be a valuable index to verify that emotional stimuli are saliently processed during the pre-cue phase when participants do not know yet whether they need to remember or forget the presented stimulus.

Taken together, the processes and mechanisms associated with intentional remembering and forgetting of emotional stimuli, and in particular of emotional words, have led to inconsistent results on a behavioral as well as on a brain activation level. Their link to a third processing dimension, namely embodied simulations, has not yet been explored. Therefore the present research implemented a slightly modified DF item paradigm to assess intentional forgetting and inhibition of neutral, negative and positive words, while simultaneously recording participant's EMG and ERP responses. The DF paradigm was adapted to include an emotional-intensity rating task during the encoding phase, requiring a deep emotion oriented processing of each word prior to seeing the R-cue or F-cue. As explained previously in this chapter, the level of processing depth that participants exert during the encoding phase could have been a factor contributing to the variance in previously reported results. If differences in findings for emotional pictorial vs. emotional verbal stimuli in terms of the DF effect, were caused by the higher automatic emotional accessibility to the pictorial vs. lexical stimuli, then reinforcing a deep encoding of the word's emotional connotation may lead to a reduced or absent DF effect for them as well. Furthermore, the simultaneous EMG and ERP recordings did not only allow for an in-depth investigation of previously reported strategic mechanisms subserving intentional emotional forgetting, but it also allowed the investigation of how such mechanisms may be embodied.

The associated hypotheses are summarized as followed: In respect to the pre-cue encoding phase, I expected to observe an augmented EPN component in response to emotional words as compared with neutral words. The processing of the emotional information should then furthermore lead to facial motor resonance in congruency with the valence of the presented word. Thus, negative words were expected to elicit enhanced corrugator and decreased zygomaticus muscle activity and positive words were expected to provoke the opposite pattern, with increased zygomaticus and decreased corrugator muscle activity. Presentation of neutral words was not expected to modulate facial muscle activity. Depending on the cue type (R-cue vs. F-cue) presented after the participant's rating, I predicted a differential activation of both brain activations and facial motor resonance. As outlined in more detail above, the R-cues are believed to elicit generally more P3/LPP activity indexing rehearsal and motivated attention mechanisms. I predicted that R-cues following both types of emotional stimuli would lead to even stronger P3/LPP activation compared with neutral words, due to the assumed preferential processing of emotional stimuli. In terms of embodied simulations, such effortful remembering may also be mirrored in congruent muscle activations comparable to the pattern of muscle activation to be expected for the pre-cue phase. In contrast the F-cues were expected to elicit enhanced inhibitory mechanisms. In regard to the associated brain activation, I expected an augmented frontal activation in line with previous findings (Van Hooff & Ford, 2011). Even though previous studies came to inconclusive results as to whether this activation is modulated by emotional words, it is conceivable that the deep emotion oriented encoding phase added in the present study would increase the required effort to forget emotional stimuli to an extent that it is eventually also reflected in stronger frontal activations. Inhibitory mechanisms were expected to also modulate the level of embodiment. Since the previous chapters demonstrated that facial motor resonance supports the enhanced encoding and memory of emotional stimuli, I expected that under conditions in which such enhanced processing is not desired, embodied simulations decrease.

## 5.2 Methods

### *5.2.1 Participants*

Twenty-one healthy young native Italian speakers (14 females) participated in the experiment. Age ranged from 21-30 years (*M* = 24 years, *SD* = 3.1). All participants were right-handed, as determined by the Edinburgh Handedness Inventory (Oldfield, 1971). They were all free of preexisting neurological or psychiatric conditions, provided informed consent, and received monetary compensation for participation. The experimental procedure was conducted in accordance with the Declaration of Helsinki. Three participants were discarded from all analyses: one because he failed to follow the task instructions of the encoding task, and the other two because gross-movement artifacts left too few data points for the EMG and EEG analyses.

### *5.2.2. Stimulus material*

Six-hundred-and-sixty words were selected from the Italian version of the ANEW database (Montefinese, Ambrosini, Fairfield, & Mammarella, 2014). Depending on their valence ratings they were categorized as either being positive, negative, or neutral (220 words for each category). The original ratings were done on a scale from 1(*very negative*) – 9(*very positive*). Any word that was rated on average below 3.5 was considered to be negative, words with average ratings from 3.5 to 6.5 were considered to be neutral, and words with an average rating higher than 6.5 to be positive. All words were further matched across valence categories for the following dimension: word length, frequency in Italian language, rated imageability, rated concreteness (all *F*s(2,659) < 2.8, all *p*s > .17). Positive and negative words were marginally different in their arousal ratings, with negative words being slightly more arousing on average than the positive ones (*F*(1,439) = 2.9, *p* = .09). All mean ratings and their SEs for each word type and dimension are listed in Table 5.1 for further reference. In a second step, all words were divided into 2 sets for counterbalancing purposes. These two sets were designed to not differ in terms of valence, word length, frequency, imageability, concreteness, and arousal ratings within each word type (all *F*s(1,218) < 1.6, all *p*s > .20). Each of the two sets contained 110 positive, 110 negative, and 110 neutral words.

| | **Valence category** | | | | | |
|---|---|---|---|---|---|---|
| | **neutral** | | **negative** | | **positive** | |
| | *mean* | *SE* | *mean* | *SE* | *mean* | *SE* |
| **Valence** | 5.36 | 0.04 | 2.24 | 0.03 | 7.7 | 0.03 |
| **Word length** | 7.58 | 0.14 | 7.59 | 1.43 | 7.66 | 0.14 |
| **Concreteness** | 6.08 | 0.12 | 5.93 | 0.08 | 5.83 | 0.11 |
| **Arousal** | 4.99 | 0.04 | 6.24 | 0.05 | 6.12 | 0.06 |
| **Imageability** | 6.67 | 0.1 | 6.6 | 0.06 | 6.85 | 0.07 |
| **Frequency** | 124 | 15.59 | 98 | 13.53 | 124 | 8.84 |

**Table 5.1**. Summary of word ratings. Valence was rated on a scale from 1(negative) to 9(positive). The factors concreteness, arousal, and imageability were each rated on a scale from 1(low) to 9(high). Word frequency is based on the Corpus and Frequency Lexicon of Written Italian (CoLFIS). See Montefinese et al. (2014) for detailed information on the word assessment procedure.

### *5.2.3 Procedure*

After reading and signing the informed consent and complete the Edinburgh Handedness Inventory (Oldfield, 1971), participants were prepared for the EEG/EMG recording. The experiment took place in a dimly lit soundproof chamber. Written instructions were presented on the computer screen. The experiment was introduced as a memory experiment involving an encoding and a retrieval phase divided by intervening task. The computer-based tasks were programmed using *PsychoPy software in Python* (Peirce, 2007).

### *Encoding phase*

During the encoding phase participants were presented with the words of one set. Words were presented in lower case in black ink-color on a light grey background. Participants' task was to rate the valence of a presented word on a scale from 1 (very negative) to 9 (very positive). After the rating, a cue would indicate whether the rated word should be remembered (TBR words) or to be forgotten (TBF words; see Figure 5.1 for a visualization of the experimental design). Half of the words of each word-type category (neutral, negative, positive) were TBR items, while the other half were TBF items. Order of word presentation was pseudo randomized to prevent the same cue or word type (positive vs. negative vs. neutral) from occurring more than three times in a row. Participants were falsely informed that only their memory for the TBR words would be tested and that, given the length of the list (330 words), it would be beneficial to forget the remaining words because otherwise they would interfere with retrieval of the TBR words. Participants were given 2 short breaks (2 minutes) throughout the encoding phase, dividing it into three blocks of 110 words each.

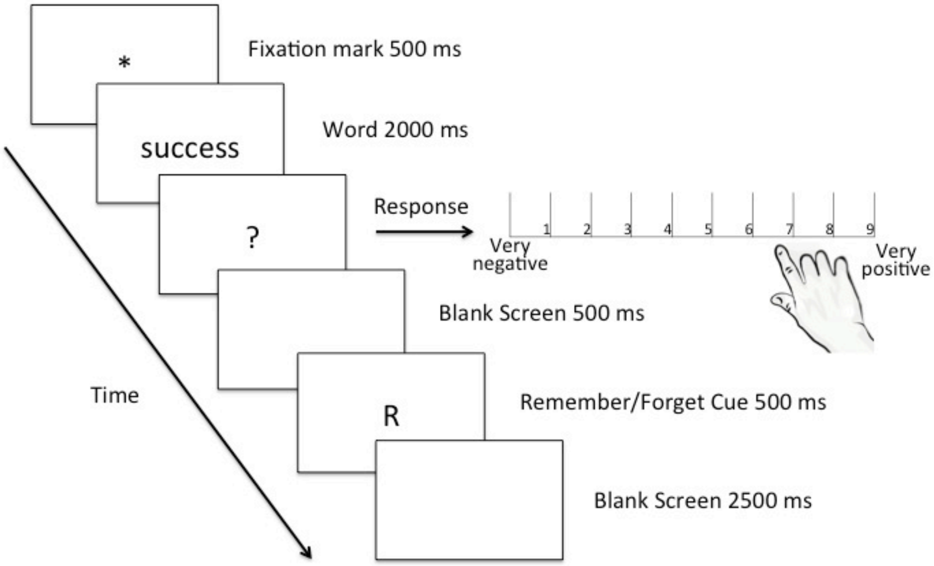


Figure 5.1. Experimental paradigm. Each trial started with a fixation mark for 500 ms followed by a word (neutral, negative, or positive) presented for 1500ms. Next, a question mark appeared signaling the participant to rate the valence of the previously seen word from 1 (very negative) to 9 (very positive) by pressing a number on the computer keyboard using the right hand. After a blank screen presented for 500 ms a cue appeared indicating to either forget or remember the earlier presented word. Each trial ended with a 2500 ms period allowing participants to engage either in active inhibition or encoding processes.

### *Intervening tasks*

After the encoding phase participants completed the Italian version of the Positive and Negative Affect Schedule (PANAS; Terracciano, McCrae, & Costa, 2003) and 12 Raven's Advanced Progressive Matrices. These two tasks respectively measured participant's current mood states and intelligence, and served as a distractor task to avoid ceiling effects for the retrieval phase. After completion of those two tasks, before the retrieval phase, participants were given a 5-minute break.

*Retrieval phase*

Retrieval was measured with a computer-based recognition task. All 330 words from the encoding phase and the 330 words from the second word set were each presented for 1500 ms in random order preceded by a fixation mark for 500 ms. Each word was followed by a question mark prompting the participant to judge whether the word was "old" (i.e., presented during the encoding phase) or "new" (i.e., never presented during the encoding phase) irrespectively of the remember or forget instruction associated to it. The response was given by pressing one of two pre-instructed buttons on the keyboard. Two signs next to each side of the computer helped participants to remember the key-assignment during the task. The question mark remained on the screen until a response was made.

### *5.2.4 EEG data acquisition and preparation*

EEG was recorded from 128 scalp sites using a Biosemi™ ActiveTwo EEG system with sintered Ag-AgCl electrodes (of a modified 10/20 system headcap). Recording voltages were referenced online to mastoid electrodes and EEG signal was continuously sampled at 1024 Hz. Scalp impedance of each sensor was kept below 20 kΩ. The acquired data were analyzed with EEGLAB 7.2 (Delorme & Makeig, 2004) and ERPLAB 4.0 (Lopez-Calderon & Luck, 2014), two open-source MATLAB (The Mathworks, Natick, NA) toolboxes for EEG analysis. Offline data were first filtered with a high pass filter at 0.5 Hz and subsequently with a low pass filter at 30 Hz. The data were resampled to 256 Hz and re-referenced offline to a common average reference. Next, the data were split into non-overlapping epochs from (-200 ms to 700 ms), and baseline corrected using the full 200 ms baseline. To clean the epochs of movement and non-stereotyped artifacts, segments with improbable data patterns were identified by visual inspection and rejected. The data were subsequently submitted to extended infomax Independent Component Analysis (ICA; Bell and Sejnowski, 1995, Delorme and Makeig, 2004) using binica from the EEGLAB toolbox. Artifacts, such as eye blinks, were identified by visual inspection of the scalp maps, time courses and activation spectra, and were discarded from the data by back-projecting all but these components to the data matrix. Event related potentials (ERPs) were assessed from grouped averages of frontal and posterior channel-clusters previously used in the literature for the analysis of the components of interest, namely the EPN, frontal activations, and the P3/LPP. Electrode locations were identified using Oostenveld & Praamstra (2000) as a guideline. In the subsections below, the electrode location names for the Biosemi headcap are given in brackets. The respective time windows were determined based on visual inspection of the grand averages at the typical electrode locations and were similar to the ones reported in previous studies.

*EPN:* The EPN, previously suggested to be sensitive to emotional word processing was measured between 210 - 290 ms after word onset and quantified at the left hemisphere (P09 (A12), P07 (A10), P7(D31), TP7(D24), P5(D30), P9(D32) and at the right (P010(B9), P08(B7), P8(B11), TP8(B14), P6(B12), P10(B10); (See Kissler, Herbert, Winkler, & Junghofer, 2009 and Scott, O'Donnell, Leuthold, & Sereno, 2009 for similar channel locations).

*Early frontal activation*: The early frontal activation previously associated with inhibitory processes, was measured between 100 - 300 ms after cue onset. Frontal activation was averaged and quantified at left hemisphere cluster (FP1(C29), F7(D7), F3(D4), AF3 (C27), AF5(C31) and right hemisphere cluster FP2(C18), F8(C7), F4(C4), AF4(C14), AF6(C9). See Van Hooff and Ford, (2011) for a similar sensor choice.

*P3/LPP:* The P3/LPP components, believed to reflect attention and motivated encoding processes, were measured between 300 - 600 ms after cue onset and averaged at centro-parietal regions. For the left, the sensors of interest were: P3(A7), CP1(D16), FC1(D2) C3(D19). For the right hemisphere P4(B4), CP2(B2), FC2(C2), C4(B22). Sensor selection coincides with the regions were the P3 and LPP components have previously been assessed (e.g. Kissler et al., 2009; Yang et al., 2012).

### *5.2.5 EMG data acquisition and preparation*

EMG was recorded from the same BIOSEMI Active-Two amplifier system. Four surface electrodes were attached to the corrugator supercilii and zygomaticus major muscles on the left side of the face, corresponding to two bipolar montages (Fridlund & Cacioppo, 1986). The EMG was continuously recorded with the same sampling rate as described for the EEG recordings above. Data were offline filtered with bandpass filter from 20 - 400Hz. Noisy segments as indicated by trials in which the difference of activity between a given time-bin and the following one was superior to 3.5 standard deviations of the mean value for the whole trial were rejected. EMG signals were rectified, integrated and averaged for a period of 1500 ms in chunks of 250 ms after stimulus / cue onset. A baseline of 250 ms was subtracted from the mean activity. Finally, all data were z-transformed for each subject and each zygomaticus and corrugator muscle separately.

## 5. 3 Results

### *5.3.1 Behavioral results*

Participant's correct recognition scores during the memory phase were submitted to a 3 (emotion: neutral, positive, negative) X 2 (cue: remember vs. forget) repeated measures ANOVA. The analysis revealed a main effect of emotion (*F*(2,34) = 7.21, *p* < .01, whereby memory for negative words was highest (*M* = 87, *SE*= .02), slightly lower for positive (*M* = 84, *SD* = .02) and lowest for neutral words (*M* = 82, *SD* = .02). Pairwise comparisons showed that the differences between memory rates for neutral vs. negative and neutral vs. positive were both significant (both *p*s < .05), demonstrating typical EEM effects. The difference in memory rates between negative and positive words was not significant (*p* = .47, all *p*s Holm-Bonferroni corrected). Furthermore, a main effect of cue (*F(*1,17) = 23, *p* < .001) revealed that memory for words followed by a remember cue (*M* = .88, *SD* = .02) was higher than for words which were followed by a an instruction to forget (*M* = .83, *SD* = .02). No significant interaction between emotion and cue was present *F*(2,34) = .06, *p* = .94, suggesting that emotional words were not less likely to be forgotten than neutral words. Planned pairwise comparisons revealed that the DF effect was observed in each of the emotion conditions (all *t*s > 2.6, all *p*s < .05; *p* values were Holm-Bonferroni corrected; see Figure 5.2).

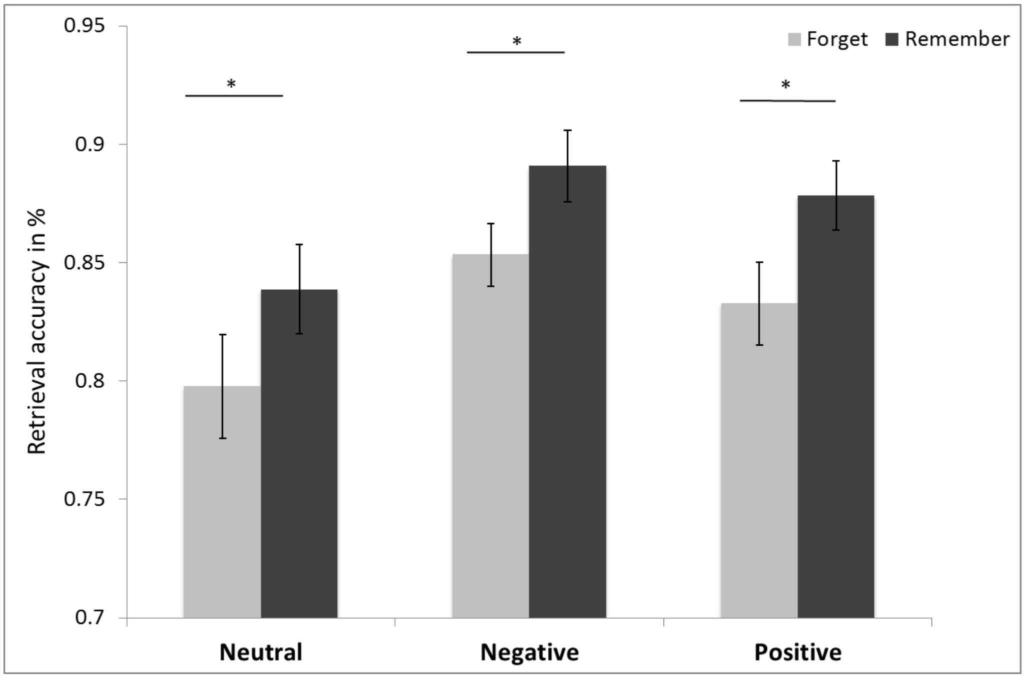


**Figure 5.2** Retrieval accuracy as a function of Emotion (neutral vs. negative vs. positive) and cue (forget vs. remember). Error bars represent ± 1SE. * $p$ < .05

### *5.3.2 EMG results*

*Word presentation*

EMG responses to word presentation were analyzed with a 2(muscle: zygomaticus vs. corrugator) X 3 (word type: neutral vs. negative vs. positive) X 6 (time point: 250 ms vs. 500 ms 750 ms vs. 1000 ms vs. 1250 ms vs. 1500 ms) repeated measures ANOVA with all factors being within-subjects. This resulted in a significant 3-way interaction between muscle, word type and time point ($F(10,170) = 2.00$ $p = .04$). Consequently for each word type separately a 2(muscle: zygomaticus vs. corrugator) X 6(time point: 250 ms vs. 500 ms 750 ms vs. 1000 ms vs. 1250 ms vs. 1500 ms) repeated measures ANOVAs, with both factors being within subjects were conducted. For the neutral word type this analysis revealed no main effects or interaction (all *F*s < 1.53, all *p*s > .20, Huynh-Feldt corrected; see Figure 5.2, upper panel. For the negative words a marginal effect of muscle emerged (*F*(1,17) = 3.22, *p* = .09), but no other effects (both *F*s < 1.48, both *p*s > .29). The marginal effect was driven by a general activation of the corrugator muscle (*M* = .19, *SD* = .17) and a relaxation of the zygomaticus muscle (*M* = -.17, *SD* = .17, see Figure 5.3 middle panel). For the positive word type a marginal effect of muscle (*F*(1,17) = 3.78, *p* = .07), driven by an activation of the zygomaticus muscle (*M* = .17, *SD* = .14) and relaxation of the corrugator muscle (*M* = -16, *SD* = .13), and a significant interaction between muscle and time (*F*(5,85) = 5.20, *p* < .001) emerged. Paired samples t-tests comparing the zygomaticus vs. the corrugator activation in response to positive words at each time point revealed that the differential activation of the two muscles was largest in the time window 750 ms – 1000 ms (*t*(17) = 2.38, *p* = .02 and remained marginally significant for the subsequent time window ranging from 1000 ms – 1250 ms (*t*(17) = 1.95, *p* = .07; both *p*s one-tailed and Holm-Bonferroni corrected; see Figure 5.3, lower panel).

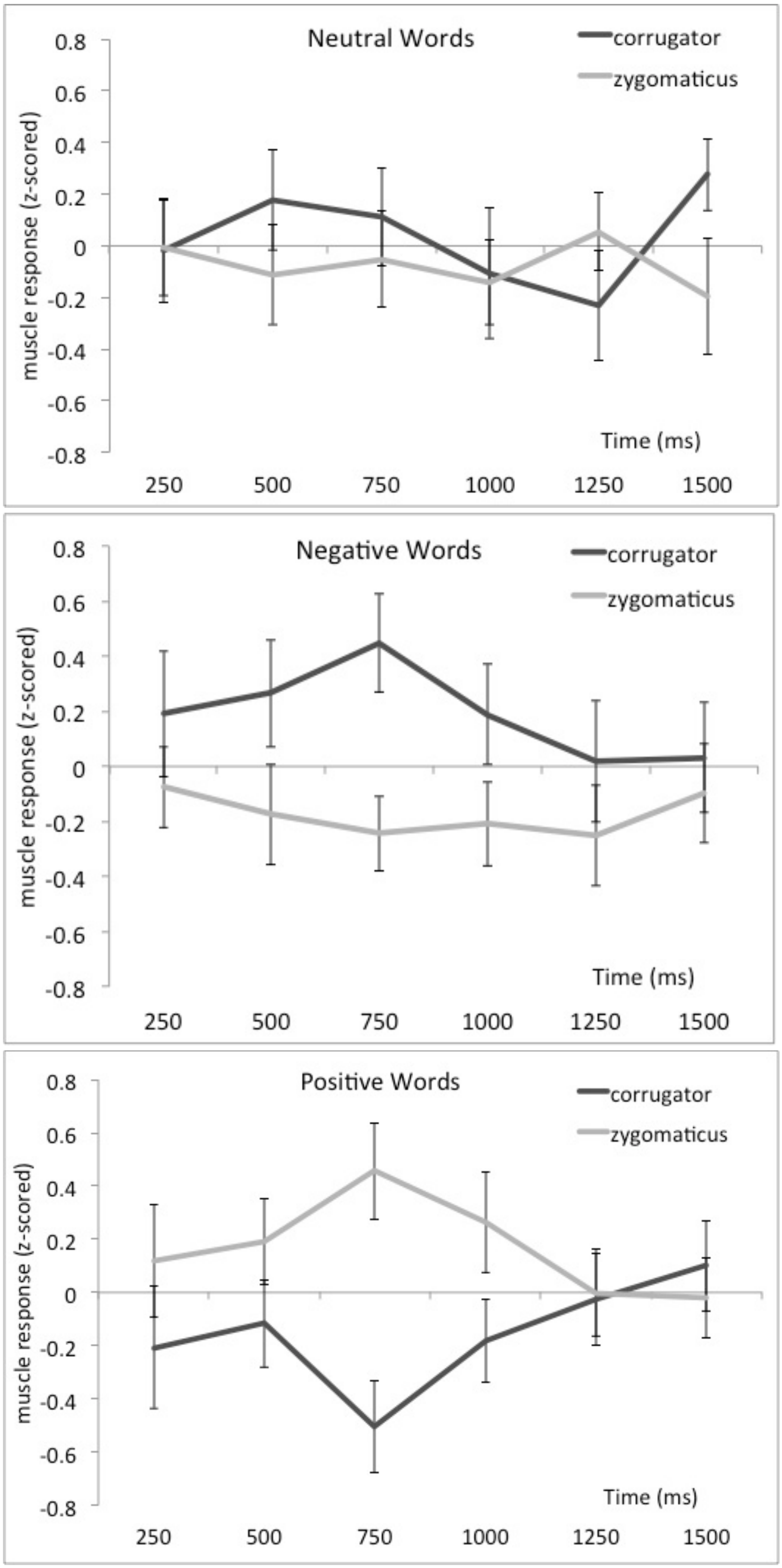


**Figure 5.3** Muscle activation for the corrugator and zygomaticus muscle in response to each emotional word type (neutral, negative, and positive) across time. Error bars represent ± SE of means.

### *Cue presentation*

EMG responses to cue presentations were analyzed with a 2 (muscle: zygomaticus vs. corrugator) X 3 (word type: neutral vs. negative vs. positive) X cue (remember vs. forget) X 6 (time point: 250 ms vs. 500 ms 750 ms vs. 1000 ms vs. 1250 ms vs. 1500 ms) repeated measures ANOVA, with all factors being within subjects. This resulted in a significant interaction between muscles and word type (*F*(2,34) = 5.50), *p* = .009 and a marginal interaction between muscle, word type and cue (*F*(2,34) = 3.00, *p* = .06. No other effects emerged (all *F*s < 1.05, all *p*s > .31). Since the hypothesis held that muscle activation would be modulated by the remember or forget instruction for the negative and positive words but not for the neutral words, the ANOVA was split and analyzed for each word type individually, disregarding the factor time point, which had not led to any interaction in the previous analysis. Thus, each word type was analyzed by a 2 (muscle: zygomaticus vs. corrugator) X 2 (cue: remember vs. forget) repeated measures ANOVA, with both factors being within-subjects factor. For cues following neutral words, this analysis revealed no main effects and no interaction (all *F*s < .53, all *p*s > .47). In contrast, cues following negative words revealed a significant main effect of muscle (*F*(1,17) = 5.00, *p* = .04), driven by a general relaxation of the zygomaticus (*M* = -.10, *SE* = .11) and an activation of corrugator muscle (*M* = .27, *SE* = .01). More importantly there was also a significant interaction between muscle and cue (*F*(1,17) = 4.30, *p* = .05). See also the middle panel of Figure 5.4 for an illustration of the effect. Consequently, two paired t-tests comparing separately for each muscle its activation (zygomaticus and corrugator) in response to remember vs. forget cues following negative words were conducted. This revealed a marginal significant increase of corrugator activation when the instruction was to remember the word (*M* = .50, *SD* = .55) as opposed to when the instruction was to forget (*M* = .05, *SD* = .10; *t*(17) = 1.5, *p* = .07). Despite the fact that the zygomaticus relaxed in response to a remember cue following negative words (*M* = -.24, *SD* = .79) and showed slight activation in response to forget cues (*M* = .04, *SD* = .65), this pattern was not significant (*t*(17) = .96, *p* = .35; both *p*s are one-tailed and Holm-Bonferroni corrected). The repeated measures ANOVA for cues following positive words led again to a significant effect of muscle (*F*(1,17) = 7.38, *p* = .01) driven by an activation of the zygomaticus (*M* = .25, *SE* = .13) and a relaxation of the corrugator muscle (*M* = -.27, *SE* = .12). The interaction between muscle and cue did, however, not reach significance (*F*(1,17) = 2.55, *p* = .13). See also the lower panel of Figure 5.4. Because of the a-prior interest, planned paired t-test comparing R-cue vs. F-cue were conducted for each muscle separately. They revealed a marginally enhanced activation of the zygomaticus muscle if the cue instructed to remember the previously presented positive word (*M* = .44, *SD* = .65) as compared to when the instruction was to forget it (*M* = .05, *SD* = .92, *t*(17) = 1.45, *p* = .08). No effect emerged from the comparisons of cue instruction after positive words within the corrugator muscle (R-cue: *M* = -.36, *SD* = .72; F-cue: *M* = -.19, *SD* = .73; *t*(17) = .69, *p* = .50; both *p*-values are one-tailed and Holm-Bonferroni corrected).

The partially only marginally significant results reported here did not allow for clear conclusions as to how far R- or F-cues modulate the recruitment of facial motor resonance. However, the visual inspection of the results (see Figure 5.4) clearly suggested that facial motor resonance was enhanced after R-cues as opposed to F-cues for both types of emotional words. Hence, to give further insights as to how far the recruitment of facial muscles may be adapted to remember or forget-intention and alternative set of pairwise comparisons was conducted comparing for each word type the corrugator vs. the zygomaticus activation within the remember condition and within the forgetting condition, separately. Different from the approach above, which investigated the modulatory power of R- and F-cues on the activation within each facial muscle, the current approach explored how these cues modulate the overall recruitment of facial motor resonance across muscles. For the negative words this revealed a significant difference between the two muscles in the remember condition ($t(17) = 4.2$, $p < .01$), and no difference in the forgetting condition ($t(17) = .05$, $p = .96$; *p*-values are Holm-Bonferroni corrected; see Figure 5.4 middle panel for corresponding means and SEs). Similar results were obtained for cues following positive words, for which the remember condition revealed a significant difference between corrugator and zygomaticus activation ($t(17) = 3.34$, $p < .01$), while any pattern of facial motor resonance remained insignificant in the forgetting condition ($t(17) = .90$, $p = .39$; *p*-values are Holm-Bonferroni corrected; see Figure 5.4 lower panel for corresponding means and SEs).

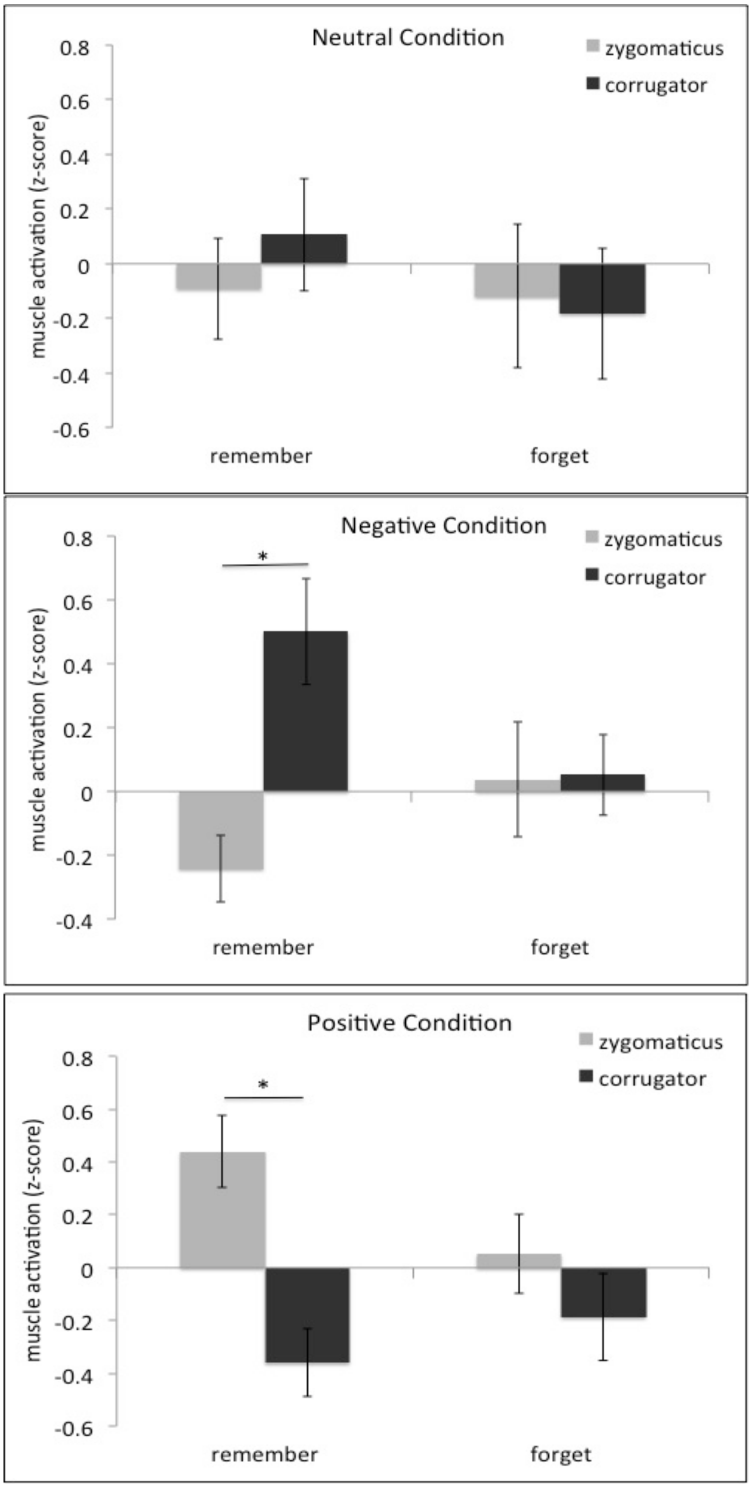


**Figure 5.4** Muscle activation for the zygomaticus and corrugator muscle in response to the "remember" instruction (center bars) or "forget" instruction (right bars) following neutral words (upper panel), negative words (middle panel), and positive words (lower panel). Error bars represent ± 1SE. See text for corresponding statistics. *$p < .05$.

### 5.3.3 EEG results

*Word presentation*

EPN: The EPN was analyzed with a 2 X (hemisphere: left vs. right) X 3 (word type: neutral vs. negative vs. positive) repeated measures ANOVA, which resulted in a marginal main effect of word type *F*(1,2) = 2.7, *p* = .09, driven by an enhanced negativity for positive words (*M* = -.59 µV *SD* = .43) , slightly less enhanced negativity for negative words (*M* = -.36 µV, *SD* = .50) and least negative amplitude for neutral words (*M* = .-28 µV, *SD* = .43). Furthermore, there was a marginal main effect of hemisphere (*F*(1,17) = 3.1, *p* = .09, caused by more pronounced activation of the left hemisphere than of the right hemisphere. This left-lateralization during the early processing of lexical stimuli is well documented in the literature (for example, see Abbassi, Kahlaoui, Wilson, & Joanette, 2011, for a review). In fact, the presence of the EPN component was better identifiable within the left hemisphere than within the right hemisphere (see Figure 5.5). Therefore despite the non significant interaction between hemisphere and word type (*F*(2,34) = .84, *p* =. 42; Huynh-Feldt corrected), the analysis was repeated for each hemisphere separately. The left hemisphere showed a significant effect of word type (*F*(2,34) = 2.47, *p* = .02). Pairwise comparisons showed that the EPN was significantly stronger for positive words (*M* = -1.04 µV, *SD* = .50) vs. negative (*M* = -.72 µV, *SD* = .55, *p* = .04) and vs. neutral words (*M* = -.58 µV, *SD* = .48, *p* = .05). The difference between neutral and negative words was not significant (*p* = .37, all *p*s were Holm-Bonferroni corrected). The right hemisphere did not reveal a difference between word types (neutral: *M* = .02, *SD* = 2.07, negative: *M* = .0, *SD* = 2.28, positive: *M* = -.13, *SD* = 2.2; *F*(2,34) = .33, *p* = .65). See Figure 5.5 for corresponding scalp maps and ERP graphs.

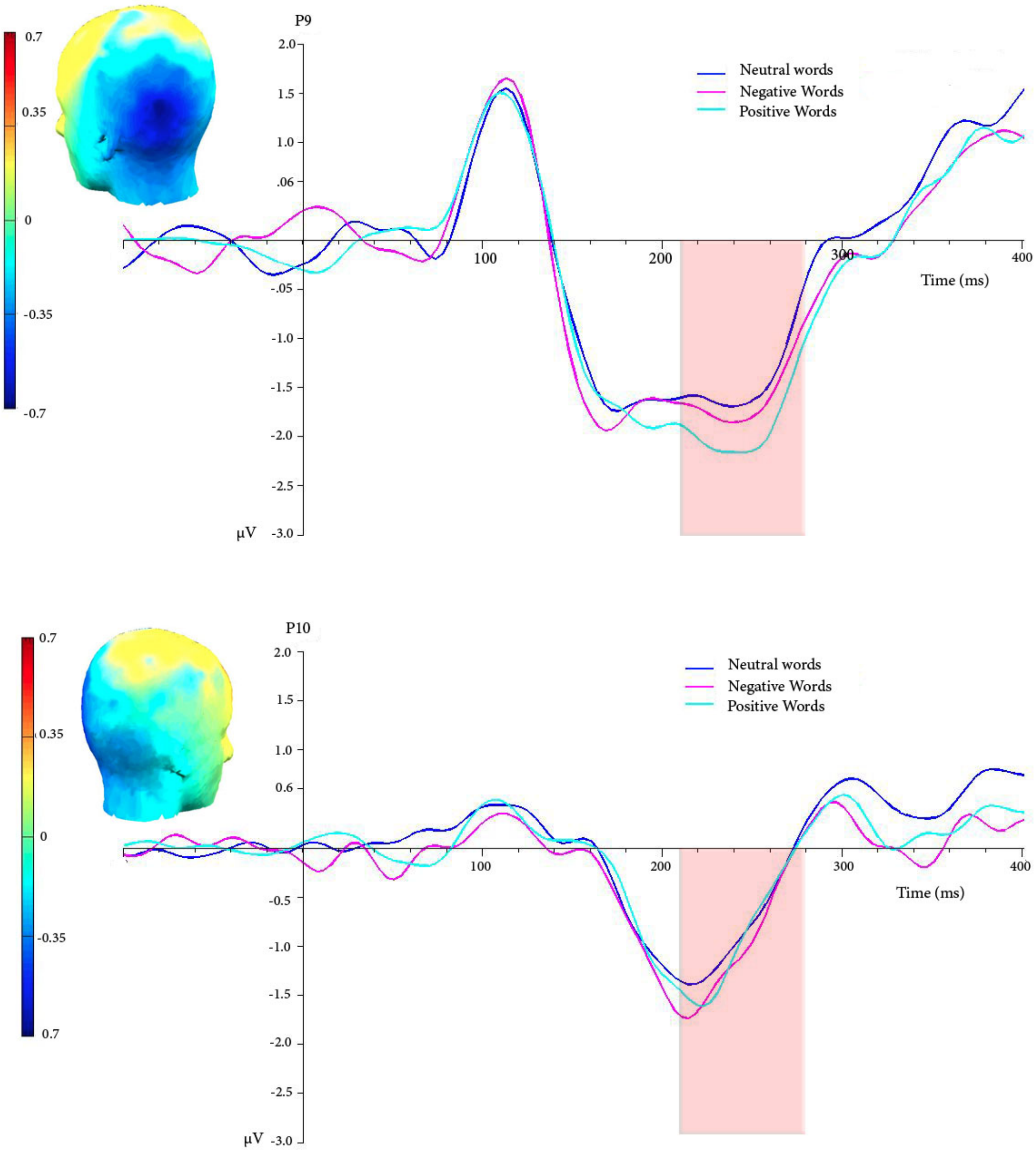


**Figure 5.5** ERPs in response to neutral, negative, and positive words. The upper panel displays the activation within the left hemisphere and the lower panel displays the activation from the right hemisphere. The topographical maps illustrate the difference potential between neutral and emotional words averaged over time range between 210 – 280ms. Cooler colors indicate more negative-going potentials. The graphs show the time course of cortical activation at the P9 sensor for left hemisphere and at the P10 sensor for the right hemisphere. The time window of interest is marked by a light pink quadrat.

*Cue presentation*

Frontal areas: A 2 (hemisphere: left vs. right) X 3 (word type: neutral vs. negative vs. positive) X 2 (cue: remember vs. forget) repeated measures ANOVA, with all factors being within subjects, resulted in a significant interaction between hemisphere, word-type and cue *F*(2,34) = 3.74, *p* = .03 and no other effects (all *F*s < 1.97, all *p*s > .16). Subsequently, two separate 3(word type: neutral vs. negative vs. positive) X 2 (cue: remember vs. forget) repeated ANOVAs were conducted for each hemisphere separately. Analysis of the left hemisphere resulted in marginal interaction between word type and cue (*F*(2,34) = 3.27, *p* = .06 (Huynh-Feldt corrected). Pairwise comparisons within each word-type showed that the difference between F-cue and R-cue elicited significant activation only for the negative emotion condition, with F-cues triggering more positive going activation than R-cues (*t*(17) = 4.12, *p* = .001; see Figure 5.6 upper panel for the associated topographical map and ERP waves). Neither the neutral nor the positive condition had a significant effect on the cue-related activation (both *t*s < 1.28, both *p*s > .42; all *p*s are Holm-Bonferroni corrected). Analysis of the right hemisphere resulted likewise in a marginal interaction between word type and cue (*F*(2,34) = 2.82, *p* = .07). Pairwise comparisons for each word type separately showed that the difference between F-cue and R-cue elicited significant activation this time only for the positive emotion condition, with F-cues triggering more positive going activation than R-cues (*t*(17) = 1.85, *p* = .04 (one-tailed; see Figure 5.6 lower panel for the associated topographical map and ERP waves). Neither the neutral nor the negative emotion condition showed a significant effect on the cue-related activation within the right hemisphere (both *t*s < 1.17, *p*s > .50, all *p*s are Holm-Bonferroni corrected).

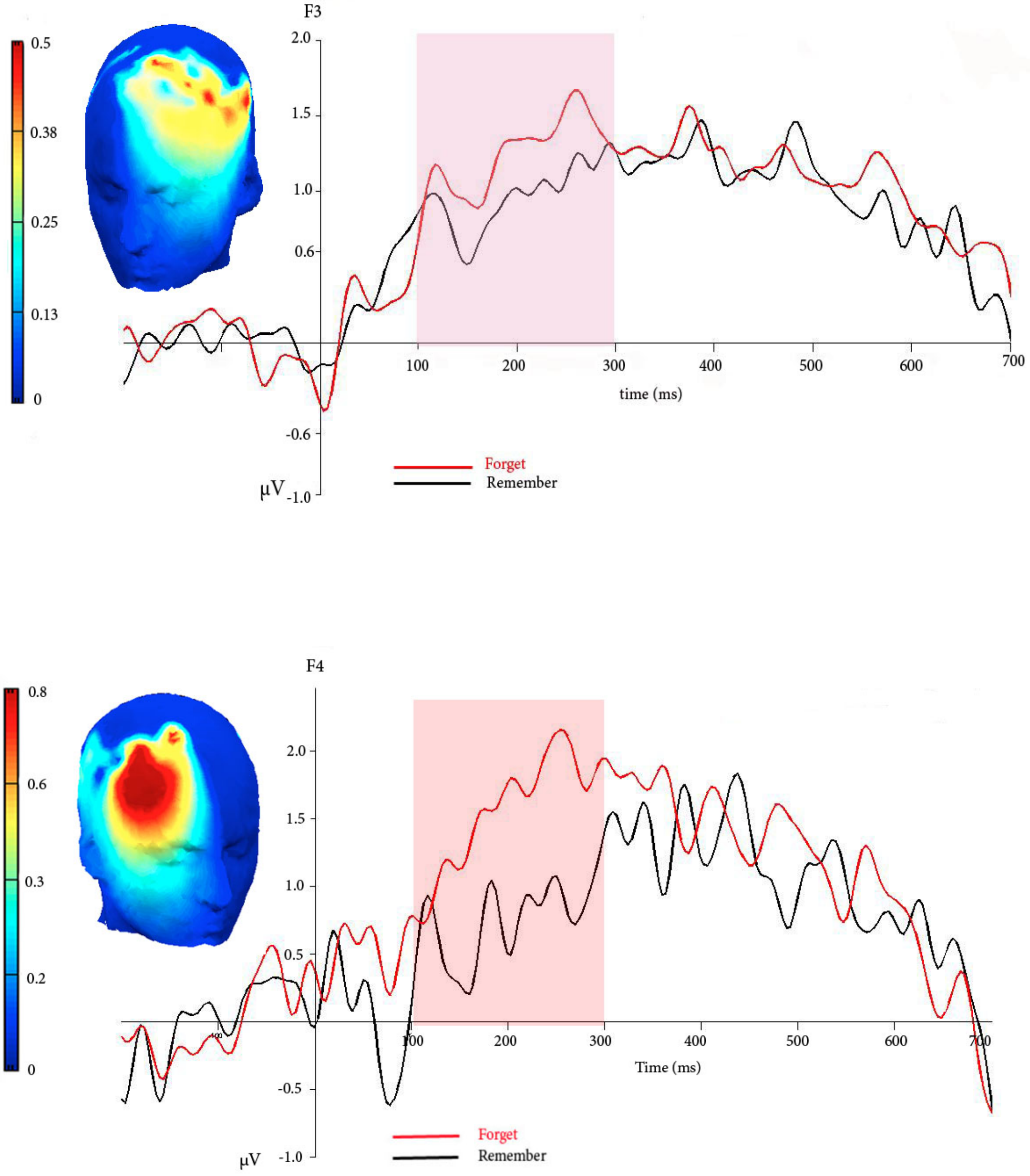


**Figure 5.6** ERPs triggered by the intentional attempt to remember or to forget a previously seen negative (upper panel) or positive word (lower panel). The topographical maps illustrate the difference in potential between F-cues and R-cues (F-cue – R-cue) for the respective word type averaged over the time range between 100 – 300ms. Warm colors indicate more neural activity during attempts to forget a previously presented word relative to trying to remember it. The graphs show the time course of cortical activation at the F3 sensor for left hemisphere and at the F4 sensor for the right hemisphere. The time window of interest is marked by a light pink quadrat.

P3/LPP: A 2 (hemisphere: left vs. right) X 3 (word type: neutral vs. negative vs. positive) X 2 (cue: remember vs. forget) repeated measures ANOVA revealed a significant effect of cue with R-cues evoking more positive activation than F-cues (*F*(1,17) = 4.37 *p* = .05). See Figure 5.7a for the corresponding scalp maps and brain waves. Furthermore, there was a significant interaction between hemisphere and word type (*F*(2,34) = 2.45, *p* = .03; Huynh-Feldt corrected), as cues following positive words generally evoked more activation within the right hemisphere (*M* = .43, *SD* = .15) than left hemisphere (*M* = .27, *SD* = .20) and cues following negative words showed the opposite pattern with more activation within the left (*M* = .44, *SD* = .22) than right hemisphere (*M* = -.12, *SD* = .33). In contrast the activation for cues following neutral words was relatively stable across hemispheres (left: *M* = .18, *SD* = .27; right = .12, *SD* = .23). Another significant interaction was observed between word type and cue (*F*(2,34) = 3.92, *p* = .04; Huynh-Feldt corrected), caused by augmented activations elicited by R-cues following negative (*M* = .37, *SD* = .16) and positive (*M* = .37, *SD* = .33) words as compared with neutral words (*M* = 19., *SD* = .25; see also Figure 5.7b). Pairwise comparisons revealed that the activation elicited by R-cues was significantly stronger following negative words in comparison to R-cues following neutral words (*t*(17) = 2.25, *p* = .02). The activation for R-cues following positive words was also enhanced in comparison to the neutral condition; however, this comparison did not reach significance (*t*(17) = 1.70, *p* = .11, *p*-values are one-tailed and Holm-Bonferroni corrected). In contrast, R-cue elicited activation after negative vs. positive words did not differ (*t*(17) = .08, *p* = .94).

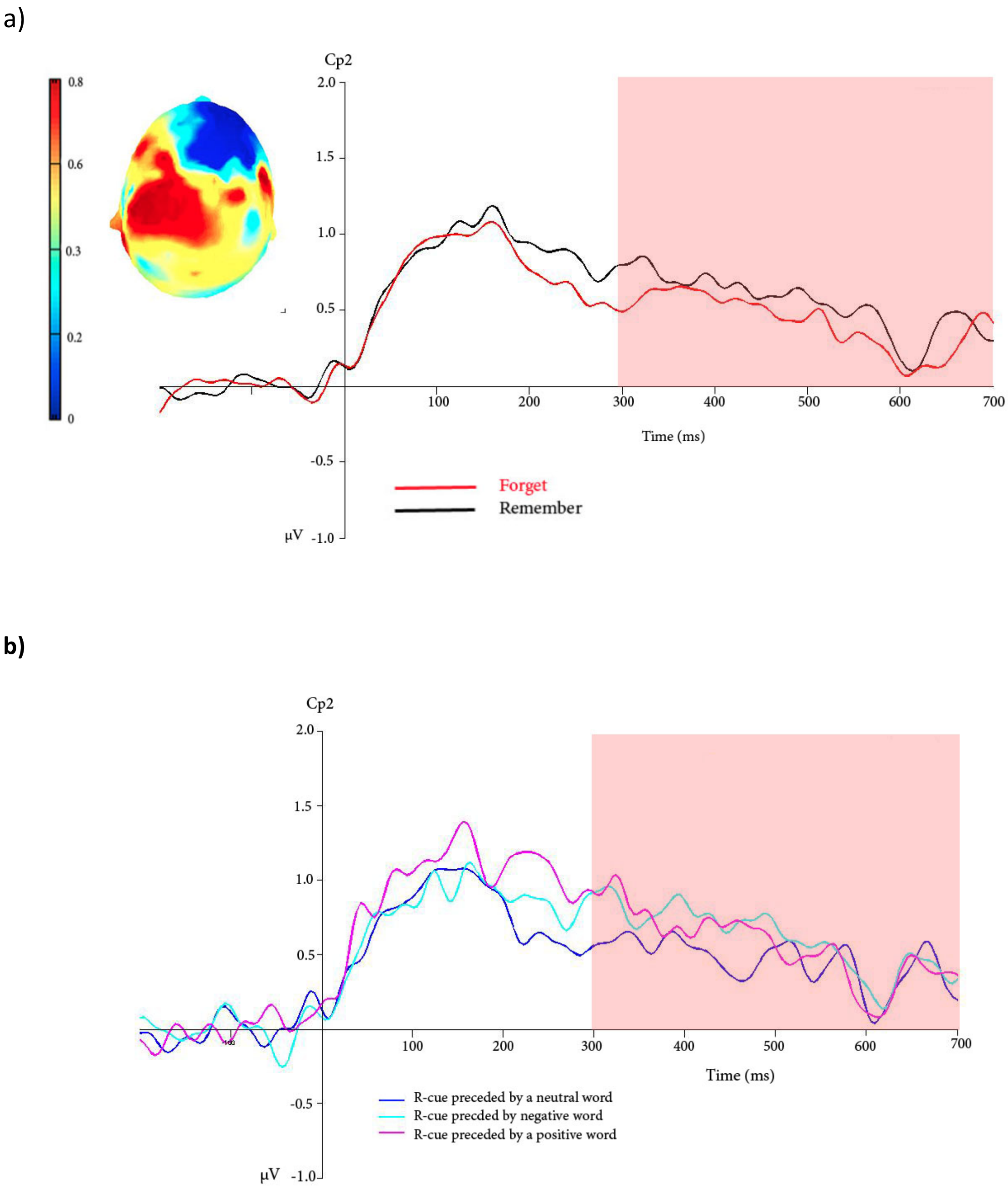


**Figure 5.7 a)** ERPs triggered by R-cues vs. F-cues averaged for all word-types (neutral, negative, and positive). The topographical maps illustrate the difference in potential between R-cues and F-cues (R-cue – F-cue averaged over time range between 300ms – 700ms). Warm colors indicate more neural activity during attempts to remember a preceding word relative to trying to forget it. The graphs show the time course of cortical activation at the centro-parietal Cp2 sensor. The time window of interest is marked by a light pink quadrat. **Panel b)** illustrates the brain waves triggered by R-cues for each word type (Neutral in blue, negative in turquoise, and positive words in magenta) separately at the CP2 sensor. The time window of interest is marked by a light pink quadrat.

### *5.3.4 Correlation analyses*

The relationship between cue-related EMG activation, ERPs and the DF effect was investigated by a series of bivariate correlation analyses. Hereby the first focus was on the exploration of possible correlations between the EMG responses (zygomaticus and corrugator) and the brain activations of interest (early frontal activation in the time window 100-300 after cue-onset and later centro-parietal activation in the time window 300-700 ms after cue onset). The early frontal activation had been associated to the active attempt to suppress TBF words from memory and the centro-parietal activation had been associated to the active attempt to remember a word (see section 5.3.3). The previously reported hemispheric differences in frontal recruitments in response to negative vs. positive TBF words was also considered for the present correlation analyses, using the right frontal activation for any correlational analysis within the positive words and the left frontal activation for the analysis of the negative words. In a second approach, the correlation of each factor (zygomaticus muscle activation, corrugator muscle activation, frontal brain activation, centro-parietal brain activation) with the DF effect of negative and positive words was investigated in separated bivariate analyses. A final bivariate correlation analysis was run to explore any possible relationship within the brain activations (frontal activation and centro-parietal activation). Below are reported only those correlations which were either significant or revealing at least a moderately strong relationship ($r > .30$). Figure 5.8 illustrates the relationships reported here.

*F-cues following negative words:* Corrugator activation in response to negative TBF words showed a marginal positive correlation with the centro-parietal activation (*r*(18) = .41, *p* = .09). In contrast the zygomaticus showed a moderate positive correlation with the activation in the frontal areas and moderately negative correlation with the centro-parietal activation, which, however, both did not reach significance (both *r*s(18) = .30, both *p*s = .22).

*F-cues following positive words*: The zygomaticus activation was marginally negatively correlated with the F-cue related frontal brain activation (*r*(18) = -.38, *p* = .06 and positively correlated with the centro-parietal activation (*r*(18) = .48, *p* =.05). The activation of the corrugator muscle and the frontal activation in response to positive TBF words, showed a moderate positive correlation, which, however, did not reach significance (*r*(18) = .30, *p* = .22. Furthermore there was a negative correlation between zygomaticus activation and the DF effect of positive words, suggesting that activation of the zygomaticus muscle interfered with the successful forgetting of positive words (*r*(18) =- .43, *p* = .04, one-tailed). A negative correlation between the centro-parietal activation and the DF effect indicated that this attention rehearsal-associated activation interfered with successful forgetting of positive TBF words. Last, there was a strong negative correlation (*r*(18) = -.63, *p* <.01) between right frontal activation and parietal activation, suggesting that participants who responded with strong frontal activations to positive TBF words recruited less centro-parietal activation at later stages of the processing.

*R-cues following negative words:* No mentionable correlations were obtained for activations associated to negative TBR words.

*R-cues following positive words:* A significant negative correlation of corrugator and parietal activation (*r*(18) = -.50, *p* = .04) indexed that relaxation of the corrugator muscle was associated to an enhancement in the centro-parietal activation in the 300-700 post stimulus time-window. Furthermore a marginal positive correlation between the right frontal activation and the corrugator activation emerged (*r*(18) = .41, *p* = .09). Further analyses revealed a positive correlation between centro-parietal activation and the DF effect for positive words (*r*(18) = .43, *p* = .05, one-tailed). There was also a marginal negative correlation between corrugator activation and the DF effect for positive words (*r*(18) = -.32, *p* = .09, one-tailed), suggesting that relaxation of the corrugator muscle in response to positive TBR words helped with the establishment of a DF effect. This time, the correlation analysis between frontal activation and parietal activation in response to positive TBR words resulted in a strong negative correlation (*r*(18) = -.50, *p* =.04).

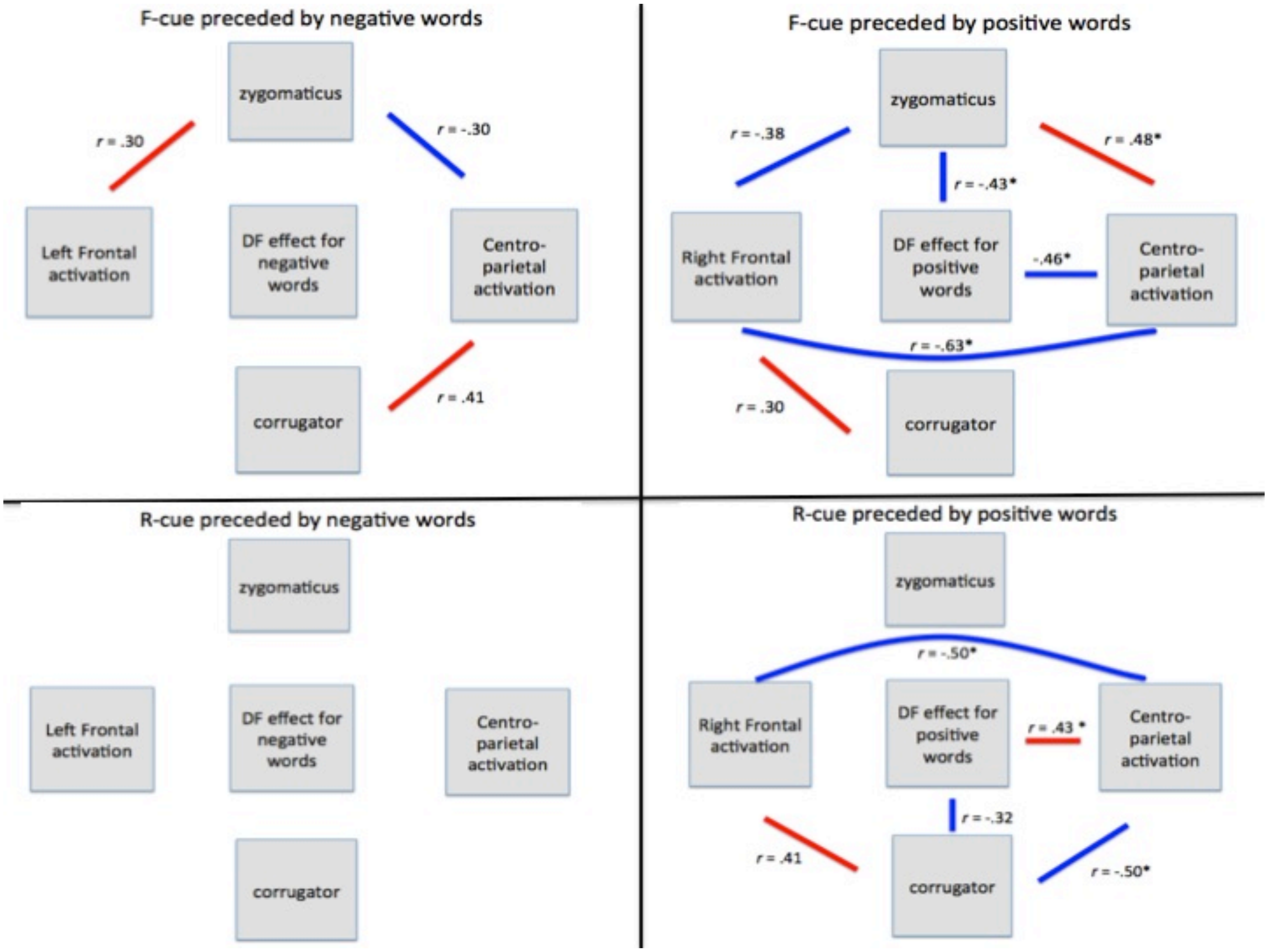


**Figure 5.8** Summary of the correlation analyses for the F-cue condition (top) and R-cue condition (bottom) for negative (left) and positive (right) words separately. A red line marks positive relationships whereas a blue line marks negative relationships. Depicted are only relationships for which *r* > .30. Significant correlations are marked by *. See the text for details on the respective variables used.

## 5.4 Discussion

The present study investigated facial motor resonance and ERPs associated to intentional encoding and forgetting of emotional words by means of an adapted version of the item-based DF paradigm (Bjork et al., 1968). In line with the hypotheses, the results indicate that instructions to remember or to forget an earlier presented word modulate embodied processes and brain mechanisms differently depending on whether the word was emotional or neutral. Despite the inclusion of an emotionality-rating task, which should have forced participants to process the emotional connotation of the presented word during the study phase, a DF effect was present regardless of the stimuli's emotionality: more TBR than TBF words were recognized. This may indicate that emotional words can just as neutral ones show a DF effect, given that sufficient additional resources are recruited to either support or to suppress their memory.

As expected, the initial viewing of emotional words during the study phase modulated both embodied simulations and emotion-related brain activation. Even though facial muscle responses were overall relatively weak, they showed the expected patterns of congruent activation in response to presented valence. Upon perception of a negative word the corrugator muscle contracted and the zygomaticus muscle relaxed. The opposite pattern was observed for positive words whereas neutral words elicited no differential facial muscle activation. With respect to the ERPs, evidence was found for differential processing of emotional relative to neutral stimuli in the form of an enhanced left-lateralized EPN component, which, however, reached significance for positive words, only. The positive valence bias of the EPN is in line with the findings by

Bayer and Schacht (2014), who argued that it might be related to a so-called *positivity offset*. This positivity offset refers to the general preference at rather low cognitive levels for positive stimuli and it is thought to be the basis of approach motivation in neutral contexts (Cacioppo & Gardner, 1999) such as the lab environment. Overall, EMG and ERP responses associated with the study phase, suggest that participants attended the stimuli's emotional connotation. Thus, the previously stated assumption that emotional words unlike emotional pictures are easily forgotten because their emotional connotation is not sufficiently processed could not be confirmed.

Consistent with the assumption that facial motor resonance plays a role in emotional memory processes, facial motor resonance was enhanced in response to a remember instruction and decreased in response to a forget instruction. More precisely, while the remember condition evoked a differential activation of the corrugator and zygomaticus muscle, congruent with the valence of the given word, this activation was reduced to statistically insignificant levels in the forgetting condition. This result agrees with the previous two studies discussed within the scope of this thesis, which showed that the presence of congruent facial motor resonance is associated with enhanced memory performance of emotional stimuli. The present study further fortifies the role of embodied simulations in emotional memory by showing that facial motor resonance is not only associated to incidental learning but is likewise modulated by the intention to remember or to forget an emotional stimulus. Hereby the enhanced facial motor resonance associated to the attempt to remember a given stimulus may reflect the internal rehearsing of the word to facilitate its later memory. In contrast, the decrease of facial motor resonance may signal a shift of attention away from the TBF word. Alternatively, it may index active inhibitory mechanisms aimed at suppressing the TBF word from entering long-term memory. This latter idea is supported by the ERP data, which demonstrated evidence for both inhibitory and active rehearsal mechanisms upon F-cues or R-cues, respectively.

In regard to F-cues an early frontal activation was elicited conforming to previous ERPs findings (Hauswald et al., 2011; Van Hooff & Ford, 2011) and fMRI studies (Nowicka et al., 2011; Rizio & Dennis, 2014), which interpreted this frontal activation as inhibitory mechanisms aimed to stop encoding processes. The current results extend such findings by showing that this frontal activation was further enhanced when the preceding stimulus had been emotional. In accordance with the asymmetric inhibition model (Grimshaw & Carmel, 2014), inhibition of negative words was left-lateralized, while the right hemisphere executed the control over positive stimuli. To my knowledge, this is the first demonstration that intentional suppression of emotional as compared with neutral lexical stimuli elicits enhanced inhibitory mechanisms similar to the processes associated with the suppression of emotional pictorial stimuli previously reported (Hauswald et al., 2011; Yang et al., 2012). The finding contrasts with the only two other ERP studies employing emotional words in a DF paradigm, which found inhibitory processes to be unaffected by emotionality (Bailey & Chapman, 2012; Brandt et al., 2013). The reason for this discrepancy may lie in the fact that in the present study participants' attention was focused on the emotional connotation of the presented words by means of emotionality rating task. This enforced deep encoding may make the forgetting of emotional words particularly laborious requiring more inhibitory activation.

In regard to R-cues, enhanced P3 and LPP components as compared with F-cues were observed at centro-parietal regions. This activation, which is thought to reflect active attention allocation and rehearsal mechanisms, matches past research employing lexical stimuli in the DF paradigm (Hsieh et al., 2009; Nowicka et al., 2009; Van Hooff & Ford, 2011). Critically, there was an additional augmentation if the R-cue had been preceded by a negative word as compared with a neutral word. A similar but statistically not significant pattern was observable for R-cues preceded by positive words. This stronger effect of negative words on late occurring ERPs is in line with the finding that negative information has a greater impact on evaluative processes than equally extreme positive stimuli (Ito, Larsen, Smith, & Cacioppo, 1998). The modulatory effect of emotional words on rehearsal mechanisms replicating the findings by Brandt et al. (2013) but conflicts with the results of Bailey and Chapman (2012), who did not find evidence for such differential processing of emotional vs. neutral words.

In order to reconcile those diverse results, one needs to also consider the behavioral effects that the present study and the studies by Brandt et al. (2013) and Bailey and Chapman (2012) obtained. The present study found no interaction between word types and cue on a behavioral level. However, these two factors showed a clear interaction in the EMG and ERP data. Brandt et al. (2013) found an even increased behavioral DF effect for negative words driven by their greater selective memory upon R-cues. Likewise their ERP data showed enhanced LPPs for emotional TBR than for neutral TBR words. In contrast, Bailey and Chapman's (2012) behavioral results showed an interaction between cue and emotion, with a reduced directed forgetting effect for emotional words but no interactions of word-type and cues on an ERP level. Closer inspection of their results suggested that their behavioral effect was mainly driven by a reduced forgetting rate of emotional TBF words but less by an increased retrieval of emotional TBR items. This could explain why Bailey and Chapman (2012) found that emotional words did not have an effect on cue-related brain activation. It appears that their participants failed to recruit the needed resources, possibly due to their variation of the DF paradigm in which the cues and words were presented simultaneously. Overall these results may suggest that emotional words are not per se resistant to forgetting but that their forgetting is simply more effortful, requiring more cognitive resources. If this recruitment of additional resources fails, then emotional words are no longer forgotten, as was observed in the study by Baily and Chapman (2012). This general assumption, that additional resources are needed in order to successfully forget emotional stimuli, is also in line with studies employing pictorial instead of lexical stimuli. For example, while Hauswald et al. (2011) found no DF effect for emotional pictures, they also did not find emotional pictures to evoke stronger inhibition or rehearsal mechanisms. In contrast, Yang et al. (2012) found a DF effect for negative stimuli and showed that the negative TBF pictures - as compared with neutral ones - elicited enhanced frontal activation and that negative TBR pictures triggered stronger LPP activation.

Further analyses in the current study were aimed at exploring the relationship between brain activations, facial motor resonance, and memory performance. The obtained correlations were overall relatively weak and only revealed few significant relationships. However, some patterns are mentionable. First, correlations were overall more profound for the positive word conditions. This is partly in line with Brandt et al. (2013), who also reported no correlation between rehearsal- / inhibition-related brain activations and the forming of a DF effect for negative words. Second, the omission of counteractive facial motor resonance seemed to correlate with the successful forgetting or remembering of a given word. In this way, the activation of the zygomaticus muscle in response to positive TBF words appeared to interfere with their intentional forgetting, and thus with the DF effect. Similarly, a decrease of corrugator muscle activation in response to positive TBR words predicted their enhanced memory. In both conditions the activation of the respective counteractive muscle (zygomaticus for the forget condition and corrugator for the remember condition) was associated with the activity of the centro-parietal area, which itself was positively associated with the DF effect in the R-cue condition and associated to decreases in the DF effect in the F-cue condition. Overall, these results are in line with the observation that the P3/LPP components, emerging from the centro-parietal area, are usually associated with enhanced retrieval (Mangels et al., 2001; Paz-Caballero et al., 2004; Paller, 1990). It thus makes sense that this activation seems to be beneficial when it comes to intentional remembering and counterproductive when the aim is to forget. Even though, the results only allow a limited interpretation of the relationship between facial motor resonance and brain activations, the general patterns suggest that augmented recruitment of rehearsal mechanisms is associated with decreases of incongruent facial muscle resonance. Similarly enhancements in forgetting mechanisms seem to correlate with the recruitment of facial motor resonance, which is incongruent with the emotionality of the given stimulus. Finally, a robust negative correlation between early frontal and later centro-parietal brain activations in response to both positive TBF and TBR words is in line with the interpretation that these brain activations are associated to oppositional processing mechanisms: The first being related to inhibitory mechanisms and the latter being associated to attention and goal-oriented encoding (Van Hooff & Ford, 2011).

Taken together, the present study provides two important novel findings. First, facial motor resonance was shown to be modulated by the intentions to remember or to forget emotional words. This further supports the idea of a relationship between embodied simulations and emotional memory, as discussed previously within this study. Second, for the first time the present study demonstrated that the directed forgetting of emotional words is associated with an additional recruitment of inhibitory mechanisms, similar to what had been found for pictorial stimuli (Yang et al. 2012). A task for future research is the investigation of the relationship between facial motor resonance and the brain mechanisms associated to the intentional forgetting and remembering. Finally, the current study aligns with previous studies by showing that both inhibitory and rehearsal mechanisms underlie the DF effect and that, if these processes are sufficiently augmented, also emotional words can be forgotten.

# Chapter 6

# General Discussion

The current experiments were designed to explore the role of embodied simulations in the encoding and memory of emotional information. The results support a tempered interpretation of the theories of embodied cognition in the sense that bodily states are not necessary for emotion processing, but they can facilitate it (Barsalou, 2008). Over the course of four experimental studies, the link between embodied simulations at initial emotion recognition and later retrieval was explored.

**Chapter 2** defined emotional intensity as an important boundary condition to the impact that facial motor resonance has on emotion understanding. The results supported the hypothesis that stimuli, which are low in emotional intensity or difficult to encode may particularly benefit from the feedback provided by facial motor resonance. The findings suggested that participants, whose muscles were treated with BTX, but not those in the control group, rated slightly but not strongly emotional sentences and faces as less emotional after their BTX treatment. **Chapter 3** pursued the question of whether embodied simulations are involved in the initial understanding of emotional information, and whether they also have a role in their later retrieval. The findings indicated that if facial muscles are blocked during the encoding and/or retrieval of emotional words, their recollection is decreased. A possibly related phenomenon was observed in **Chapter 4**, investigating embodied simulations and memory for emotional stimuli in late L2 speakers. The results suggested that the altered processing of emotional content in L2 speakers, as implied by the absence of an EEM effect, might also be reflected in altered embodied simulations. Finally, in **Chapter 5** EMG and EEG were simultaneously recorded within the scope of a DF paradigm, investigating in how far the active intention to remember and to forget may affect the level of embodied simulations. The results indicated that instructions or remember or to forget a word do not only evoke differential brain activations, but also modulate the level of embodied simulations.

Taken together, the present findings refine the link between embodied simulations and emotion processing on several dimensions. First, they define emotional intensity as an important factor in determining the impact that facial motor resonance has on emotion understanding. Second, the results reframe embodied simulations as not only being involved in the initial understanding of emotional information, but also as being associated with its later retrieval, as well as intentional forgetting. Third, the findings further support and extend the assumption that facial motor resonance in response to lexical information is a situated phenomenon and strongly context-dependent. The significance of these findings is discussed below.

## 6.1 Embodied Simulations and the Benefit of Doubt

**Chapter 2** was dedicated to resolve previous inconsistencies as to whether embodied simulations support the understanding of emotional information. My results suggest emotional intensity to be a crucial factor in determining the impact that facial motor resonance has on the understanding of emotional information as conveyed by facial expressions or sentences. In light of those findings, the question arises as to why facial feedback gains importance when the emotionality is low or the interpretation of the emotion is difficult.

A possible interpretation of the results was put forward by Adolphs (2002). In his account on facial expression recognition he argues that embodied simulations come into play when “the explicit knowledge triggered is insufficient to recognize an emotion, perhaps because that particular emotion was never seen before or because the recipe for reconstructing knowledge about it provides insufficient detail” (p. 29). In line with this assumption one could argue that motor resonance functions primarily as an ancillary information resource, providing additional feedback to the cognitive processes in question. Under clear-cut conditions, the information provided by facial feedback may be superseded by dominant established cognitive processes associated to the evaluation of emotional content, reducing its influence on our percept and behavior. However, when the emotional intensity decreases, the interpretation of the emotional stimulus by means of memory and logical reasoning becomes more difficult. Consequently, in order to make a fast and qualified response to a given ambiguous stimulus, we rely more on bodily feedback. In this way, the influence that facial motor resonance has on the interpretation of emotional stimuli increases when cognitive resources reach their limits or leave us uncertain. Following this interpretation, not only low emotional intensity (as in the study of Chapter 2 of my thesis, or in the study by

Davis et al., 2010, and Oberman et al., 2007), but also generally difficult tasks or ambiguity in the stimuli may increase the decisive power of embodied simulations.

This broader interpretation of the results also aligns with the hypotheses put forward by other authors. For example, Pourtois et al. (2004) found that interference with embodied simulations greatly affects the recognition of fearful faces, but not of happy ones. They proposed that since happy faces are easily processed through a single visual feature (smile), they have usually particularly high recognition rates (see Adolphs et al., 1996; Adolphs, et al., 2000; Oberman et al., 2007). For this reason, happy faces are processed with less dependency on the somatosensory system than fearful faces. Similarly, Künecke et al. (2014) argued that embodied simulations facilitate the classification of facial expressions, especially when the task conditions are difficult. Finally, Kilts et al., (2003) showed that static facial expressions evoke more motor cortex activity than dynamic facial expressions. Consistent with the account I proposed here, they argue that their results may reflect a stronger need for motor simulation for the degraded emotional information presented by static facial expressions.

The insufficient details of emotional words presented in the absence of any context may also be the reason why blocked embodied simulations have been shown to interfere with their otherwise salient processing (see Chapter 3 and Niedenthal et al., 2009). As described earlier in this thesis, emotional words have been shown to elicit congruent facial motor resonance given that their valence is task-relevant. However, in comparison to other emotional stimuli, affective words have also been shown to induce less arousal-related processes, despite of high arousal ratings (Bayer & Schacht, 2014).

This possibly makes the interpretation of their emotionality harder (see also De Houwer & Hermans, 1994) increasing the importance of embodied simulations in understanding their emotionality. In line with this assumption, the results of Chapter 3 showed that blocking facial muscle resonance interferes with the recognition of the emotionality of a given word. However, the impact of facial motor resonance does not seem to be limited to the initial recognition and judgment of emotional stimuli; Chapters 3-5 suggested that it also seems to affect retrieval and forgetting processes.

## 6.2 Embodied Memories

The studies discussed in Chapters 3 to 5 pushed new frontiers on the theories of embodied cognition by elucidating the importance of facial motor resonance in emotional memory. From a theoretical perspective, the findings align with some major assumptions of embodied cognition approaches. Theories of embodied cognition assume that simulations, situational context, and bodily states play central roles in human cognition (e.g., Barsalou, 2008).

In **Chapter 3,** I demonstrated that participants whose muscles had been blocked at encoding, retrieval, or both showed decreased retrieval rates for emotional words. Such results agree with the belief that knowledge of the external world is at least to some extent multimodally grounded. In that sense, hindering the access to one modality – for example, by blocking the motor actions of the face – interferes with the internal representation associated with a given stimulus, making it harder to encode or to recall it. This finding extends previous approaches, which investigate the impact of posed and externally commanded enactment on memory. For example, a few studies have previously shown that explicit body movements congruent with the stimulus can determine whether we are more likely to retrieve positive or negative memories (Casasanto & Dijkstra, 2010; Förster & Strack, 1996). These approaches have a clear source in the account of action-event memory, which holds that memory for self-performed actions (such as performing the action of *clapping*) is better than memory for the verbal description of the action (such as doing a categorization task on the word *clapping*; e.g. Cohen, 1989; Macedonia, 2014; Ross, Wang, Kramer, Simons, & Crowell, 2007; Saltz & Donnenwerth-Nolan, 1981; see also Engelkamp & Zimmer, 1985, for a review). The present thesis fills the gap that these previous accounts left in regard to how naturally occurring and situated embodied simulations are tied to our memory.

The link between facial motor resonance and memory was further pursued in **Chapter 4**, in which the assumption of an emotional distance to a second language was supported by a decrease or absence of facial motor resonance and SC measures. Such findings suggest a possible boundary condition to the grounding of knowledge, suggesting that the embodiment of emotion-related stimuli seems to be specific to a native language and to be less developed in an L2 (see also Hsu, et al., 2014; Foroni, N.d.). Thus, processing information in L2 may depend more on executive control functions (Keysar et al., 2012), making the emotion-cognition coupling less efficient. It is cogitable that the weak link between L2 words and grounded knowledge may have consequently led to the observed interference with the EEM effect – an effect, which had previously been shown in Chapter 3 to be hampered by the absence of facial motor resonance.

Finally, in **Chapter 5** the tie between embodied simulations and emotional memory was shown to be modulated by our intentions to remember or to forget emotional words. If participants aimed at remembering a word, they showed strong facial motor resonance. If, in contrast, the instruction was to forget an emotional word, the recruitment of facial motor resonance significantly decreased. The results suggest that top-down higher-level factors, such as intentions to remember or to forget a stimulus, shape the way that we simulate them. This is particularly interesting as it underlines the situated action aspect of embodied simulations, which claims that embodied simulations evolved to support our perception and action in specific situations. It stresses the assumption that embodied simulations and their interaction with perception, action, and the environment are goal-directed (Barsalou, 2008; Niedenthal et al., 2009) and extends this view by giving the first indications that embodied simulations may possibly also function as a mnemonic tool.

It is also conceivable that the enhanced facial motor resonance upon R-cues and the decrease upon F-cues, are only epiphenomenal reflecting internal reiteration and active inhibition mechanisms, respectively. In line with this, the simultaneously recorded brain processes gave clear indications of intentional rehearsal and suppression processes. However, the relationship between these brain processes and embodied simulations remained vague, leaving room for speculation on how facial motor resonance is linked to central processes.

## 6.3 Neuroscientific Perspectives on Facial Motor Resonance

In the following section I aim to integrate the findings presented here with neural processes associated to facial motor resonance, in the hope of providing vital insights into how peripheral and central processes are linked during the encoding and retrieval of emotional information. A major finding in this line of research is that blocking facial muscles attenuates amygdala activity (Hennenlotter et al., 2009). As previously discussed in sections 1.2 and 1.5, the amygdala holds a central role in the processing of emotional stimuli, helping with their recognition and memory (e.g. Kensinger & Schacter, 2006, see also within this thesis). The link between facial muscles and the amygdala activity is consistent with the anatomical observation that the amygdala is part of a joint network including cortical and subcortical sensory and motor areas which, by means of reciprocal connections, may modulate both the perception and the production of facial expressions (Gothard, 2014). Thus, it seems likely that similar mechanisms also played a role in the findings reported here. Given the findings outlined above, the blocking of facial muscle by means of BTX (Chapter 2) or by means of a hardening mask (Chapter 3) are likely to have led to a decrease in amygdala activation, which in turn may have contributed to the observed interference with normal emotion processing. However, the question then arises as to why such a decrease in amygdala activity should specifically interfere with the processing of stimuli conveying weak, ambiguous, or difficult to encode emotional information.

A model able to explain such results is the one put forth by Pessoa and Adolphs (2010). They propose that instead of the classical amygdala dependent *low road* model of emotion processing (see LeDoux, 1996), *many roads* may be used to evaluate emotional significance of a stimulus, fortifying the role of the cortex and assigning a modulatory role to the amygdala in the processing of emotional stimuli. They suggest that, ”visual information proceeds simultaneously along parallel channels creating multiple waves of activation across the visual cortex and beyond” (p. 9). In this way, the processing of emotional stimuli engages simultaneously several different cortical and subcortical brain sites. Hence, the rapid processing of emotional stimuli may not depend on a single specific structure like the amygdala, but emotional stimuli may also able to be efficiently processed through bypass connections with almost no delay in RTs.

Critically for the results presented here, Pessoa and Adolphs (2010) argued that the cost of bypassing the amygdala route is that only very global emotional information is processed, because the amygdala is thought to be crucial for allocating enriched higher order processing resources to encode the fine detailed information of the relevant stimulus. This view is also consistent with the hypothesis that the amygdala is preferentially engaged when the stimulus is ambiguous and additional detailed information is required for its understanding (Whalen, 1998). Taken together, the *many roads model* of the processing of emotional stimuli is compatible with the findings discussed within this thesis, which show that blocking facial muscles, presumably leading to an interruption of amygdala activity (Hennenlotter et al., 2009), particularly affected the processing of weakly emotional stimuli and context-free words, which are assumed to have evoked a rather ambiguous processing condition.

An important aspect to consider is that the activation or blocking of facial muscles is thought to have emotion-specific effects. This may at first seems contradictory to the assumption that blocking facial muscles interferes with the activation of the amygdala in general. However, despite the fact that the amygdala has been treated for reasons of simplification as unity throughout this thesis, it is in fact a complex of several subnuclei that are thought to have different functions (see Janak & Tye, 2015, for a review). The spatial resolution of human neuroimaging studies such as the one by Hennenlotter et al. (2009) do however not allow for the differentiation of the separate nuclei. Yet, electrophysiological studies have shown that in humans the amygdala contains neurons that are tuned to categories in general (Kreiman, Koch, & Fried, 2000) and in monkeys also to specifically to different emotions (Gothard, Battaglia, Erickson, Spitler, & Amaral, 2007). It may thus be possible, that the link between facial muscle resonance and activity in the amygdala is specific to the emotional information to be processed.

The activation of the amygdala has been found to not only be modulated by external face blocking, but also to be sensitive to top-down controlled active suppression (Depue, Curran, & Banich, 2007) and attention (Pessoa, Kastner, & Ungerleider, 2003) mechanisms, similar to those observed in the DF paradigm. Since the amygdala is closely linked to the facial muscles (Gothard, 2014), such top-down control of the amygdala may have played a role in the finding that the intention to remember or to suppress an emotional word also modulates facial muscle resonance (see Chapter 5). However, despite clear indications of intentional remembering and forgetting processes on a cortical level, the relationship between these processes and the embodied simulations could not be clearly answered, giving a considerable potential for future research.

Extending knowledge of how peripheral and central mechanisms collaborate in the processing of emotional stimuli would be an interesting direction for further studies. The present results gave first indications that cortical mechanisms seem to correlate particularly with the activation and relaxation of the counteractive facial muscle (see section 5.4). Whether such patterns will be confirmed requires further investigation. A potentially well-suited methodology for future exploration of this issue could involve experimental designs and analyses on a trial-by-trial basis.

## 6.4 Shortcomings and Limitations

Some of the findings presented here are associated to methodological limitations, thus there are several reasons why they should be interpreted carefully. First, the results of Chapter 2 are based on a very small sample size, causing a degree of uncertainty in the results that should be reduced by further testing with larger sample sizes. Second, there is a general shortcoming of studies employing BTX-treatments due to the demographic homogeneity of the patient group, which mostly includes married, college-educated, employed women with children (Schlessinger, Schlessinger, & Schlessinger, 2010). Third, even though the technique of using facial masks applied in Chapter 3 had several benefits, it was also associated to some methodological difficulties, as it did not allow for the simultaneous collection of facial motor resonance data. Therefore, the conclusion that facial muscle resonance was successfully blocked by the hardening mask could only be deduced from the observation that the ability to discriminate between emotional words and neutral words was impaired, as had also been observed in another study that blocked facial muscles (Niedenthal et al., 2009; see subsection 3.4.2 on the manipulation check). Fourth, the study discussed in Chapter 4 left led to some uncertainty in regard to the interpretation of the results. For example, it remained unclear whether the performance slump in the categorizing L2 words was mainly caused by lower proficiency in L2 or by other mechanisms. This ambiguity in results could possibly be avoided in the future by using only highly frequent words, which L2 speakers are more likely to be familiar with. Furthermore, due to the small sample size, the statistical power was low, which most likely played a role in the accumulation of the reported marginal effects. Finally, throughout the present thesis it has been argued that the amygdala played a crucial role in the reported effects. Again, this assumption was deduced from other studies (e.g. Hennenlotter et al., 2009), but was never directly tested. This gives considerable room for future research, investigating the link between embodied simulations and amygdala activity.

## 6.5 Conclusion

The present findings contribute to our understanding how emotion processing occurs and frames the role of facial motor resonance. While the link between emotion to salient processing and memory had previously been well established, the present thesis integrated embodied simulations into this relationship – an aspect that had so far received little attention. Over the course of this thesis, it was shown that embodied simulations help with the processing of indefinite emotional information and assist with the formation of enduring representations of emotional stimuli. I conclude that what matters in the understanding and remembering of emotions is not in the brain nor in the body, but in the interactions and collaborations between the two. Through reciprocal connections they constitute a synergy in human cognition, in general, and in goal-directed behavior, specifically.

# References

Abbassi, E., Kahlaoui, K., Wilson, M. a, & Joanette, Y. (2011). Processing the emotions in words: the complementary contributions of the left and right hemispheres. *Cognitive, Affective & Behavioral Neuroscience*, *11*(3), 372–85. doi:10.3758/s13415-011-0034-1

Adolphs, R. (2002). Recognizing Emotion From Facial Expressions. *Behavioral and Cognitive Neuroscience Reviews*, *1*, 21–62. doi: 10.1177/1534582302001001003

Adolphs, R., Damasio, H., Tranel, D., Cooper, G., & Damasio, A. R. (2000). A role for somatosensory cortices in the visual recognition of emotion as revealed by three-dimensional lesion mapping. *Journal of Neuroscience, 20*, 2683-2690. Retrieved from http://www.jneurosci.org/content/20/7/2683.full.pdf+html

Adolphs, R., Damasio, H., Tranel, D.,& Damasio, A. R. (1996). Cortical systems for the recognition of emotion in facial expressions. *Journal of Neuroscience, 16*, 7678-7687. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.333.5482&rep=rep1&type=pdf

Adolphs, R., Cahill, L., Schul, R., & Babinsky, R. (1997). Impaired declarative memory for emotional material following amygdala damage in humans. *Learning & Memory, 4,* 291-300. doi: 10.1101/lm.4.3.291

Aggleton, J. P., & Mishkin, M. (1986). The amygdala sensory gateway to the emotions. In R. Plutchick & H.Kellerman (Eds.), Emotion: theory, research and experience. Biological foundations of emotion (pp. 281–299). Orlando, FL: Academic Press.

Anooshian, J.L., Hertel, T.P., 1994. Emotionality in free recall: language specificity in bilingual memory. *Cognition and Emotion 8*, 503–514. doi:10.1080/02699939408408956

Aron, A. R., Fletcher, P. C., Bullmore, E. T., Sahakian, B. J., & Robbins, T. W. (2003). Stop-signal inhibition disrupted by damage to right inferior frontal gyrus in humans. *Nature Neuroscience, 6*, 115–6. doi:10.1038/nn1003

Arnell, K. M., Killman, K. V., & Fijavz, D. (2007). Blinded by emotion: Target misses follow attention capture by arousing distractors in RSVP. *Emotion*, *7*, 465–477. doi: 10.1037/1528-3542.7.3.465

Ayçiçeği, A., Harris, C.L., 2004. Bilinguals recall and recAy e Ayçiçe i, Harris, C. L. (2004). Bilinguals' Recall and Recognition of Emotion Words. *Cognition & Emotion*, *18*, 977-987.

Ayçiçeği-Dinn, A., & Caldwell-Harris, C. (2009). Emotion-memory effects in bilingual speakers: A level of processing approach. *Bilingualism: Language and Cognition*, *12*, 291–303.

Retrieved from http://stantatkin.com/wp-content/uploads/2012/12/import/ans/library/Tronick06.doc

Bailey, K., & Chapman, P. (2012). When can we choose to forget? An ERP study into item-method directed forgetting of emotional words. *Brain and Cognition, 78*, 133–47. doi:10.1016/j.bandc.2011.11.004

Barsalou, L. W. (1999). Perceptual symbol systems. *Behavioral and Brain Sciences*, *22*, 577–660. doi:10.1017/S0140525X99002149

Barsalou, L. W. (2003). Abstraction in perceptual symbol systems. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *358*, 1177–87. doi:10.1098/rstb.2003.1319

Barsalou, L. W. (2008). Grounded cognition. *Annual Review of Psychology*, *59*, 617–45. doi:10.1146/annurev.psych.59.103006.093639

Basden, B.H., Basden, D.R., 1996. Directed forgetting: further comparisons of the items and list methods. *Memory 4,* 633–653.

Bayer, M., & Schacht, A. (2014). Event-related brain responses to emotional words, pictures, and faces - a cross-domain comparison. *Frontiers in Psychology*, *5*, 1–10. doi:10.3389/fpsyg.2014.01106

Beck, A. T., Steer, R. A., Brown, G. K. (1996). Beck Depression Inventory-Second Edition Manual. San Antonio (TX): The Psychological Corporation; 1996.

Bjork, R. A., LaBerge, D., & LeGrand, R. (1968). The modification of short-term memory through instructions to forget. *Psychonomic Science, 10,* 55–56. doi:10.3758/BF03331404

Blairy, S., Herrera, P.,& Hess, U. (1999). Mimicry and the judgment of emotional facial expressions. *Journal of Nonverbal Behavior, 23*, 5–41. doi:10.1023/A:1021370825283

Blaney, P. H. (1986). Affect and memory: a review. *Psychological Bulletin, 99*, 229–246. doi: 10.1037/0033-2909.99.2.229

Bond, M. H., & Lai, T. (1986). Embarrassment and code-switching into a second language. *The Journal of Social Psychology*, *126*(2), 179–186. Retrieved from http://psycnet.apa.org/psycinfo/1987-25041-001

Bradley, M. M., Lang, P. J. (2007). Emotion and motivation. In J.T. Cacioppo , L.G. Tassinary, & G. Berntson (Eds). *Handbook of Psychophysiology* (pp. 581–607). New York: Cambridge University Press.

Brandt, K. R., Nielsen, M. K., & Holmes, A. (2013). Forgetting emotional and neutral words: an ERP study. Brain Research, 1501, 21–31. doi:10.1016/j.brainres.2013.01.019

Brierley, B., Medford, N., Shaw, P., & David, A. S. (2004). Emotional memory and perception in temporal lobectomy patients with amygdala damage. *Journal of Neurology, Neurosurgery, and Psychiatry, 75*, 593-999. doi: 10.1136/jnnp.2002.006403

Brown, S. B. R. E., van Steenbergen, H., Band, G. P. H., de Rover, M., & Nieuwenhuis, S. (2012). Functional significance of the emotion-related late positive potential. *Frontiers in Human Neuroscience, 6*, 33. doi:10.3389/fnhum.2012.00033

Bub, D. N., Masson, M. E. J., & Cree, G. S. (2008). Evocation of functional and volumetric gestural knowledge by objects and words. *Cognition, 106*, 27–58. doi:10.1016/j.cognition.2006.12.010

Buchanan, T. W. & Adolphs, R. 2002. The role of the human amygdala in emotional modulation of long-term declarative memory. In S. Moore & M. Oaksford (Eds.), *Emotional cognition: From brain to behavior* (pp. 9–34). Amsterdam: John Benjamins Publishing.

Buchanan, T. W., Etzel, J. a, Adolphs, R., & Tranel, D. (2006). The influence of autonomic arousal and semantic relatedness on memory for emotional words. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology, 61*, 26–33. doi:10.1016/j.ijpsycho.2005.10.02

Cacioppo, J. T., & Gardner, W. L. (1999). Emotion. *Annual Review of Psychology, 50*, 191–214. doi:10.1146/annurev.psych.50.1.191

Cacioppo, J. T., & Petty, R. E. (1981). Electromyograms as measures of extent and affectivity of information processing. *American Psychologist, 36*, 441-456. doi: 10.1037/0003-066X.36.5.441

Cahill, L., Babinsky, R., Markowitsch, H. J., & McGaugh, J. L. (1995). The amygdala and emotional memory. *Nature, 377*, 295-296. doi: 10.1038/377295a0

Cahill, L., Haier, R. J., Fallon, J., Alkire, M. T., Tang, C., Keator,D., Wu,J., & McGaugh, J. L. (1996). Amygdala activity at encoding correlated with long-term, free recall of emotional information. *Proceedings of the National Academy of Sciences, 93,* 8016-8021.

Caldwell-Harris, C. L., & Ayçiçeği-Dinn, A. (2009). Emotion and lying in a non-native language. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *71*(3), 193–204. doi:10.1016/j.ijpsycho.2008.09.006

Cannon, W. B. (1927). The James-Lange theory of emotion. *American Journal of Psychology 39*, 106-124.

Carr, L., Iacoboni, M., Dubeau, M.-C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences, 100*, 5497-5502. doi: 10.1073/pnas.0935845100

Casasanto, D., & Dijkstra, K. (2010). Motor action and emotional memory. *Cognition, 115*, 179–185. doi: 10.1016/j.cognition.2009.11.002

Chainay, H., Michael, G. A., Vert-Pré, M., Landré, L., & Plasson, A. (2012). Emotional enhancement of immediate memory: Positive pictorial stimuli are better recognized than neutral or negative pictorial stimuli*. Advances in Cognitive Psychology*, *8,* 255–266. doi: 10.2478/v10053-008-0121-1

Cloitre, M., & Liebowitz, M. R. (1991). Memory bias in panic disorder: An investigation of the cognitive avoidance hypothesis. *Cognitive Therapy and Research, 15*, 371–386. doi: 10.1007/BF01173032

Codispoti, M., Bradley, M. M., & Lang, P. J. (2001). Affective reactions to briefly presented pictures. *Psychophysiology*, *38*(3), 474–8. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/1135213

Codispoti, M., Ferrari, V., De Cesarei, A., & Cardinale, R. (2006). Implicit and explicit categorization of natural scenes. In S. Anders, G. Ende, M. Junghofer, J. Kissler, & D. Wildgruber (Eds.). *Understanding Emotions* (pp. 53-65). Amsterdam: Elsevier.

Cohen, R. L. (1989). Memory for action events: The power of enactment. *Educational Psychology Review*, *1*, 57–80. doi:10.1007/BF01326550

Colbeck, K. L., & Bowers, J. S. (2012). Blinded by taboo words in L1 but not L2. *Emotion*, *12*, 217–22. doi:10.1037/a0026387

Conrad, M., Recio, G., & Jacobs, A. M. (2011). The Time Course of Emotion Effects in First and Second Language Processing: A Cross Cultural ERP Study with German-Spanish Bilinguals. *Frontiers in Psychology*, *2*, 351. doi:10.3389/fpsyg.2011.00351

Dalgleish, T. (2004). The emotional brain. *Nature Reviews Neuroscience, 5*, 583–589. doi: 10.1038/nrn1432

Damasio, A. R., Everitt, B. J., Bishop, D. (1996). The Somatic Marker Hypothesis and the Possible Functions of the Prefrontal Cortex. *Philosophical Transactions: Biological Sciences*, *351*,1413-1420.

Dawson, M. E., Schell, A.M., Filion, D.L. (2007). The Electrodermal System. In J.T. Cacioppo, L.G. Tassinary, & , G. Berntson. *Handbook of Psychophysiology* (pp. 159-181). Cambridge: Cambridge University Press.

Decloe R., Obhi S.S. (2013). Motor cortical processing is causally involved in object recognition. *BMC Neuroscience.14:155*. doi:10.1186/1471-2202-14-155.

De Houwer, J., Hermans, D. (1994). Differences in the affective processing of words and pictures. Cognition & *Emotion, 8*, 1-20. doi: 10.1080/02699939408408925

Depue, B. E., Curran, T., & Banich, M. T. (2007). Prefrontal regions orchestrate suppression of emotional memories via a two-phase process. *Science*, *317*, 215–9. doi:10.1126/science.1139560

Dijksterhuis, A., & Bargh, J. A. (2001). The perception-behavior express- way: Automatic effects of social perception on social behavior. In M. P. Zanna (Ed.), Advances in Experimental social psychology (Vol. 33.) (pp. 1–40). San Diego, CA: Academic Press.

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious facial reactions to emotional facial expressions. *Psychological Science, 11,* 86–89. doi: 10.1111/1467-9280.00221

Dimberg, U., Thunberg, M., & Grunedal, S. (2002). Facial reactions to emotional stimuli: Automatically controlled emotional responses. *Cognition & Emotion, 16*, 449–471. doi: 10.1080/02699930143000356

Dooley, C., George, R. E. (1988). A single Case Study Illustrating the Reduction in Subvocalisation with Electromyography. *Behavioural Psychotherapy, 16,* 231-240. doi:10.1017/S0141347300013677

Eich, E. (1995). Searching for mood dependent memory. *Psychological Science, 6,* 67-75. doi: 10.1111/j.1467-9280.1995.tb00309

Eilola, T. M., & Havelka, J. (2010). Behavioural and physiological responses to the emotional and taboo Stroop tasks in native and non-native speakers of English. *International Journal of Bilingualism*, *15*, 353–369. doi:10.1177/1367006910379263

Eilola, T. M., Havelka, J., & Sharma, D. (2007). Emotional activation in the first and second language. *Cognition & Emotion*, *21*, 1064–1076. doi:10.1080/02699930601054109

Ekman, P. & Friesen, W. (1978). *Facial Action Coding System: A Technique for the Measurement of Facial Movement.* Palo Alto: Consulting Psychologists Press.

Engelkamp, J., and Zimmer, H. D. (1985). Motor programs and their relation to semantic memory. *German Journal of Psychology, 9*, 239-254.

Fischer, A. H., Becker, D., & Veenstra, L. (2012). Emotional mimicry in social context: the case of disgust and pride. *Frontiers in Psychology*, *3*, 475. doi:10.3389/fpsyg.2012.00475

Fitzgerald, D. A., Arnold, J. F., Becker, E. S., Speckens, A. E. M., Rinck, M., Rijpkema, M., … & Tendolkar, I. (2011). How mood challenges emotional memory formation: an fMRI investigation. *NeuroImage, 56*, 1783–1790. doi: 10.1016/j.neuroimage.2011.02.061

Foroni, F. (2014). The Second Language Disadvantage: Evidence for the 'partial' simulation during processing of a second language. Manuscript submitted for publication.

Foroni, F., & Semin, G. R. (2009). Language that puts you in touch with your bodily feelings: The multimodal responsiveness of affective expressions. *Psychological Science, 20,* 974–980. doi: 10.1111/j.1467-9280.2009.02400.x-980

Foroni, F. & Semin, G.R. (2011). When does mimicry affect evaluative judgment? *Emotion, 11*, 687-690. doi: 10.1037/a0023163

Foroni, F., & Semin, G.R. (2012). Not all implicit measures of attitudes are created equal: Evidence from an embodiment perspective. *Journal of Experimental Social Psychology, 48*, 424-427. doi: 10.1016/j.jesp.2011.08.015

Förster, J., Strack F. (1996). Influence of overt head movements on memory for valenced words: a case of conceptual-motor compatibility. *Journal of Personality and Social Psychology, 3,* 421-430. doi: 10.1037/0022-3514.71.3.421

Gallese, V. (2003). A neuroscientific grasp of concepts: from control to representation. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences*, *358*, 1231–40. doi:10.1098/rstb.2003.1315

Gothard, K. M. (2014). The amygdalo-motor pathways and the control of facial expressions. *Frontiers in Neuroscience*, *8*, 1–7. doi:10.3389/fnins.2014.00043

Gothard, K. M., Battaglia, F. P., Erickson, C. a, Spitler, K. M., & Amaral, D. G. (2007). Neural responses to facial expression and face identity in the monkey amygdala. *Journal of Neurophysiology*, *97*, 1671–1683. doi:10.1152/jn.00714.2006

Gray, S. G., Hughes, H. H., & Schneider, L. J. (1982). Physiologial responsivity to a socially stressful situation: The effect of level of moral development. *Psychological Record, 32*, 29–34.

Green, D. M., & Swets, J. A. (1966). *Signal detection theory and psychophysics.* New York: Wiley.

Grimshaw, G. M., Carmel, D. (2014). An asymmetric inhibition model of hemispheric differences in emotional processing. *Frontiers in Psychology, 5*, 489. doi: 10.3389/fpsyg.2014.00489

Halberstadt, J., Winkielman, P., Niedenthal, P. M., Dalle, N. (2009). Emotional Conception: How embodied emotion concepts guide perception and facial action. *Psychological Science, 20*, 1254-1261. doi: 10.1111/j.1467-9280.2009.02432

Hamann, S. (2001). Cognitive and neural mechanisms of emotional memory. *Trends in Cognitive Sciences, 5*, 394–400. doi: 10.1016/S1364-6613(00)01707-1

Harris, C. L. (2004). Bilingual Speakers in the Lab: Psychophysiological Measures of Emotional Reactivity. *Journal of Multilingual and Multicultural Development*, *25*, 223–247. doi:10.1080/01434630408666530

Harris, C.L., Ayçiçeği, A., Gleason, J.B. (2003). Taboo words and reprimands elicit greater autonomic reactivity in a first language than in a second language. *Applied Psycholinguistics, 24*, 561-579. doi:http://dx.doi.org/10.1017/S0142716403000286

Hauswald, A., Schulz, H., Iordanov, T., & Kissler, J. (2011). ERP dynamics underlying successful directed forgetting of neutral but not negative pictures. *Social Cognitive and Affective Neuroscience, 6*, 450–9. doi:10.1093/scan/nsq061

Havas, D. A., Glenberg, A. M., Gutowski, K. A., Lucarelli, M. J., & Davidson, R. J. (2010). Cosmetic use of botulinum toxin-A affects processing of emotional language. *Psychological Science*, *21*, 895–900. doi: 10.1177/0956797610374742

Hawk, S. T., Fischer, A. H., & Van Kleef, G. A. (2012). Face the noise: Embodied responses to nonverbal vocalizations of discrete emotions. *Journal of Personality and Social Psychology*, *102*, 796-814. doi: 10.1037/a0026234

Hennenlotter, A., Dresel, C., Castrop, F., Ceballos-Baumann, A. O., Baumann, A. O. C., Wohlschläger, A. M., & Haslinger, B. (2009). The link between facial feedback and neural activity within central circuitries of emotion--new insights from botulinum toxin-induced denervation of frown muscles. *Cerebral Cortex (New York, N.Y. : 1991)*, *19*, 537–42. doi:10.1093/cercor/bhn104

Herz, R. S. (1997). The effects of cue distinctiveness on odor-based context-dependent memory. *Memory and Cognition, 25,* 375–380.

Hess, U., & Blairy, S. (2001). Facial mimicry and emotional contagion to dynamic emotional facial expressions and their influence on decoding accuracy. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology*, *40*(2), 129–41. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11165351

Hess, U., & Fischer, A. (2013). Emotional mimicry as social regulation. *Personality and Social Psychology Review : An Official Journal of the Society for Personality and Social Psychology, 17*, 142–57. doi:10.1177/1088868312472607

Hess U, Fischer A. (2014). Emotional Mimicry: Why and When We Mimic Emotions. *Social and Personality Psychology Compass, 8*, 45–57. doi:10.1111/spc3.12083.

Hietanen, J. K., Surakka, V. & Linnankoski, I. (1998). Facial electromyographic responses to vocal affect expressions. *Psychophysiology, 35*, 530–536. doi: 10.1017/S004857729 8970445

Hillyard, S.A., Hink, R.F., Schwent, V.L., Picton, T.W. (1973). Electrical signs of selective attention in the human brain. *Science, 182,* 177–80. Retrieved from http://ling.umd.edu/~ellenlau/courses/nacs642/Hillyard_1973.pdf

Hinojosa, J. A., Carretié, L., Valcárcel, M. A., Méndez-Bértolo, C., & Pozo, M. A. (2009). Electrophysiological differences in the processing of affective information in words and pictures. *Cognitive, Affective & Behavioral Neuroscience, 9*, 173–89. doi:10.3758/CABN.9.2.173

Hinojosa, J. A, Méndez-Bértolo, C., & Pozo, M. A. (2010). Looking at emotional words is not the same as reading emotional words: Behavioral and neural correlates. *Psychophysiology, 47,* 748–57. doi:10.1111/j.1469-8986.2010.00982.x

Hogeveen, J., & Obhi, S. S. (2012). Social Interaction Enhances Motor Resonance for Observed Human Actions. *Journal of Neuroscience*. doi:10.1523/JNEUROSCI.5938-11.2012

Hourihan, K. L., Ozubko, J. D., & MacLeod, C. M. (2009). Directed forgetting of visual symbols: evidence for nonverbal selective rehearsal. *Memory & Cognition*, *37*, 1059–68. doi:10.3758/MC.37.8.1059

Hsieh, L.-T., Hung, D. L., Tzeng, O. J.-L., Lee, J. R., & Cheng, S. (2009). An event-related potential investigation of the processing of Remember/Forget cues and item encoding in item-method directed forgetting. *Brain Research, 1250*, 190–201. doi:10.1016/j.brainres.2008.11.016

Ilves, M., & Surakka, V. (2012). Heart Rate Responses to Synthesized Affective Spoken Words. *Advances in Human-Computer Interaction*, *2012*, 1–6. doi:10.1155/2012/158487

Ito, T. A., Larsen, J. T., Smith, N. K., & Cacioppo, J. T. (1998). Negative information weighs more heavily on the brain. *Journal of Personality and Social Psychology, 4*, 887-900. Retrieved from: http://psychology.uchicago.edu/people/faculty/cacioppo/jtcreprints/ilsc98.pdf

James, W. (1884). What is an Emotion? *Mind, 9:* 188-205 (available online at: http://psychclassics.yorku.ca/James/emotion.htm).

James, W. (1890). *The Principles of Psychology* (Vol. 1). Cambridge: Harvard University Press.

Janak, P. H., & Tye, K. M. (2015). From circuits to behaviour in the amygdala. *Nature, 517,* 284-292. doi:10.1038/nature14188

Jay, T., Caldwell-Harris, C., & King, K. (2008). Recalling taboo and nontaboo words. *American Journal of Psychology*, *121*, 83-103. doi: 10.2307/20445445

Johnson, H., Thompson, A. (2008). The development and maintenance of posttraumatic stress disorder (PTSD) in civilian adult survivors of war trauma and torture: A review. *Clinical Psychology Review,* 28, 36-47. doi: http://dx.doi.org/10.1016/j.cpr.2007.01.017

Katsikitis, M. (2003). The Human Face. Meeasurement and Meaning. Massachusetts: Kluwer Academic Publishers.

Keillor, J. M., Barrett, A. M., Crucian, G., P., Kortenkamp, S., Heilman, K., M. (2002). Emotional experience and perception in the absence of facial feedback. *Journal of the International Neuropsychological Society, 8,* 130-135. doi: http://dx.doi.org/10.1017/S1355617701020136

Keith Payne, B., & Corrigan, E. (2007). Emotional constraints on intentional forgetting. *Journal of Experimental Social Psychology, 43,* 780–786. doi:10.1016/j.jesp.2006.07.005

Kensinger, E. A., & Corkin, S. (2003). Memory enhancement for emotional words: Are emotional words more vividly remembered than neutral words? *Memory & Cognition, 31*, 1169–1180. doi: 10.3758/BF03195800

Kensinger, E. A., & Corkin, S. (2004). Two routes to emotional memory: distinct neural processes for valence and arousal. *Proceedings of the National Academy of Sciences of the United States of America*, *101*(9), 3310–5. doi:10.1073/pnas.0306408101

Keysar, B., Hayakawa, S. L., & An, S. G. (2012). The foreign-language effect: thinking in a foreign tongue reduces decision biases. *Psychological Science*, *23*(6), 661–8. doi:10.1177/0956797611432178

Kissler, J., Herbert, C., Winkler, I., & Junghofer, M. (2009). Emotion and attention in visual word processing: an ERP study. *Biological Psychology, 80*, 75–83. doi:10.1016/j.biopsycho.2008.03.004

Kreiman, G., Koch, C. & Fried, I. (2000). Category-specific visual responses of single neurons in the human medial temporal lobe. Nature Neuroscience, 3, 946–953. doi:10.1038/78868

Künecke, J., Hildebrandt, A., Recio, G., Sommer, W., & Wilhelm, O. (2014). Facial EMG responses to emotional expressions are related to emotion perception ability. *PloS One*, *9*, e84053. doi:10.1371/journal.pone.0084053

LaBar, K. S., & Cabeza, R. (2006). Cognitive neuroscience of emotional memory. *Nature Reviews Neuroscience*, *7*, 54-64.doi: 10.1038/nrn1825

Lakoff, G., Johnson, M. (1980). *Metaphors we live by.* Chicago, IL: University of Chicago Press.

Lamendella, J. 1977. General principles of neurofunctional organization and their manifestations in

primary and non-primary language acquisition. *Language Learning, 27*, 155-196.

Laney, C., Campbell, H. V., Heuer, F., & Reisberg, D. (2004). Memory for thematically arousing events. *Memory & Cognition*, *32*, 1149-1159. doi: 10.3758/BF03196888

Lang, A. J., Craske, M. G., Brown, M., & Ghaneian, A. (2001). Fear-related state dependent memory. *Cognition and Emotion, 15*, 695–703. doi: 10.1080/0269993012581

Lange, C. G. (1912). The mechanisms of emotion. In: Rand B, editor. The Classical Psychologists. Boston: Houghton Mifflin. pp. 672–684. available online at: (http://psychclassics.yorku.ca/Lange/)

Larsen, J. T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology*, *40*, 776–785. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/14696731

LeDoux, J. E. The Emotional Brain (1996). New York: Simon & Schuster.

Lee, T. W., Josephs, O., Dolan, R. J., & Critchley, H. D. (2006). Imitating expressions: emotion-specific neural substrates in facial mimicry. *Social Cognitive and Affective Neuroscience, 1*, 122–135. doi: 10.1093/scan/nsl012

Lopez-Calderon, J., & Luck, S. J. (2014). ERPLAB: An open-source toolbox for the analysis of event-related potentials. Frontiers in Human Neuroscience, 8:213. doi: 10.3389/fnhum.2014.00213

Liu, W.-H., Wang, L.-Z., Zhao, S.-H., Ning, Y.-P., & Chan, R. C. K. (2012). Anhedonia and emotional word memory in patients with depression. *Psychiatry Research, 2-3*, 361-367. doi: 10.1016/j.psychres.2012.07.02

Macedonia, M. (2014). Bringing back the body into the mind: gestures enhance word learning in foreign language. *Frontiers in Psychology*, *5*(December), 1467. doi:10.3389/fpsyg.2014.01467

MacLeod, C. M. (1998). Directed forgetting: The human memory literature. In J. M. Golding & C. M. MacLeod (Eds.), *Intentional forgetting: Interdisciplinary approaches* (pp. 1–57). Mahwah, NJ: Erlbaum.

Mangels, J. A., Picton, T. W., & Craik, F. I. (2001). Attention and successful episodic encoding: an event-related potential study. *Cognitive Brain Research, 11*, 77e95. http://dx.doi.org/ 10.1016/S0926-6410(00)00066-5. Matsuhashi,

Marian, V., Blumenfeld, H.K., & Kaushanskaya, M. (2007). The Language Experience and Proficiency
Questionnaire (LEAP-Q): Assessing Language Profiles in Bilinguals and Multilinguals. *Journal of Speech Language and Hearing Research, 50*, 940-967. doi:10.1044/1092-4388(2007/067)

Maringer, M., Krumhuber, E. G., Fischer, A. H., & Niedenthal, P. M. (2011). Beyond smile dynamics: Mimicry and beliefs in judgments of smiles. *Emotion, 11*, 181-187. doi:10.1037/a0022596

Markowitsch, H. J., Calabrese, P., Würker, M., Durwen, H. F., Kessler, J., Babinsky, R., Gehlen, W. (1994). The amygdala's contribution to memory: A study on two patients with Urbach-Wiethe disease. *Neuroreport, 5*, 1349–1352. doi:10.1097/00001756-199406270-00013

Marx, B. P., Marshall, P. J., & Castro, F. (2008). The moderating effects of stimulus valence and arousal on memory suppression. *Emotion, 8,* 199–207. doi:10.1037/1528-3542.8.2.199

McGaugh, J. L. (2004). The amygdala modulates the consolidation of memories of emotionally arousing experiences. *Annual Review of Neuroscience*, *27*, 1–28. doi:10.1146/ annurev.neuro.27.070203.144157

McGinnies, E. (1949). Emotionality of perceptual defense. *Psychological Review, 56*, 244–251.

Mead, K. L.,& Ball, L. (2007). Music tonality and context-dependent recall: The influence of key change and mood mediation. *European Journal of Cognitive Psychology. 19,* 59–79.

Merckelbach, H., Van Hout, W., Van den Hout, M. A., Mersch, P. P. (1989). Psychophysiological and subjective reactions of social phobics and normals to facial stimuli. *Behavior Research and Therapy, 27*, 289-294. doi:10.1016/0005-7967(89)90048-X

Metzger, M. M. (2011). Directed Forgetting: Differential Effects on Typical and Distinctive Faces. *The Journal of general psychology, 138*, 155-168. doi: 10.1080/00221309.2011.557407

Montefinese, M., Ambrosini, E., Fairfield, B., Mammarella, N. (2014). The adaptation of the Affective Norms for English Words (ANEW) for Italian. *Behavior Research Methods, 46,* 887-903. doi 10.3758/s13428-013-0405-3

Nakamura, H., Ito, Y., Honma, Y., Mori, T., & Kawaguchi, J. (2014). Cold-hearted or cool-headed: physical coldness promotes utilitarian moral judgment. *Frontiers in Psychology*, *5*(October), 1–10. doi:10.3389/fpsyg.2014.01086

Neal, D. T., Chartrand, T. L. (2011). Embodied emotion perception: Amplifying and dampening facial feedback modulates emotion perception. *Social Psychology and Personality Science, 2,* 673-678. doi: 10.1177/1948550611406138

Niedenthal, P. M. (2007). Embodying emotion. *Science, 316,* 1002–5. doi:10.1126/science.1136930

Niedenthal, P. M., Barsalou, L. W., Winkielman, P., Krauth-Gruber, S., & Ric, F. (2005). Embodiment in attitudes, social perception, and emotion. *Personality and Social Psychology Review, 9*, 184–211. doi: 10.1207/s15327957pspr0903_1

Niedenthal, P. M., Brauer, M., Halberstadt, J. B., & Innes-Ker, Å. H. (2001). When did her smile drop? Facial mimicry and the influences of emotional state on the detection of change in emotional expression. *Cognition & Emotion, 15,* 853–864. doi: 10.1080/ 02699930143000194

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *The Behavioral and Brain Sciences*, *33*(6), 417–33. doi:10.1017/S0140525X10000865

Niedenthal, P. M., Winkielman, P., Mondillon, L., & Vermeulen, N. (2009). Embodiment of emotion concepts. *Journal of Personality and Social Psychology*, *96*, 1120–36. doi:10.1037/a0015574

Nietzsche, F. (1872). *Philosophenbuch*, translated in D. Breazeale (1979) *Philosophy and Truth*: Selections from Nietzsche's Notebooks of the Early 1870s. Sussex, New Jersey: Humanities Press, pp. 50-51.

Nowicka, A., Marchewka, A., Jednorog, K., Tacikowski, P., Brechmann, A. (2011). Forgetting of emotional information is hard: an fMRI study of directed forgetting. *Cerebral Cortex 21,* 539–549. doi: 10.1093/cercor/bhq117

Nowicka, A., Jednoróg, K., Wypych, M., & Marchewka, A. (2009). Reversed old/new effect for intentionally forgotten words: an ERP study of directed forgetting. *International Journal of Psychophysiology : Official Journal of the International Organization of Psychophysiology, 71,* 97–102. doi:10.1016/j.ijpsycho.2008.06.009

Oberman, L. M., Winkielman, P., & Ramachandran, V. S. (2007). Face to face: Blocking facial mimicry can selectively impair recognition of emotional expressions. *Social Neuroscience, 2,* 167–178. doi:10.1080/17470910701391943

Oostenveld, R., & Praamstra, P. (2001). The five percent electrode system for high-resolution EEG and ERP measurements. *Clinical Neurophysiology, 112*, 713–719. doi:10.1016/S1388-2457(00)00527-7

Overtoom, C. C., Kenemans, J. L., Verbaten, M. N., Kemner, C., van der Molen, M. W., van Engeland, H., Buitelaar, J. K., Koelega, H. S. (2002). Inhibition in children with attention-deficit/hyperactivity disorder: a psychophysiological study of the stop task. *Biol Psychiatry. 51*, 668--676. doi:10.1016/S0006-3223(01)01290-2

Paller, K. A. (1990). Recall and stem-completion priming have different electrophysiological correlates and are modified differentially by directed forgetting. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 16*, 1021–1032. doi:10.1037//0278-7393.16.6.1021

Pavlenko, A. (2012). Affective processing in bilingual speakers: disembodied cognition? *International Journal of Psychology, 47*, 405-428. doi: 10.1080/00207594.2012.743665

Paz-Caballero, M. (2004). Predictive validity of event-related potentials (ERPs) in relation to the directed forgetting effects. *Clinical Neurophysiology, 115,* 369–377. doi:10.1016/j.clinph.2003.09.011

Peirce, J.W. (2009). Generating stimuli for neuroscience using PsychoPy. *Front. Neuroinform.2*:10. doi:10.3389/neuro.11.010.2008

Pessoa, L., & Adolphs, R. (2010). Emotion processing and the amygdala: from a "low road" to "many roads" of evaluating biological significance. *Nature Reviews. Neuroscience*, *11*, 773–83. doi:10.1038/nrn2920

Pessoa, L., Kastner, S., & Ungerleider, L. G. (2003). Neuroimaging studies of attention: from modulation of sensory processing to top-down control. *The Journal of Neuroscience : The Official Journal of the Society for Neuroscience*, *23*, 3990–3998. doi:23/10/3990

Piaget, Jean (1952). The origins of intelligence in children. New York, NY, US: W W Norton & Co.

Ponari, M., Conson, M., D'Amico, N. P., Grossi, D., & Trojano, L. (2012). Mapping Correspondence Between Facial Mimicry and Emotion Recognition in Healthy Subjects. *Emotion, 12*, 1528-3542. doi:10.1037/a0028588

Pourtois, G., Sander, D., Andres, M., Grandjean, D., Reveret, L., Olivier, E., & Vuilleumier, P. (2004). Dissociable roles of the human somatosensory and superior temporal cortices for processing social face signals. *The European Journal of Neuroscience*, *20*, 3507–15. doi:10.1111/j.1460-9568.2004.03794.x

Quené, H., Semin, G. R., & Foroni, F. (2012). Audible smiles and frowns affect speech comprehension. *Speech Communication*, *54*, 917-922. doi: 10.1016/j.specom. 2012.03.004

Rieger M, Gauggel S, Burmeister K. (2003). Inhibition of ongoing responses following frontal, nonfrontal, and basal ganglia lesions. *Neuropsychology. 17*, 272—282. doi:10.1037/0894-4105.17.2.272

Rizio, A. A., & Dennis, N. A.. (2014). The cognitive control of memory: age differences in the neural correlates of successful remembering and intentional forgetting. *PloS One, 9*, e87010. doi:10.1371/journal.pone.0087010

Robinson, S. J. & Rollings, L. J. L. (2011). The Effect of Mood-Context on Visual Recognition and Recall Memory. *The Journal of General Psychology, 138*, 66 -79

Ross, B. H., Wang, R. F., Kramer, A. F., Simons, D. J., & Crowell, J. a. (2007). Action information from classification learning. *Psychonomic Bulletin & Review*, *14*, 500–504. doi:10.3758/BF03194097

Saltz, E., and Donnenwerth-Nolan, S. (1981). Does motoric imagery facilitate memory for sentences: A selective interference test*. Journal of Verbal learning and Verbal Behavior, 20*, 322-332. doi:10.1016/S0022-5371(81)90472-2

Sandín, B., Chorot, P., Lostao, L., Joiner, T.E., Santed, M.A., Valiente, R.M. (1999). Psicothema, 11, 37-51. Retrieved from: http://www.psicothema.com/pdf/229.pdf

Santiago-Rivera, A. L., & Altarriba, J. (2002). The role of language in therapy with the Spanish-English bilingual client. *Professional Psychology: Research and Practice*, *33*, 30–38. doi:10.1037/0735-7028.33.1.30

Schlessinger, J., Schlessinger, D., & Schlessinger, B. (2010). Prospective demographic study of cosmetic surgery patients. *The Journal of Clinical and Aesthetic Dermatology*, *3*, 30–35. Retrieved from http://www.ncbi.nlm.nih.gov/pmc/articles/PMC2989811/pdf/jcad_3_11_30.pdf

Schupp, H. T., Junghöfer, M., Weike, A. I., & Hamm, A. O. (2003). Emotional facilitation of sensory processing in the visual cortex. *Psychological Science, 14,* 7–13. doi:10.1111/1467-9280.01411

Schwanberg, J. S. (2010). Does language of retrieval affect the remembering of trauma*? Journal of Trauma and Dissociation, 11*, 44-56. doi:10.1080/15299730903143550

Schwartz, G. E., Fair, P. L., Salt, P., Mandel, M. R., & Klerman, G. L. (1976). Facial muscle patterning to affective imagery in depressed and nondepressed subjects. *Science, 192*, 489–491.

Scott, G. G., O'Donnell, P. J., Leuthold, H., & Sereno, S. C. (2009). Early emotion word processing: evidence from event-related potentials. *Biological Psychology, 80*, 95–104. doi:10.1016/j.biopsycho.2008.03.010

Semin, G. R.,&Cacioppo, J. T. (2008). Grounding social cognition: Synchro- nization, entrainment, and coordination. In G. R. Semin & E. R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches* (pp. 119–147). New York: Cambridge University Press.

Sharot, T., & Phelps, E. a. (2004). How arousal modulates memory: disentangling the effects of attention and retention. *Cognitive, Affective & Behavioral Neuroscience*, *4*, 294–306. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15535165

Smith, S. M., & Vela, E. (2001). Environmental context-dependent memory: A review and meta-analysis. *Psychonomic Bulletin & Review*, *8*, 203–220. doi:10.3758/BF03196157

Terracciano, A., McCrae, R. R., & Costa, P. T., Jr. (2003). Factorial and construct validity of the Italian Positive and Negative Affect Schedule (PANAS). European Journal of Psychological Assessment: Official Organ of the European *Association of Psychological Assessment, 19*, 131–141. doi: 10.1027//1015-5759.19.2.131

Tottenham, N., Tanaka, J., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B. J., Nelson, C.(2009). The NimStim set of facial expressions: judgments from untrained research participants. P*sychiatry Research, 168,* 242–249. doi:10.1016/j.psychres.2008.05.006

Tucker, M., & Ellis, R. (1998). On the relations between seen objects and components of potential actions. Journal of Experimental Psychology. *Human Perception and Performance, 24*, 830–46. Available at http://www.ncbi.nlm.nih.gov/pubmed/9627419

Tucker, M., & Ellis, R. (2004). Action priming by briefly presented objects. *Acta Psychologica*, *116*, 185–203. doi:10.1016/j.actpsy.2004.01.004

Watson, D., Clark, L. A., & Tellegen, A. (1988). Development and validation of brief measures of positive
and negative affect: The PANAS scales. *Journal of Personality and Social Psychology, 54, 1063*-1070.

Van Hooff, J. C., & Ford, R. M. (2011). Remember to forget: ERP evidence for inhibition in an item-method directed forgetting paradigm. *Brain Research, 1392,* 80–92. doi:10.1016/j.brainres.2011.04.004

Wessel, I., & Merckelbach, H. (2006). Forgetting “murder” is not harder than forgetting “circle”: Listwise-directed forgetting of emotional words. *Cognition & Emotion, 20*, 129–137. doi: 10.1080/02699930500260195

Whalen, P. J. (1998). Fear, Vigilance, and Ambiguity: Initial Neuroimaging Studies of the Human Amygdala. *Current Directions in Psychological Science*, *7*, 177–188. doi:10.1111/1467-8721.ep10836912

Wild, B., Erb, M., Eyb, M., Bartels, M., & Grodd, W. (2003). Why are smiles contagious? An fMRI study of the interaction between perception of facial affect and facial movements. *Psychiatry Research*, *123*, 17–36. doi: 10.1016/S0925-4927(03)00006-4

Williams, M., Woodman, G. F. (2012). Directed forgetting and directed remembering in visual working memory. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 38,* 1206-1220. doi: 10.1037/a0027389

Winkielman, P., Berridge, K. C., & Wilbarger, J. L. (2005). Unconscious affective reactions to masked happy versus angry faces influence consumption behavior and judgments of value. *Personality and Social Psychology Bulletin, 31*, 121–135. doi: 10.1177/ 0146167204271309

Wu, L., & Barsalou, L. W. (2009). Perceptual simulation in conceptual combination: evidence from property generation. *Acta Psychologica*, *132*, 173–89. doi:10.1016/j.actpsy.2009.02.002

Wylie, G. R., Foxe, J. J., & Taylor, T. L. (2008). Forgetting as an active process: an FMRI investigation of item-method-directed forgetting. *Cerebral Cortex, 18*, 670–82. doi:10.1093/cercor/bhm101

Yang, W., Liu, P., Xiao, X., Li, X., Zeng, C., Qiu, J., & Zhang, Q. (2012). Different neural substrates underlying directed forgetting for negative and neutral images: an event-related potential study. *Brain Research, 1441*, 53–63. doi:10.1016/j.brainres.2011.10.042

Zwaan, R., & Taylor, L. J. (2006). Seeing, acting, understanding: Motor resonance in language comprehension. *Journal of Experimental Psychology: General, 135,* 1–11. doi: 10.1037/0096-3445.135.1.1