Facial Mimicry and the Processing of Facial Emotional Expressions

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Um sich zu erkennen, muss man in die Gesichter der anderen sehen.

(Michael Rumpf)

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List of Abbreviations

ADS-K	Allgemeine Depressionsskala, short-version (K)
ANOVA	Analysis of Variance
BDI	Beck Depression Inventory
BOTOX	Botulinum toxin
CI	confidence interval
dB	decibel
dlPFC	dorsolateral prefrontal cortex
EEG	electroencephalography
eMMN	expression-related mismatch negativity
EMG	electromyography
ERP	event-related potential
FDR	false discovery rate
FMM	facial muscle manipulation
fMRI	functional magnetic resonance imaging
HCs	healthy controls
Hz	hertz
IPANAT	Implicit Positive and Negative Affect Test
ISI	interstimulus interval
LED	daily levodopa equivalent dose
M	mean
mg	milligram
MMN	mismatch negativity
MNS	mirror neuron system
msec	millisecond
OFC	orbitofrontal cortex

PD	Parkinson's Disease
pwPE	precision-weighted prediction error
RM-ANOVA	repeated measures ANOVA
RT	reaction time
SD	standard deviation
SE	standard error
SHAPS-D	Snaith-Hamilton-Pleasure-Scale, german (D) version
STS	superior temporal sulcus
vMMN	visual mismatch negativity
WM	working memory
μV	microvolt

Abstract

In social interactions, facial expressions make a major contribution to our daily communication as they can transmit internal states like motivations and feelings of our conspecifics. In the last decades, research has revealed that facial mimicry plays a pivotal role in the accurate perception and interpretation of facial expressions. Embodied simulation theories claim that facial expressions are automatically mimicked, thereby producing a facial feedback signal, which in turn activates a corresponding state in the motor, somatosensory, affective and reward system of the observer. This activation - in turn - facilitates the processing of the observed emotional expression and hence supports the understanding of its meaning. Research on the influence of facial mimicry on the perception of emotional expressions is, to a large extent, driven by facial mimicry manipulation studies. Especially the classical facial mimicry manipulation method introduced by Strack, Martin, and Stepper (1988) has become a popular and established method. Here participants have to hold a pen in different positions with the mouth inducing a smiling or a frowning expression. The present thesis assessed the influence of facial mimicry on cognitive processes by means of this classical facial mimicry manipulation method. In three projects, I investigated the impact of (1) facial mimicry on the automatic processing of facial emotional expressions, (2) facial mimicry on the working memory for emotional expressions, and (3) facial mimicry manipulation on an impaired processing of emotional expressions in patients with Parkinson's disease (PD).

In a first project, the impact of facial mimicry manipulation was measured by electrophysiological recordings of the expression related mismatch negativity to unattended happy and sad faces. The findings reveal that the automatic processing of facial emotional expressions is systematically influenced by facial mimicry. In the second project, I assessed the behavioral performance during a facial emotional working memory task while the mimicry of participants was manipulated. Findings of this project highlight that working memory for emotional expressions is influenced by facial mimicry. Finally, in the third project, I investigated the link between the reduced facial mimicry in PD patients and their impaired ability to recognize emotional expressions. For this purpose, I compared the data of PD and healthy individuals during the performance of an emotional change detection task while undergoing facial mimicry manipulation. Although healthy participants show a typical pattern of facial

mimicry manipulation influence, PD patients do not profit of the applied manipulation.

The results of the present thesis demonstrate that facial mimicry is an indispensable part in our daily social interaction as it affects the processing of emotions on a perceptual as well as a cognitive level. I showed that facial mimicry influences the automatic processing of - as well as the working memory for - observed facial emotional expressions. Furthermore, the empirical evidence of the third project suggests that not only facial mimicry is reduced in patients with PD but rather that the whole process of facial feedback processing is impaired in those individuals. These results demonstrate the applicability of the classical facial mimicry manipulation method and further highlight the importance of research on the influence of facial mimicry on cognitive processing as our ability to understand the emotional expressions of our conspecifics and thus our social interaction depends on an intact facial mimicry processing.

1. Introduction

Our social life is characterized by interpersonal relationships. Within these interpersonal relationships, communication plays a pivotal role. A successful communication with our conspecifics depends on the exchange of information by verbal as well as nonverbal language. Facial expressions display such a nonverbal communication channel (Adolphs, 1999) and are classified as innate and automatic patterns of behavior (Darwin, 1872). Emotional expressions as communicatory signal convey motivation and the emotional state of the other and can thus trigger appropriate behavior (Blair, 2003). Consequently, the correct extraction of this information from facial expressions is critical for our daily social interactions. Interestingly, the extraction of such information from the emotional expressions of our conspecifics is supported by our own facial expressions in that we mimic the observed facial expressions.

During the last decades, several research assumed that these facial mimicry processes exert a considerable influence on the recognition of facial emotional expressions of others. The present PhD thesis shall constitute a contribution to this field of research and aimed to further uncover the link between facial mimicry and facial emotion processing.

For this purpose, three projects will be presented in chapters two to four in which I investigated whether facial mimicry influences 1) the automatic processing of emotional expressions, 2) the memory for emotional expressions and 3) the impaired emotion recognition in patients with Parkinson's disease. The present chapter will give an overview of the theory and research behind facial mimicry processes.

1.1. Facial Mimicry towards Emotional Expressions

Facial mimicry of emotional expressions occurs within the first 300-400msec after the exposure to an emotional expression and often even without attention and consciousness (U. Dimberg, 1990; U. Dimberg & Thunberg, 1998; U. Dimberg, Thunberg, & Elmehed, 2000). In contrast to emotional contagion, which reflects an affective state matching the observed facial display, facial mimicry is defined as the facial reaction to an observed emotional facial displays. (Hess & Blairy, 2001). Furthermore, the facial reaction must temporally as well as physiologically match the observed expression in order to be classified as mimicry (Niedenthal, Korb, Wood, & Rychlowska, 2016). In accordance with embodied simulation theories, facial mimicry produces a somatosensory facial feedback, starting from the facial musculature, which triggers a corresponding state in the observer's motor, somatosensory, affective and reward system, thereby helping to understand the meaning of the observed expression (Niedenthal et al., 2016).

In the following chapter, I will briefly outline the theory of embodied simulation and relevant research in this field.

1.2. The Theory of Embodied Simulation

Embodiment

A first approach of embodied cognition theories can be assigned to Varela, Thompson, and Rosch (1991) who claimed that cognition is not merely a "brain process" but involves the brain as well as the body and the environment, constantly interacting with each other. Today, the term embodiment can be found in interdisciplinary research including philosophy, psychology, neuroscience and robotics (Gallagher, 2012). In neurobiology the *embodied mind* was primary introduced by Damasio (1994). He states that "*the mind is embodied, [...], not just embrained*", meaning that the brain interacts with the body and analyzes and evaluates information from the environment. Therefore, the body influences pre-conceptual and preconscious meaning and provides information, e.g. from the viscera, the muscles and the joints (Damasio, 1994). In such a way, our perception, memories, attention and decisions can be influenced by hormonal changes, visceral processes and by feedback signals from the motor system (Gallagher, 2012). Consequently, the encounter with a horse might be very differentially perceived, depending on the environmental context and body reactions – like whether I will meet the horse on the floor or in meadow and whether my heartbeat is racing or calm.

The influence of the body on cognitive processes has been demonstrated in several studies. In an initial study, Wells and Petty (1980) showed that head nodding in contrast to head shaking results in more positive attitudes towards a simultaneously listened message. In the following research, the influence of an adopted body posture has been assessed. It could be shown that an upright posture in contrast to a slumped body posture increases the perseverance during a frustrating task (Riskind & Gotay, 1982). Analogously, participants that have been praised during a slumped body posture are less proud about themselves when compared to those which were in an upright posture (Stepper & Strack, 1993). Finally, different body postures also modulate the experienced affect of the participants (Duclos et al., 1989).

These studies impressively demonstrate that our body and the resulting body feedback influences our mental experience. If such feedback can be ascribed to the facial musculature, it is called facial feedback.

Facial Feedback

Early studies on facial feedback investigated whether different adopted facial expressions can modulate emotional experience (J. D. Laird, 1974; Strack et al., 1988). In the seminal study by J. D. Laird (1974) participants were asked to either pose a smiling or a frowning facial expression. As a result, during smiling they reported to be happier while during the frowning condition they reported to be angrier. Additionally, when they were asked to rate cartoons during these different facial expressions, more humorous ratings were submitted during smiling compared to frowning expression. The authors implicate that the *expressive behavior* modulates the quality of the emotional experience.

However, one criticism of this study concerns the methodology of the facial simulation procedure. Participants were asked to contract certain muscles on the ground that the activity of their facial muscles will be measured under different conditions. However, according to Strack et al. (1988) this procedure cannot exclude the possibility that participants are aware of the link between the contraction of certain muscles and the emotional meaning behind it. As a consequence, Strack and his colleagues introduced a new, yet today classical, facial muscle manipulation method. Here participants have to hold a pen with their mouth to pose different facial expressions. This allows for inducing a smiling or frowning expression, without the explicit knowledge about the related emotions of the participants (see Figure 1). Holding a pen with the teeth requires the contraction of the Musculus zygomaticus major and M. risorius, both activated during smiling expressions, while holding the pen with the lips contracts the M. orbicularis oris which activation is incompatible with smiling. Holding the pen with the non-dominant hand allows free mimicry and thus serves as control condition (Strack et al. (1988), see Figure 2 for overview of mimic musculature). Similar to the study by J. D. Laird (1974), in their seminal study Strack and colleagues showed that the smiling facial muscle manipulation (i.e. the teeth condition) increased the funniness rating of cartoons whereas the inhibition of smiling in the lips condition reduced the funniness rating – thereby providing further evidence that facial feedback can influence the emotional experience.

Figure 1. Different pen holding conditions introduced by Strack et al. 1988. Holding the pen with the teeth **(A)** contracts the M. zygomaticus major and the M. risorius, both activated during smiling, while holding the pen with the lips **(B)** activates the M. orbicularis oris and is incompatible with smiling.

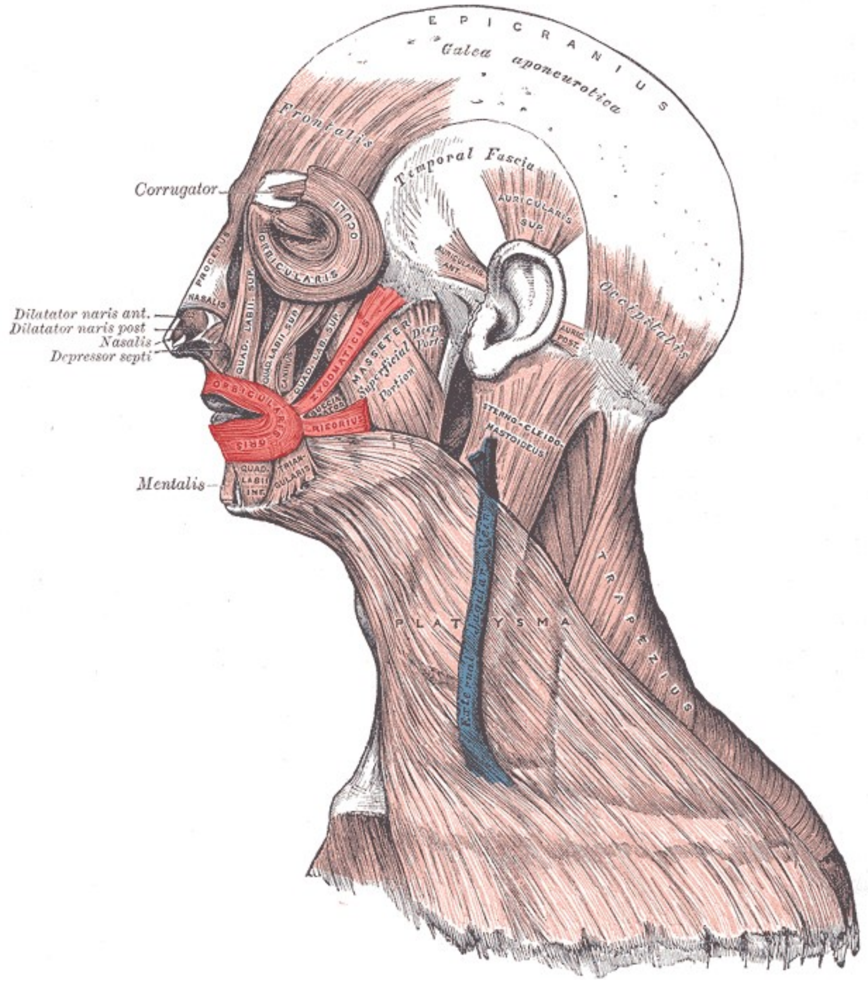

Figure 2. Mimic musculature. Highlighted in red are the muscles M. zygomaticus major, M. risorius and M. orbicularis oris (Gray, 1918).

This and further methods for systematic facial muscle manipulation have been applied in several research to investigate the influence of facial feedback on cognitive processes, especially on the recognition of facial emotional expressions. In the next section, I will give an overview of this research.

1.3. Studies on Facial Muscle Manipulation

Neurobiological embodiment accounts claim that the information from our body, like feedback from facial muscles, can modulate attentional, perceptual and memory processes. The automatic facial mimicry towards observed facial emotional expressions and its resulting somatosensory feedback can be considered as such an embodied process. According to theories of embodied simulation, this automatic mimicry helps to understand the meaning of the observed emotional expression as the resulting facial feedback facilitates the embodied simulation of the expression and the related affective state (Niedenthal et al., 2016).

By the application of facial muscle manipulation methods over the past 2 decades, several research provided ample evidence that facial mimicry can modulate the experience of emotion (McArthur, Solomon, Jaffe, & Psychology, 1980; Söderkvist, Ohlén, & Dimberg, 2018) and the consciousness processing of emotional stimuli (Ulf Dimberg & Söderkvist, 2011), especially of facial emotional expressions (Lobmaier & Fischer, 2015; Neal & Chartrand, 2011; Niedenthal, Brauer, Halberstadt, & Innes-Ker, 2001; Lindsay M Oberman, Winkielman, & Ramachandran, 2007; Ponari, Conson, D'Amico, Grossi, & Trojano, 2012).

The studies by Niedenthal et al. (2001) and Lobmaier and Fischer (2015) adopted the facial muscle manipulation by Strack et al. (1988) by asking participants to hold a pen with their mouth (Niedenthal et al.) or with their lips or teeth (Lobmaier & Fischer) in order to investigate the influence of facial feedback on the detection of emotional changes in facial expressions. For this purpose, the authors created morph sequences where an initial emotional expression (e.g. a happy face) changed frame by frame into another emotional expression (e.g. into a neutral face). Participants had to indicate when they detect this expression change. As a result, a general facial mimicry restriction (Niedenthal et al.) delayed the detection of emotional changes while the more specific pen holding conditions of the second study generated also more specific results. This is reflected by an improved detection and perception of happy expressions during the smiling inducing (teeth) condition and, in contrast, an improved detection and perception of sad expressions when smiling was inhibited (lip condition). These results indicate that facial mimicry and its manipulation can support the detection of emotional changes in facial expressions especially when the mimicry is congruent to the observed expression (Lobmaier & Fischer, 2015). Another way of experimentally manipulating facial mimicry is demonstrated in the study by Neal and Chartrand (2011). The authors dampened facial feedback by the injection of botulinum toxin (BOTOX) at the glabellar lines, forehead and crows feet and enhanced facial feedback by applying a restriction gel to the face. Here, BOTOX reduces facial feedback by paralyzing facial muscles. In contrast, the restriction gel amplifies facial feedback as it has been shown that the subjective feeling of resistance to facial muscle contractions increased the afferent feedback signal to the brain. This study gives another evidence of the influence of facial feedback in facial expression recognition as it has shown that dampening the facial feedback significantly impaired emotion perception while facial feedback amplification improved it (Neal & Chartrand, 2011).

Only two studies so far have investigated the effect of facial feedback and its manipulation on the perception of emotional expressions on an electrophysiological level (Davis, Winkielman, & Coulson, 2017; Sel, Calvo-Merino, Tuettenberg, & Forster, 2015). Facial mimicry of participants was induced into a smiling expression in the study by Sel et al. (2015) while they had to make emotional intensity judgments of facial expressions. Results reveal that the smiling mimicry manipulation modulates the face sensitive N170 component. Davis et al. (2017) disrupted the facial feedback of the participants by asking them to bite on chopsticks while investigating its influence on semantic processing of facial expressions. In this study, the disruption increased the N400 component, which represents the access to semantic information from memory, to happy and disgusted facial expressions.

The studies mentioned above demonstrate that facial feedback can be manipulated by several facial muscle manipulation methods and that this manipulation influences the processing of emotional expressions on a behavioral as well as on an electrophysiological level. Another possibility to study the influence of facial mimicry and the resulting facial feedback lies in the investigation of clinical cohorts with deficient facial mimicry. On overview of those deficits will be provided in the following section.

1.4. Deficits in Facial Mimicry

The importance of an intact facial mimicry and the processing of the resulting facial feedback for the recognition of emotional expressions is further affirmed by several clinical observations. Impairments in the recognition of emotional expressions are evident in patients with movement disorders like patients with Parkinson's disease (S. Argaud, 2018), in patients with mental disorders like depression, bipolar disorders (Kohler, Hoffman, Eastman, Healey, & Moberg, 2011) and schizophrenia (Kohler, Walker, Martin, Healey, & Moberg, 2010), and in patients with developmental disorders like autism spectrum disorder (Harms, Martin, & Wallace, 2010). Common in these disorders is a reduced facial mimicry (Livingstone, Vezer, McGarry, Lang, & Russo, 2016; L. M. Oberman, Winkielman, & Ramachandran, 2009; Sloan, Bradley, Dimoulas, & Lang, 2002; Varcin, Bailey, & Henry, 2010; Zwick & Wolkenstein, 2017). Therefore, it seems reasonable to suppose that the impairments of facial emotion recognition are associated with the deficits in facial mimicry. In the following section I will briefly outline research on patients suffering from Parkinson's disease (PD) supporting this assumption.

Emotion Recognition and Facial Mimicry in PD

Parkinson's disease is a neurodegenerative disease with motor as well as non-motor symptoms caused by the loss of dopaminergic neurons in the substantia nigra and structural changes within extranigral components of the motor, limbic and autonomic system (Braak, Rüb, & Braak, 2000; Jankovic, 2003). The 4 cardinal motor symptoms comprise slowing of voluntary movement (bradykinesia), involuntary rhythmic oscillation of body parts (resting tremor), stiffness (rigor) and postural instability (Braak et al., 2003). Also the face is affected by bradykinesia, as it can show impairments in emotional, spontaneous and voluntary facial movements (Bologna et al., 2013) with the result that it is often perceived as a masked face (hypomimia) (S. Argaud, 2018). Patients with PD often suffer from their hypomimia, which is the reason that it influences their quality of life and well-being (Gunnery, Habermann, Saint-Hilaire, Thomas, & Tickle-Degnen, 2016). However, patients with PD do not only suffer from their impairments of self-expressing emotions but also from their impairment of recognizing emotional expressions of others (Peron, Dondaine, Le Jeune, Grandjean, & Verin, 2012; Sprengelmeyer et al., 2003). In accordance with embodied simulation theories, it has been suggested that the deficits in facial emotion recognition in patients with PD can be linked to the prominent facial mimicry reduction (S. Argaud, 2018; Prenger & MacDonald, 2018). Accordingly, studies measuring facial muscle activation by means of electromyography (EMG) demonstrated a reduced facial mimicry towards emotional expressions (Soizic Argaud et al., 2016; Livingstone et al., 2016) and revealed a correlation between reduced facial expressivity and emotion recognition deficits (Marneweck, Palermo, & Hammond, 2014; Ricciardi et al., 2017). These investigations of patients with PD provide further evidence that the process of facial mimicry is importantly involved in the recognition of facial emotional expressions.

2. Project Outline

The present PhD thesis aims at investigating the influence of facial mimicry and the resulting facial feedback on the processing of facial emotional expressions. In particular, I want to examine whether facial feedback manipulation can influence (1) the automatic processing of emotional expressions, (2) the memory for emotional expressions, (3) the detection of emotional changes in facial expressions in patients with PD. See Table 1 for an overview of experimental design.

Table 1. Experimental Design Overview

Project	*Sample*	*Paradigm*
1	19 healthy participants	emotional oddball paradigm
2	37 healthy participants	emotional working memory paradigm
3	20 PD patients 20 healthy participants (age- and gender-matched)	emotional change detection paradigm

Project 1

Theories of embodied simulation assume that facial mimicry supports the processing of facial emotional expressions by triggering the simulation of corresponding motor, somatosensory and affective states (Niedenthal, Mermillod, Maringer, & Hess, 2010). This assumption has been verified in several studies demonstrating that facial mimicry manipulation can modulate the explicit judgments on facial emotions (e.g. Lobmaier and Fischer, 2015; Niedenthal et al., 2001; Lindsay M Oberman et al., 2007). However, in daily life, changes of emotional expressions occur largely outside the focus of our attention. Therefore, project 1 investigates the influence of facial feedback on the automatic processing of *unattended* facial emotional expressions. For this purpose, I apply the classical facial muscle manipulation method of Strack et al. (1988), where participants have to hold a pen with their teeth - to induce a smiling expression -, with their lips - to inhibit a smiling expressions -, or with their non-dominant hand - control condition allowing free mimicry. This project measures the influence of this manipulation electrophysiologically by recording the expression-related mismatch negativity (eMMN) during an emotional facial oddball paradigm.

Hypotheses

(1) I hypothesize that facial muscle manipulation influences the automatic processing of emotional expressions indexed by electrophysiological modulations of the eMMN.

(2) Additionally, I assume that the influence on the automatic processing of happy and sad facial expressions will depend on the different facial mimicry manipulations.

Project 2

Results of *Project 1* indicate that facial mimicry and the resulting facial feedback have an impact on the automatic and unconscious processing of emotional expressions. This is indicated by a distinct automatic processing of happy and sad faces during the smiling manipulation condition. However, also I was able to measure this modulation electrophysiologically by means of eMMN modulation, the underlying process remains concealed. One of the proposed explanations is that the facial feedback manipulation might have changed the encoding and retrieval of happy and sad expressions. Thus, facial mimicry might also have an influence on our memory for emotional expressions.

To investigate this assumption, in Project 2, facial muscle manipulation (holding a pen with the teeth vs. holding a pen with the non-dominant hand) is applied during an emotional working memory paradigm where participants have to encode and retrieve the intensity of happy and sad emotional expressions.

Hypotheses

(1) I expect that memory performance will decrease with the level of ambiguity – low intensity emotional expressions will be remembered worse compared to high intensity emotional expressions.

(2) I hypothesize that the induction of a smiling expression will improve memory for happy faces, particularly for happy faces of high ambiguity

(3) In accordance with research suggesting an advantage for women over men in recognition memory for (emotional) faces, I assume that the applied facial muscle manipulation will differently influence the memory performance depending on the gender of the individual.

Project 3

Patients with PD suffer from hypomimia and show reduced facial mimicry towards facial emotional expressions. Next to these motor symptoms, these patients are additionally impaired in the recognition of emotional expressions. As theories of embodied simulation forecast a link between facial mimicry and emotion recognition it has been assumed that the prominent emotion recognition impairments might be attributed to the reduced, or even missing, facial mimicry in patients with PD.

To investigate whether the restricted facial mimicry in patients with PD causes the emotion recognition impairments I measure the ability of patients with PD and of a healthy control group to detect emotional changes in facial expressions while they undergo the classical facial muscle manipulation conditions (holding a pen with the teeth vs. lips vs. non-dominant hand).

Hypotheses

(1) Generally, I predict that patients with PD will detect emotional changes of faces later than healthy controls.

(2) Following previous studies, I assume that facial muscle manipulation will influence the emotional change detection in faces.

(3) More specifically, I hypothesize that during the smiling induction participants will offer an advantage in the perception and detection of happy faces, while the inhibition of smile will improve the perception and detection of sad faces.

(4) Furthermore, I suspect that not only the emotion change detection rate of healthy participants, but also that of PD patients will be modulated in such a way by the facial feedback manipulation.

3. Project 1

Out of Focus: Facial Feedback Manipulation Modulates Automatic Processing of Unattended Emotional Faces

Specific aim:

In this project, I want to examine the influence of facial feedback on the automatic processing of unattended facial emotional expressions.

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ABSTRACT

While behavioral and electrophysiological studies have confirmed the influence of facial feedback on the perception of facial emotional expressions, the influence of facial feedback on the automatic processing of such stimuli is largely unexplored. The automatic processing of unattended facial expressions can be investigated by visual expression-related MMN. The expression-related MMN reflects a differential ERP of automatic detection of emotional changes elicited by rarely presented facial expressions (deviants) among frequently presented facial expressions (standards). In this study, I investigated the impact of facial feedback on the automatic processing of facial expressions. For this purpose, participants (n = 19) performed a centrally presented visual detection task while neutral (standard), happy, and sad faces (deviants) were presented peripherally. During the task, facial feedback was manipulated by different pen holding conditions (holding the pen with teeth, lips, or nondominant hand). My results indicate that automatic processing of facial expressions is influenced and thus dependent on the own facial feedback.

3.1. Introduction

Interpersonal relationships determine our everyday life. Within these interpersonal relationships, the perception and interpretation of emotional facial expressions is indispensable. A growing body of literature emphasizes the pivotal role of facial mimicry in the perception of facial expressions of others. Accordingly, embodied cognition theories suggest that we automatically simulate or mimic emotional expressions of others and the resulting somatosensory facial feedback facilitates the processing of facial emotional stimuli (Niedenthal, Barsalou, Winkielman, Krauth-Gruber, & Ric, 2005). Thus, the perception of a facial emotional expression results in a reexperience of this emotion on a perceptual, somatovisceral, as well as motoric level (Niedenthal, 2007) and in turn facilitates the recognition of these emotional stimuli by evoking a corresponding emotional state in ourselves (Niedenthal et al., 2005). Hence, facial feedback has been proposed to play an important role in interpreting the facial expressions of our counterparts.

The relevance of facial mimicry and the resulting facial feedback for processing facial expressions of emotion is supported by several clinical observations. Severe limitations in the recognition of facial expressions have been observed in patients with movement disorders (i.e., Parkinson's disease; S. Argaud, Vérin, Sauleau, and Grandjean, 2018), but also in people with mental disorders, such as depression, bipolar disorder (Kohler et al., 2011), schizophrenia (Kohler et al., 2010), autism spectrum disorder (Harms et al., 2010), and psychopathy (Dawel, O'Kearney, McKone, & Palermo, 2012). In these pathologies, observed deficits in facial emotion recognition are accompanied by reduced or delayed facial mimicry (Livingstone et al., 2016; L. M. Oberman et al., 2009; Varcin et al., 2010), suggesting a causal role of facial mimicry in the perception of facial expressions of emotion.

Experimental evidence for the more general account that facial feedback influences our affective responses is provided by studies investigating the direct consequence of facial feedback manipulation (e.g. J. D. Laird, 1974; Lobmaier and Fischer, 2015; Neal and Chartrand, 2011; Niedenthal et al., 2001; Lindsay M Oberman et al., 2007; Strack et al., 1988). In the seminal studies by J. D. Laird (1974) and later by Strack et al. (1988), participants were asked to rate the funniness of cartoons while their own facial muscle activity was systematically modulated. In the former study, participants were asked to contract their facial muscles in a way that they would unconsciously pose either a smiling or a frowning facial expression. This facial muscle manipulation influenced the mood of the participants as well as their ratings of the funniness—smiling participants felt happier and rated cartoons to be funnier as in the frowning condition (J. D. Laird, 1974). To exclude that participants recognize the emotional meaning of the facial muscle manipulation, Strack et al. (1988) introduced a new method of facial feedback manipulation— participants had to hold a pen with either the teeth, the lips, or with the nondominant hand while rating the funniness of cartoons. In these conditions, holding a pen with the teeth requires contracting the musculus zygomaticus major and the musculus risorius, both also activated while smiling, whereas holding a pen with the lips requires contracting the musculus orbicularis oris and is incompatible with the contraction of the musculus zygomaticus major and risorius that are used in smiling. In accordance with the study by J. D. Laird (1974), holding the pen with the teeth and thereby inducing smiling increased funniness ratings, whereas the inhibition of smiling resulted in less funny ratings. Notwithstanding recent contentious debate (Noah, Schul, & Mayo, 2018; Wagenmakers et al., 2016), several studies consistently evidenced that facial feedback specifically influences emotional face perception supporting the facial feedback hypothesis of embodied emotion accounts (e.g., Lobmaier and Fischer, 2015; Neal and Chartrand, 2011; Niedenthal et al., 2001; Lindsay M Oberman et al., 2007; Sel et al., 2015).

Two recent studies adopted the methodological implementation of facial feedback manipulation used by Strack et al. (1988) by asking participants to hold a pen with their mouth Niedenthal et al. (2001) or with their lips or teeth (Lobmaier & Fischer, 2015) while rating morph sequences of changing facial emotional expressions. Results indicate that a general facial muscle restriction delayed the detection of changes in emotional expressions (Niedenthal et al., 2001), while detection of emotional changes strongly relied on the pen holding condition in the second study (Lobmaier & Fischer, 2015). Particularly, induced smiling during the teeth-holding condition resulted in a facilitated detection and perception of happy facial expressions. In contrast, when smiling was inhibited during the lip-holding condition, detection and perception of sad facial expressions was facilitated. The authors conclude that facial feedback supports the detection of intensity changes of facial expressions of emotions when these are congruent to the own facial expression.

Only a few studies so far have tested the influence of facial feedback manipulation on the processing of emotional faces on an electrophysiological level (Davis et al., 2017; Sel et al., 2015). In the study by Sel et al. (2015), participants had to adopt a happy facial expression by biting on a pen or maintain a neutral facial expression by relaxing their facial muscles while they had to judge the intensity of facial expressions. The concurrent EEG revealed that such facial feedback manipulation modulates the N170, a face-sensitive component of the visually evoked potential. In contrast, by biting on chopsticks, Davis et al. (2017) attempted to disrupt the naturally produced feedback from the lower half of facial muscles and investigated the influence on the later semantic processing of facial expressions—with the result that this disruption increased the N400 (which is representative for the access to semantic information within memory) to happy and disgusted faces. Thus, the electrophysiological results of both studies indicate that facial mimicry manipulation can influence early perceptual as well as later semantic processing of facial emotional expressions. Above-mentioned studies consistently demonstrate the important role of facial mimicry and the resulting facial feedback on the conscious processing of facial expressions of emotions. These studies investigated the relevance of facial feedback in explicit judgments of facial emotions on a behavioral as well as electrophysiological level. However, changes in facial expressions regularly occur outside the focus of attention. Accordingly, in various everyday situations, facial expressions are processed automatically without conscious awareness, challenging the general external validity of previous investigations. Therefore, the aim of this study was to assess the influence of facial feedback manipulation on the automatic processing of facial expressions of emotion when no overt attention is allocated to the emotional stimuli.

A classical approach to investigate stimulus processing under attention-independent condition is provided by recordings of the MMN. This negative sensory electrophysiological component is elicited by regularity violations and is considered to display automatic change discrimination processes (Näätänen, Astikainen, Ruusuvirta, & Huotilainen, 2010). Although the MMN was first observed in the auditory domain, there is clear evidence for a visual analogue, the visual MMN (vMMN; Pazo-Alvarez, Cadaveira, and Amenedo, 2003). In accordance with predictive coding theory, vMMN represents a predictive error elicited by the mismatch between a current input and a prediction induced by representations of visual objects in memory (Winkler & Czigler, 2012). Previous studies indicate that vMMN is sensitive to individual stimulus features like color, orientation, and direction, but also to more complex stimulus characteristics such as categories like gender and color, but also facial emotional expressions. In such studies, MMN to facial expressions (eMMN) is measured during a visual oddball paradigm where a stream of frequently presented faces of one emotion category (standard) is occasionally interrupted by rare emotional faces of another emotion category (deviant; for a review, see I. Czigler, 2014; Pazo-Alvarez et al., 2003). The process of automatic change detection of emotional faces (as measured by eMMN) is assumed to be emotion-sensitive. This sensitivity can be indexed by negative bias, for example, an enhanced processing (increase in eMMN amplitude and/or reduced eMMN latency onset) of negative emotional deviants (like angry, fearful, or sad faces) compared with neutral or positive emotional deviants (happy or neutral faces; Kimura, Kondo, Ohira, and Schroger, 2012; Kovarski et al., 2017; Stefanics, Csukly, Komlosi, Czobor, and Czigler, 2012; Zhao and Li, 2006). Furthermore, several studies reveal a modification in eMMN characteristics in clinical populations (such as schizophrenia, mood disorders, and developmental disorders; Kremlacek et al., 2016). Thus, the nonconscious change detection of facial emotional expressions by means of eMMN appears to be a promising procedure to measure automatic affective responsiveness to emotional faces.

3.2. Methods

Participants

Twenty-eight individuals took part in this study. To assess current depressive disorders and self-reported anhedonia participants completed the Beck Depression Inventory-II (Hautzinger, Keller, & Kühner, 2006) and the German version of the Snaith–Hamilton Pleasure Scale (Franz et al., 1998). One participant was excluded from further analysis due to reported psychiatric disease, and data of eight participants were discarded due to less than 60% remaining trials for eMMN analysis (7) or more than ±3 SD from the statistical mean (1) in any experimental condition, resulting in 19 participants (eight women, mean age = 26.3, SD = 7.7). All remaining participants had normal or corrected-to-normal vision and affirmed to have no neurological or psychiatric diseases. Participants' characteristics are presented in Table 2. They were naïve of the aim of the study and signed informed consent before data collection according to the

Declaration of Helsinki. The study was approved by the Ethical Committee of the University Magdeburg.

Table 2. Sample Characteristics

Measure (n = 19)	*M(SD)*	*Range*
Age	26.3 (7.7)	19-56
BDI	3.9 (2.4)	1-9
SHAPS-D	0.3 (0.9)	0-4

BDI = Beck Depression Inventory; SHAPS-D = Snaith-Hamilton Pleasure Scale.

Stimuli and Procedure

After EEG preparation, participants sat in a comfortable chair in a dimly lit room. Visual stimuli were presented on a gray background on a computer screen (Samsung SyncMaster SA450, 22 in.) at a viewing distance of 0.9 m. Stimuli consisted of black and white photographs taken from the Karolinska face database (Lundqvist, Flykt, & Öhman, 1998). We chose 18 male (AM01, AM02, AM04, AM05, AM06, AM07, AM08, AM10, AM11, AM13, AM14, AM17, AM18, AM22, AM23, AM25, AM34, AM35) and 18 female models (AF01, AF02, AF03, AF05, AF06, AF07, AF09, AF11, AF13, AF14, AF17, AF19, AF20, AF22, AF24, AF26, AF29, AF33), each expressing three different emotions (neutral, happy, sad). To control for low-level properties of the images, mean luminance and contrast of all stimuli were equated using the SHINE toolbox for MATLAB (Willenbockel et al., 2010). Stimulus presentation was controlled with Presentation software (Version 21, Neurobehavioral Systems, Inc.).

The experiment consisted of three blocks. In each block, participants underwent a different facial muscle manipulation condition. In accordance with the study by Strack et al. (1988), facial muscle activity was manipulated by holding a pen with the teeth (innervating muscles responsible for smiling), with the lips (inhibiting muscles responsible for smiling), or with the nondominant hand (control condition). The order of these conditions was counterbalanced across participants, such that participants were assigned to one of nine possible predefined sequences of the facial mimicry manipulation conditions. To cover the study objective, participants were instructed that they are part of a stroke study investigating the influence of paralysis on RT measurements. As they will serve as a control group, the paralysis is simulated by holding a pen with the teeth, the lips, or the nondominant hand. Participants were fully debriefed about the study objective at the end of the experiment. Before each block, participants were carefully briefed how to hold the pen.

Each block started with a familiarization task followed by three visual detection tasks (see Figure 3). Additionally, for each of the three blocks, a set of six male and six female faces from the initial set of 18 male and 18 female faces was selected. During the familiarization task, the faces presented during the visual detection tasks were introduced to exclude any novelty effects on subsequent eMMN measurements. The faces, each displaying three different emotions (happy, sad, neutral), were randomly displayed while participants had to rate the emotional expressions (see Figure 3).

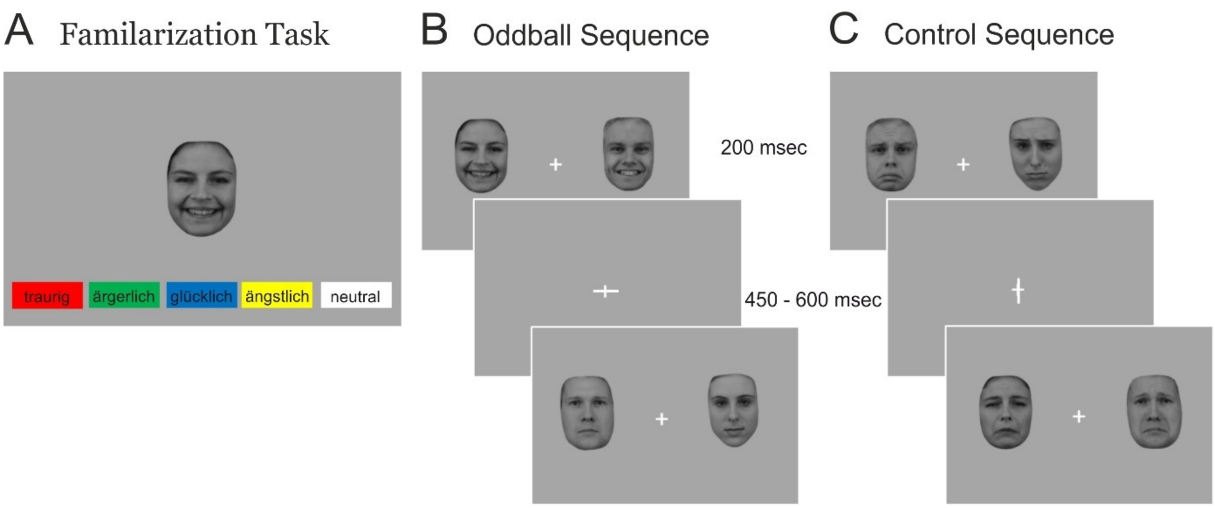

Figure 3. Stimuli and procedure for one block. Each block started with a familiarization task **(A)**, where participants were asked to choose the best fitting emotional expression of a face among five options displayed below the image. During the oddball sequence **(B)**, neutral (standard), happy, or sad (deviant) face pairs were presented bilaterally to a centrally presented fixation cross for 200 msec. In the control sequence **(C)**, only happy or sad face pairs were presented. In both sequences, presentation of face pairs was followed by an ISI of 450–600 msec. Participants were asked to focus on the fixation cross and indicate whenever the vertical or horizontal line changed its size. Fixation cross changes occurred only during the ISI, and for the oddball sequence only before a standard stimulus.

In the following three visual detection tasks (one oddball sequence, two control sequences), participants were asked to focus on a centrally presented fixation cross (1.3°) and detect size changes in horizontal or vertical line (1.9°) while ignoring the two bilaterally presented faces (see Figure 3). Participants responded to size changes by pressing either the left or right mouse button, depending on the changed line orientation. Target buttons were pseudorandomly assigned for each participant, such that the response buttons for horizontal and vertical line changes (either left for horizontal and right for vertical line changes or vice versa) were counterbalanced across the participants. A practice block was conducted at the start of the experiment.

Bilaterally presented face pairs covering an area of 5.4 × 7.9° were composed of one male and one female character displaying the same emotion presented for 200 msec followed by an ISI of 450-650 msec. The position of the male and female face was randomly assigned, and identities changed from trial to trial. Fixation cross changes occurred only during the ISI and only before standard trials. In each oddball sequence, neutral faces were presented as standard and happy and sad faces as deviants. At the beginning of each oddball sequence, 10 standards were presented to establish a sensory memory pattern of a neutral facial expression. One hundred twenty deviants (60 sad, $p = .1$; 60 happy, $p = .1$) and 480 standards ($p = .8$) were presented pseudorandomly, with the restriction that at least two standards were interspersed between consecutive deviants. In the following two control sequences, only happy or sad faces were presented (102 happy, 102 sad; see Figure 3). The order of happy and sad control sequences was pseudorandomly assigned between each block, so that the order of happy and sad control sequences changed within each participant between the three blocks.

EEG Recording and Data Analysis

EEG was recorded with Brain Vision Recorder software (Version 1.20 Brain Products GmbH) at electrode positions F3, Fz, F4, C3, Cz, C4, P7, P3, Pz, P4, P8, PO7, POz, PO8, O1, Oz, O2, right and left mastoids according to the international 10-20 system. Horizontal and vertical electrooculograms were recorded from two electrodes placed below and lateral to the right eye. Data were online referenced to the tip of the nose, recorded with a sampling rate of 500 Hz and digitally online filtered with a high-pass filter of 0.1 Hz. The impedances were kept below 5 kΩ. EEG data were offline-processed using BrainVision Analyzer (Version 2.1, Brain Products GmbH). Data were re-referenced to the common average potential, notch-filtered (50 Hz), and band-pass filtered between 0.1 and 40 Hz using a second-order zero-phase IIR Butterworth filter (12 dB/oct). Epochs of 800 msec (including 200 msec prestimulus interval) relative to the onset of the face pairs were extracted. Epochs with artifacts were excluded from further analyses according to predetermined rejection criteria (maximal allowed voltage step 100 µV/msec, maximal allowed difference of values in intervals 500 µV, maximal/minimal allowed amplitude 100 µV/−100 µV, lowest allowed activity in intervals 0.5 in 100 msec). As a result, data sets of eight participants were excluded from further analysis due to a loss exceeding 40% of trials. Furthermore, data of the first 10 trials and trials after a fixation cross change were not included into further processing. Data were averaged for deviant (happy deviant and sad deviant) and stimuli from the control sequence (happy control and sad control) separately for the different facial feedback manipulation conditions. Based on previous studies (Chang, Xu, Shi, Zhang, & Zhao, 2010; Wu et al., 2017; Zhao & Li, 2006) and visual inspection, data of P7/PO7 and P8/PO8 were pooled. Finally, differential waveforms were calculated separately for each facial feedback manipulation condition and emotion (deviant happy-control happy for happy-eMMN, deviant sad-control sad for sad-eMMN). Time windows for the analysis of the eMMN were selected based on previous studies (Csukly, Stefanics, Komlósi, Czigler, & Czobor, 2013; Stefanics et al., 2012; Wu et al., 2017) and on visual inspection of grand-averaged waveforms of happy- and sad-eMMN for the hand condition only. This resulted in three time windows reaching 70-140 , 180-270, and 280-360 msec (see Figure 4). Within these time windows, mean amplitudes over a 20 msec interval around the most negative peak (±10 msec) of happy- and sad-eMMNs for the different facial muscle manipulation conditions were extracted for further statistical analysis.

The statistical analysis was performed using IBM SPSS software 24. Peak amplitudes of difference waveforms of happy-eMMN and sad-eMMN were analyzed by repeated measures ANOVA with Hemisphere (left vs. right) × Emotion (happy vs. sad) × Facial Muscle Manipulation (hand vs. teeth vs. lips) as within-participant factors separately for each time window. Greenhouse-Geisser adjustment was used, if necessary, to correct for violations of sphericity. For significant interactions, post hoc comparisons were conducted using paired t tests. To correct for multiple comparisons the false discovery rate (FDR) correction was used (Benjamini & Hochberg, 1995).

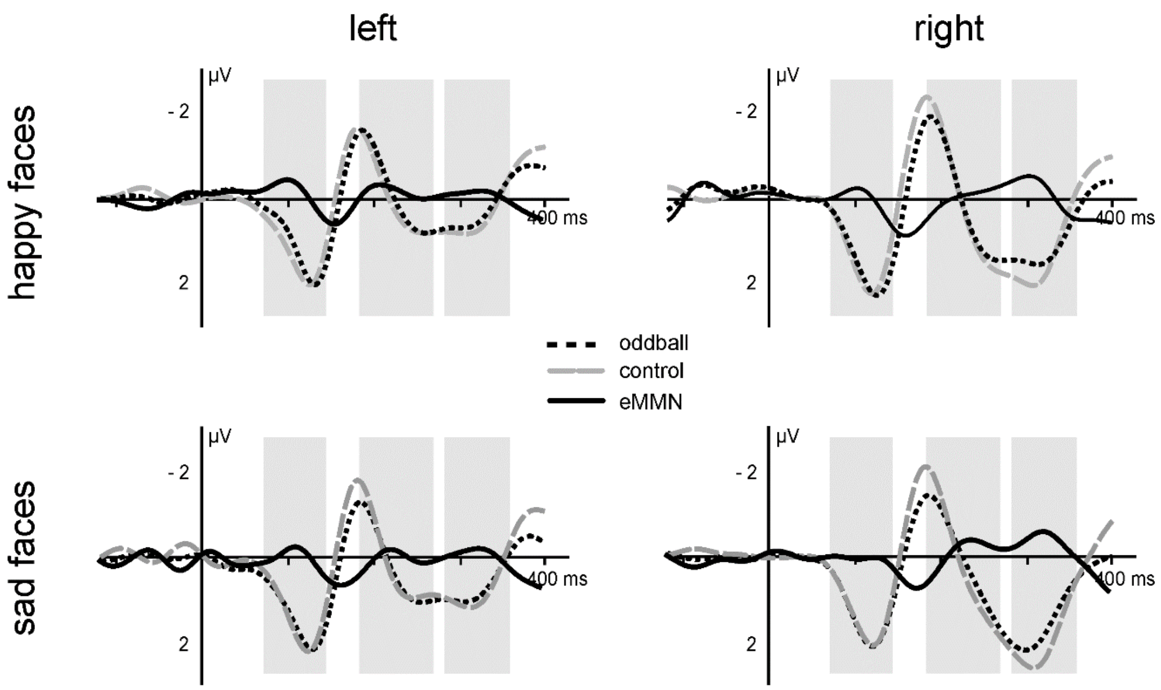

Figure 4. Three time windows resulting from hand condition. Electrophysiological responses to happy (upper) and sad (lower) faces for left (left) and right (right) hemisphere during the oddball (dotted black) and control (dashed gray) sequence and the resulting eMMN (black) for the hand condition. By visual inspection, three time windows (gray area) were extracted for further analyses reaching 70–140, 180–270, and 280–360 msec.

3.3. Results

As shown in Figure 5, facial muscle manipulation systematically influenced happy- and sad-eMMN. For further analysis, time windows were selected by visual inspection of happy- and sad-eMMN in the hand condition, resulting in three time windows (70-140, 180-270, and 280-360 msec).

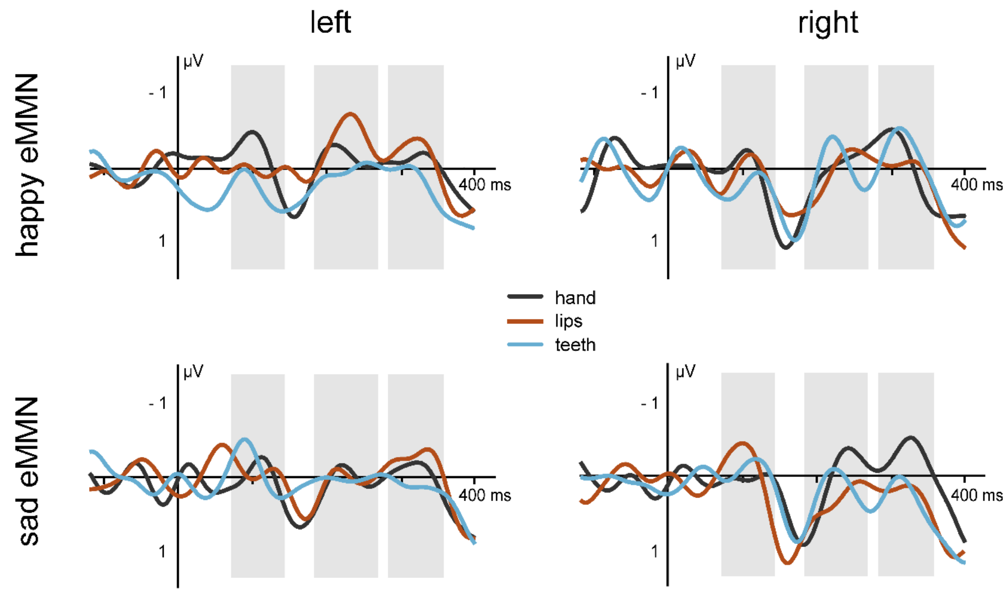

Figure 5. eMMNs for the different experimental conditions. eMMN to happy (upper) and sad (lower) faces at left (left) and right (right) hemisphere displayed for the hand (black), lip (red), and teeth (blue) condition. Gray areas represent range of analyzed time windows.

In the first time window (70-140 msec), analysis revealed a significant main effect of the factor Emotion, $F(1, 18) = 7.057$, $p = .016$, $\eta_p^2 = .282$, demonstrating more negative amplitude for sad-eMMN ($M = -0.55$, $SE = 0.09$) than for happy-eMMN ($M = -0.31$, $SE = 0.07$; see Figure 6). Furthermore, analysis revealed a significant interaction between Emotion × Facial Muscle Manipulation, $F(2, 36) = 3.297$, $p = .048$, $\eta_p^2 = .155$, as well as a Hemisphere × Emotion × Facial Muscle Manipulation interaction, $F(2, 36) = 3.510$, $p = .04$, $\eta_p^2 = .163$. Post hoc comparisons demonstrated stronger influence of facial muscle manipulation at left hemisphere. Although the sad-eMMN increased during the teeth condition ($M = -0.91$, $SE = 0.19$) compared with the hand ($M = -0.34$, $SE = 0.15$; $t(18) = 2.731$, $p = .014$, $p < .05$ FDR corrected) and the lip condition (M =−

0.49, SE=0.16; t(18)=2.385, p = .028, p < .05 FDR corrected), the happy-eMMN showed a trend for the opposite effect with a decrease during the teeth condition (M = −0.05, SE = 0.21) compared with the hand condition (M = −0.64, SE = 0.20; t(18) = −2.011, p = .06, uncorr.).

During the second time window (180-270 msec), statistical analysis revealed a significant interaction between the factors Emotion × Facial Muscle Manipulation, F(2, 36) = 3.153, p = .05, η_p^2 = .149. This interaction was driven by a significant increase of the sad-eMMN during the teeth condition (M = −0.72, SE = 0.16) compared with the lip condition (M = −0.30, SE = 0.13; t(18) = 2.361, p = .03, p < .1 FDR corrected; see Figure 7). Neither main effects nor interactions were observed in the third time window.

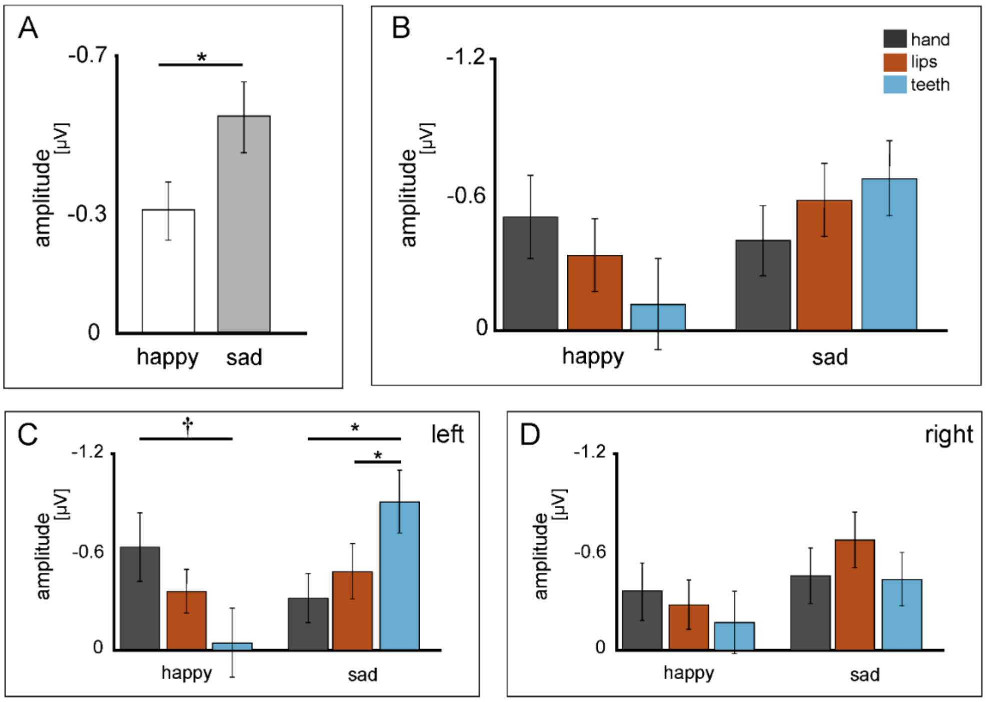

Figure 6. Overview of statistical effects within the first time window. **(A)** eMMN for happy (white) and sad (gray) faces over all facial muscle manipulation conditions. **(B)** eMMN for happy (left) and sad (right) faces plotted for each facial muscle manipulation condition. **(C)** Influence of facial muscle manipulation on happy (left) and sad (right) faces at left hemisphere. **(D)** Influence of facial muscle manipulation on happy (left) and sad (right) faces at right hemisphere. Facial muscle manipulation conditions: gray, hand; red, lips; blue, teeth. †p ≤ .06, * p < .05 FDR corrected.

In summary, results demonstrate that facial muscle manipulation influenced the automatic processing of changes in emotional expressions. The activation of facial muscles responsible for smiling (teeth condition) increases sad-eMMN and decreases happy-eMMN during a 70-140 msec (see Figure 6) and a 180-270 msec period (see Figure 7).

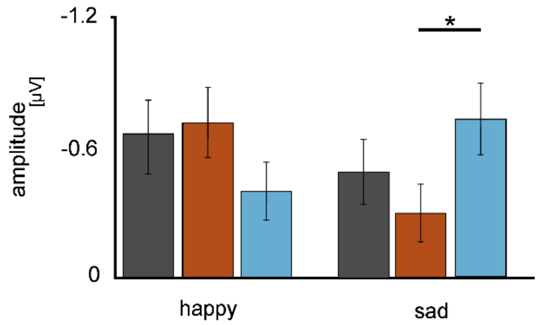

Figure 7. Overview of statistical effects within second time window. Influence of facial muscle manipulation on happy (left) and sad (right) faces for different facial muscle manipulation conditions: gray, hand; red, lips; blue, teeth. *p < .05 FDR corrected.

3.4. Discussion

This study highlights the impact of facial feedback on automatic processing of emotional facial expressions. During a visual emotional oddball paradigm, participants' attention was directed to a centrally presented fixation cross while face pairs of divergent emotions were shown at periphery. Facial feedback was manipulated by the different facial muscle manipulation conditions – holding the pen with the teeth activated muscles responsible for smiling, whereas holding a pen with the lips inhibited these facial muscles; holding the pen with the nondominant hand served as a control condition, allowing for free facial mimicry.

As hypothesized, electrophysiological data revealed an effect of facial feedback manipulation on eMMN components. Especially the activation of facial muscles responsible for smiling interfered with the automatic processing of emotional facial expressions. In particular, the activation of facial muscles responsible for smiling (teeth condition) increased eMMN to sad faces (first and second time window) and decreased eMMN to happy faces (first time window). No effects of facial feedback manipulation were observed for the late eMMN. However, because the current study is the first to report these effects with a relatively small sample size, future studies are needed to replicate the present results to make reliable conclusions.

Generally, our data revealed visually evoked eMMN responses to facial deviants in three different time intervals – an early time interval lasting from 70 to 140 msec, one middle time interval from 180 to 270 msec, and a late time interval from 280 to 360 msec at posterior sites. These time intervals are consistent with previous literature (Csukly et al., 2013; Stefanics et al., 2012; Wu et al., 2017), confirming that visually evoked mismatch responses to changes in emotional expressions can be reliably measured within these periods. However, although a study by Stefanics et al. (2012) reported an early eMMN for fearful faces only, we additionally found an early mismatch response (70-140 msec) to happy and sad faces, indicating that automatic face processing generally starts as early as 70 msec, like in potentially threatening stimuli. Different implementations to investigate the eMMN exist. These differences concern the emotion categories for standards and deviants, the central task, and the use of an additional control block. Based on these variations, studies provide partially diverging results, making it difficult to make general statements about the timing of automatic emotional processing (I. Czigler, 2014). Nevertheless, several studies consistently revealed a comparable early onset of the deviant-related negativity around 110 msec (e.g., Kovarski et al., 2017; Li, Lu, Sun, Gao, and Zhao, 2012; Susac, Ilmoniemi, Pihko, Ranken, and Supek, 2010; Wei, Chan, and Luo, 2002; Zhao and Li, 2006), supporting our finding of an early regularity violations detection in the visual system.

Effects of Facial Feedback on Happy- and Sad-eMMN

Importantly, in this study, the facial feedback manipulation differentially affected eMMNs to happy and sad faces. The activation of muscles responsible for smiling (teeth condition) increased sad- and decreased happy-eMMN. These results fit well with the facial feedback hypothesis – facial feedback influences ongoing emotional experience. Mood modulation by facial muscle manipulation was already observed by J. D. Laird (1974) where participants asked to contract muscles responsible for smiling described themselves as happier, whereas participants asked to contract muscles activated while frowning described themselves as angrier. Further studies support the role of facial feedback on emotional affect. Facial feedback manipulations influence participants' funniness rating on cartoons (Strack et al., 1988) as well as their sadness ratings of aversive photographs (Larsen, Kasimatis, & Frey, 1992). Clinical studies on depression provide further evidence for the influence of facial mimicry on emotional experience. In recent studies, depression was treated with botulinum toxin injection to the glabellar region (Finzi & Wasserman, 2006; Wollmer et al., 2012) and to the corrugator and procerus muscles (Finzi & Rosenthal, 2014) – muscles mainly activated while expressing anger, sadness, and fear. Both studies determined an antidepressant effect of the botulinum toxin injections by preventing their muscle contraction in these regions. In accordance with the facial feedback hypothesis, decreased negative facial expressions reduce the negative proprioceptive feedback from these regions, thus improving the positive feedback and the mood.

In accordance with these studies of facial feedback manipulation, holding a pen with the teeth increases positive facial feedback and thereby reinforces a happy emotional experience, whereas holding a pen with the lips inhibits facial feedback from muscles responsible for smiling and thus reduces positive facial feedback and consequently happy emotional experience. With regard to eMMN signal, it is conceivable that rarely presented happy and sad faces may additionally pose a mismatch to our own emotional experience. Thus, when we experience happiness (e.g., in the teeth condition), sad faces will constitute a greater mismatch, whereas happy faces fit more with our present emotional experience and thus produce a smaller mismatch.

Alternatively, the influence of our emotional experience on happy- and sad-eMMN could be explained by priming effects. Recently, it has been shown that affective priming influences emotional face processing (e.g., Hietanen and Astikainen, 2013; Hirai, Watanabe, Honda, Miki, and Kakigi, 2008). In the study by Hirai et al., 2008, the presentation of emotional facial expressions was primed with congruent or incongruent stimulus scenes. A larger P2 amplitude for fearful faces was observed when the faces were cued by fearful scenes compared with neutral scenes, and likewise, a larger P2 for neutral compared with fearful faces was found when they were cued by neutral scenes. Considering that neutral faces in general elicit a larger P2 amplitude compared with fearful faces, the authors suggest that congruent priming of fearful faces results in a relative shift of fearful face processing to neutral face processing (Hirai et al., 2008). In the same vein, Hietanen and Astikainen (2013) observed an analogous effect on happy and sad faces in an earlier time window. The N170 to happy faces was increased when preceded by happy scenes, whereas the N170 to sad faces was increased when they were primed by negative scenes. Thus, in this study, the emotional experience induced by facial feedback might constitute an affective prime. Thus, the activation of facial muscles responsible for smiling (teeth condition) reinforces the positive facial feedback and constitutes a positive prime, whereas the inhibition of those muscles reduces positive feedback and constitutes a negative prime. Accordingly, the positive congruent prime (teeth condition) might have shifted the processing of happy faces to neutral face processing, and consequently, these happy deviants will pose a smaller mismatch signal to the neutral standard faces. This interpretation is consistent with the degree of deviance effect (István Czigler, Balázs, & Winkler, 2002). This effect indicates that the difference between standard and deviance stimuli must be large enough for visual change detection. Thus, only a small difference between standard and deviant stimuli will be insufficient to elicit a vMMN signal. By assuming that the teeth condition and the resulting positive facial feedback shifts the processing of happy faces toward neutral faces, the difference between neutral standards and happy deviants becomes smaller and leads to the decrease in happy-eMMN amplitude. Further research will be required to investigate the influence of mood on affective priming and subsequent processing of facial expressions of emotions.

From another perspective, simulating emotional and cognitive states of others in social communication helps us to make predictions about their emotional states and intentions (Preston & de Waal, 2002).

In the light of prediction error theories, it has been supposed that our brain permanently adapts the model of its environment by comparing actual sensory inputs with predicted inputs and calculating the resulting prediction error. Depending on the reliability and level of information of the actual input, the size of the effect of the prediction error on the updated model can be different. This effect size is expressed by the precision-weighted prediction error (pwPE; den Ouden, Kok, and de Lange, 2012; Friston, 2005). Such brain model mechanisms also exist for the perception of facial emotional expressions. In a recent study, Stefanics, Stephan, and Heinzle (2019) combined computational models with fMRI measurements to investigate whether violations of different features – either emotional facial expression or color of the face – of the same stimulus activates different pwPEs. In contrast to unexpected color change, unexpected change of facial expressions of emotions elicited pwPE responses, among others, within bilateral cerebellum, lingual gyrus, precuneus, left thalamus, right supramarginal gyrus, and right posterior medial frontal cortex. Especially the activation within precuneus (Schilbach, Eickhoff, Mojzisch, & Vogeley, 2008) and cerebellum is strongly correlated with facial mimicry during the observation of facial expressions. Thus, it might be assumed that induced positive (teeth) and negative (lips) facial feedback operates as positive and negative prime and thereby activates those areas and consequently might change pwPEs to unexpected emotional changes. Further research is needed to investigate the influence of facial mimicry manipulation on pwPEs to unexpected changes of facial emotional expressions.

Our observations of opposite effects of facial feedback manipulation on happy- and sad-eMMN could be a consequence of altered encoding and retrieval skills of emotional information. It has been shown that emotions prime related perceptual codes in memory leading to facilitated encoding of emotion-congruent information. In a study by Niedenthal, Setterlund, Halberstadt, and Marc (1997), the categorization of emotional words was faster when the words were congruent to a prior induced emotional state of the participants. The authors assume that emotions activate emotion-related lexical codes, which in turn facilitate emotion-congruent word recognition. Furthermore, facial expressions facilitate recall of emotion-congruent information (James D Laird, Wagener, Halal, & Szegda, 1982). In this study, the recall of a text was facilitated when facial muscle manipulation was congruent to the emotional content of this text, which further supports the influence of facial mimicry on memory. The auditory as well as vMMN is thought to be elicited by regularity violations and reflects prediction error signals based on memory comparison processes (I. Czigler, 2014; Näätänen, Paavilainen, Rinne, & Alho, 2007). Recently, combined computational and empirical research supports the assumption that the expression-related vMMN attributes to similar processes as the well-investigated auditory MMN (Stefanics, Heinzle, Horvath, & Stephan, 2018). Thus, we can assume that contracting facial muscles responsible for smiling primes the activation of positive emotional information and thereby facilitates the encoding and retrieval of happy facial expressions. Albeit rare in appearance, the emotional valence of happy faces is stored more effectively in memory than those of sad faces during the teeth condition, and thus, rare happy faces might produce a lower mismatch signal. In contrast, the emotional valence of sad faces is stored less effectively because of the conflicting own posed happy facial expression and consequently is poorly retrieved leading to a higher mismatch signal. In this regard, facial feedback may act as an emotional prime, thereby facilitating the storage of emotion-congruent information and influence the automatic processing of emotional expression.

Not only memory encoding but also already low-level neural encoding of facial expressions is influenced by emotions. In a study by Sel et al. (2015), participants had to adopt different facial expressions while measuring their visual evoked potentials during a facial emotion judgment task. This resulted in modulation of the facespecific N170 to neutral faces during adopting a happy facial expression and indicated that neutral faces are processed similarly to happy facial expressions. The authors conclude that the low-level neural encoding of facial expressions can be influenced in a top-down manner by the own facial expressions. In this respect, it might possible that our facial feedback manipulation also affected the processing of the neutral standard stimuli. Following the conclusions of Sel et al. (2015), the teeth condition in this study could have led to similar processing of neutral and happy faces, which in turn would result in smaller mismatch responses for happy but increased mismatches for sad facial expression. Thus, our facial feedback manipulation would have affected the neutral standard rather than the emotional deviants per se. Although we cannot completely rule out this conclusion, we minimized potential effects of the standard stimuli by using an emotional control condition (comparable with Kimura et al., 2012; Kovarski et al., 2017; Li et al., 2012; Stefanics et al., 2012) to calculate the eMMN signal.

3.5. Conclusion

In summary, our findings demonstrate that our own facial expressions have a strong influence on the automatic neural processing of others' facial expressions. Although there is clear evidence that facial mimicry and the resulting feedback can influence the conscious perception and processing of facial emotional expressions on a behavioral as well as on neurophysiological level, this study demonstrates for the first time the influence of facial feedback on automatic, nonconscious processing. Especially when participants activate their facial muscles responsible for smiling, the mismatch response to unattended rare happy facial expressions decreases, whereas the mismatch response to rare sad facial expressions increases. Thus, our results strongly support previous findings on the influence of facial feedback on the processing of facial expressions. However, further research is needed to determine the precise processes behind the influence of facial feedback on the processing of unattended facial expressions.

4. Project 2

From Mimicry to Memory: The Impact of Facial Mimicry on Emotional Working Memory

Specific aim:

In this project, I want to investigate whether facial feedback influences the memory for facial emotional expressions.

The content of this chapter has been submitted to a peer-reviewed journal.

ABSTRACT

The recognition and storage of facial emotional expressions of our conspecifics constitutes an important human skill essential for a successful social interaction in daily living. While previous research revealed that facial mimicry can influence the recognition of facial emotional expressions, the question whether facial mimicry also influences memory processes of facial emotional expressions remains unsolved.

In the present study, I investigated the impact of a facial mimicry on the performance in an emotional visual working memory (WM) task. For this purpose, 37 participants underwent a classical facial mimicry manipulation (FMM) (holding a pen with the teeth – inducing a smiling expression vs. holding a pen with the non-dominant hand – as a control condition) while they performed a WM paradigm on varying intensities of happy or sad facial expressions. Results show that the smiling mimicry condition improved memory performance selectively for happy faces especially when high ambiguous facial expressions had to be remembered. Furthermore, I found that, in addition to an overall negative bias for happy faces compared to sad faces, FMM induced a general positivity bias in representing emotional facial information in WM. Finally, data demonstrate a higher vulnerability of male participants to be affected by FMM. During induced smiling mimicry especially males remembered faces less negative. These data demonstrate that the mimicry of the observers does not only influence our recognition but also systematically alters our memory of the facial emotional expressions of our conspecifics.

4.1. Introduction

In social interactions, facial expressions represent an important information medium as they can transmit internal states like motivations and feelings of our conspecifics. In return, these facial expressions are mimicked, often involuntary (e.g. U. Dimberg, 1990; U. Dimberg and Thunberg, 1998). Generally, this mimicry process appears to be automatic and can occur without attention (U. Dimberg et al., 2000). Even infants begin to imitate facial gestures only a few hours after birth (Meltzoff & Moore, 1983). Theories of embodied simulation assume that the mimicked facial expression and the resulting facial feedback from the facial muscles trigger a corresponding state in the observer's motor, somatosensory, affective and reward system, helping to decode and understand the meaning of the perceived expression (Niedenthal et al., 2016). While some studies investigated the mimicry of the observer itself by electromyographic measures (e.g. U. Dimberg and Thunberg, 1998; Korb, With, Niedenthal, Kaiser, and Grandjean, 2014; Künecke, Hildebrandt, Recio, Sommer, and Wilhelm, 2014; Sato, Fujimura, Kochiyama, and Suzuki, 2013) several further investigations experimentally manipulated the mimicry processes to investigate its impact on the processing of emotional stimuli (e.g. Lobmaier and Fischer, 2015; Lindsay M Oberman et al., 2007 Neal and Chartrand, 2011).

The classical facial mimicry manipulation method was first introduced by Strack et al. (1988). Here, participants had to hold a pen in different ways with their mouth. The underlying principle behind this approach is that different pen holding conditions differentially activate facial muscles essential for smiling. In particular, when participants have to hold a pen with their teeth they need to activate the Musculus zygomaticus major and the M. risorius – both also activated while naturally smiling. In contrast, when participants have to hold a pen with their lips they activate the M. orbicularis oris, which contraction is incompatible with smiling. During the last 2 decades, research provided ample evidence that such facial mimicry manipulation influences the consciousness processing of emotional facial expressions (e.g. Lobmaier and Fischer, 2015; Niedenthal et al., 2001; Ponari et al., 2012) as well as the automatic processing of unattended facial emotional expressions (M. Kuehne, I. Siwy, T. Zaehle, H. J. Heinze, & J. Lobmaier, 2019). Recently, we investigated the impact of facial mimicry on the automatic processing by electrophysiological measurements of the expression-related mismatch negativity (eMMN). Facial mimicry manipulation was implemented by different pen holding conditions equivalent to the study by Strack et al. (1988). While the results demonstrated that in particular the smiling condition differently influences the automatic processing of happy and sad facial expressions, the affected underlying cognitive process remained elusive. Among other opportunities, we supposed that the facial mimicry manipulation might have influenced the encoding and retrieval of happy and sad facial expressions. In such a way, the smiling facial mimicry condition might have facilitated the encoding of happy and contrarily impeded the encoding of the sad faces. Therefore, emotional valence of the happy face might have been stored more effectively (M. Kuehne et al., 2019).

However, there is a considerable lack of research assessing the influences of facial mimicry on the storage and retrieval of emotional stimuli - especially facial emotional expressions. One recent study by Pawling, Kirkham, Hayes, and Tipper (2017) evidenced that during the visual re-exposure to a facial expression of certain identity the corresponding mimicry is re-activated similar to the initial exposure. Interestingly, this emotional mimicry re-activation also occurs when the same face identity was displayed with a neutral expression during the re-exposure in contrast to an initially displayed emotional expression. These results are in accordance with the reactivation account of memory indicating that the same brain regions are reactivated during retrieval that were engaged during the process of encoding (for review see Danker and Anderson, 2010).

To examine the role of facial mimicry for memory to emotional facial expressions we conducted a facial mimicry manipulation study in the context of an emotional working memory task. Mimicry manipulation was administered following Strack et al. (1988). We applied the smile inducing condition, where participants had to hold a pen with their teeth and compared this manipulation with a neutral control condition (holding the pen with the non-dominant hand). Memory performance was investigated by a modified form of an emotional working memory (WM) paradigm with facial expressions that allows to separate overall WM accuracy from emotional biases (Mok, Hajonides van der Meulen, Holmes, & Nobre, 2019). Here, the participants' task is to encode, maintain and subsequently retrieve the valence as well as the intensity of happy and sad facial expressions. In accordance with the study by Mok et al. (2019) we expect that the emotional intensity levels will affect memory performance, with better performance for less ambiguity emotional expressions. Further, we predict that the facial mimicry manipulation will affect memory performance. Finally following several data pointing on the impact of gender on recognition memory for faces (e.g. Wang, 2013, Rehnman and Herlitz, 2007), we assume that memory performance will differ between female and male participants and that, in consequence the effect of facial mimicry manipulation might be gender dependent.

4.2. Methods

Participants

We investigated 37 healthy participants (19 female, mean age 25 years ± 3.42). This study excluded participants with neurological diseases and neuropsychiatric diseases a priori. Participants had normal or corrected to normal vision and provided informed consent. At the beginning of each measurement, they filled in the short version of the *Allgemeine Depressionsskala* (ADS-K, self-report questionnaire measuring the impairment due to depressive symptoms during the last weeks, Hautzinger and Bailer (1993)). Additionally, participants were asked to complete the *Implicit Positive and Negative Affect Test* (IPANAT, measuring implicit positive and negative affect as well as state variance, Quirin, Kazén, and Kuhl (2009)). They filled in the IPANAT three times, before, after and in between the experiment. All sample characteristics are presented in

The study and its experimental procedures were conducted in accordance with the Declaration of Helsinki (1991; p. 1194) and were approved by the local Ethical Committee of the University of Magdeburg.

Table 3. Sample Characteristics

Measure (n = 37)	*M(SD)*	*Range*
Age	25 (3.42)	18 – 34
ADS-K	7.35 (3.92)	1 – 15
IPANAT		
1	2.15_{PA} (0.39)	1 – 3
	1.82_{NA} (0.51)	1 – 3
2	2.24_{PA} (0.41)	2 – 3
	1.68_{NA} (0.42)	1 – 3
3	2.15_{PA} (0.48)	1 – 3
	1.77_{NA} (0.38)	1 – 3

Age in years, ADS-K, IPANAT before (1), during (2) and after (3) the emotional WM task separately for positive affect (PA) and negative affect (NA). Additional analysis with ADS-K as well as with IPANAT as covariate is documented in *Appendix B* and *Appendix C*.

Stimuli and Procedure

At the beginning, participants read the instruction of the task and filled in the questionnaires. During the experiment participants performed an emotional WM task (converted form of Mok et al., 2019). For this, 6 female and 7 male characters, each with 3 different emotional expressions (neutral, happy and sad), were taken from the NimStim Set of Facial Expressions (Tottenham et al., 2009) and from the Karolinska face data-base (Lundqvist, 1998)[1]. All stimuli were edited with GIMP software (Version 2.10.6). To avoid low-level visual influence the hair region of each character was cut

[1] Stimuli from NimStim Set of facial Expressions: 01F, 02F, 03F, 05F, 07F, 09F, 20M, 21M, 23M, 29M, 32M, 34M
Stimuli from Karolinska face data-base: AM14
Characters were equally assigned to different pen holding conditions (3male/female for hand and 3 male/female for teeth; 1 male for practice)

out by putting an eliptic form around the head with grey background. From this elipitic form, a scrambled mask was created separately for each character by changing pixels into random colors thereby producing white noise (see Figure 8A). To familiarize the participants with the emotional WM task, they performed a practice trial before starting the main task. During the emotional WM task, participants had to encode, retrieve and maintain the emotion itself and the specific intensity of an emotional face while holding a pencil either with the teeth or with the non-dominant hand. The two pen holding conditions alternated over 12 different blocks. Each block consisted of 21 trials (overall 126 trials for each pen holding condition). Each trial began with a starting screen lasting until participants press the right mouse button. Thereafter the target image appeared for 500msec followed by the mask for 100msec. After a delay of 3000msec the test image was shown and participants had to give their response (see below). After an interval of 800msec the next trial started (see Figure 8A). The target image displayed a face with a specific intensity of either happy or sad emotion. For this purpose, morph sequences were created from neutral to happy and from neutral to sad emotional expressions in steps of 1% to 100% for each character with java psychomorph (version 6, Tiddeman, Burt, Perrett, and applications (2001)). For target images, intensities in 10% steps were used (0% happy/sad, 10% happy/sad, 20% happy/sad, 30% happy/sad, 40% happy/sad, 50% happy/sad, 60% happy/sad, 70% happy/sad, 80% happy/sad, 90% happy/sad, 100% happy/sad, see Figure 8B). During the task, each character was presented with each intensity step as target image. The test image was always the neutral face of the character. By scrolling the mouse wheel back and forth, participants had to adjust the emotion and the intensity of the emotion of the previous seen target face. All intensity levels from 0-100% were possible for the response selection (see Figure 8C). The response time window was restricted to 11s. There were 8 different versions of the task, varying the order of pen holding conditions (starting with hand or teeth), character allocation to pen holding conditions and mouse wheel settings (scroll up: face become more happy, scroll down: face becomes more sad or vice versa). The versions were pseudorandomly assigned to the participants.

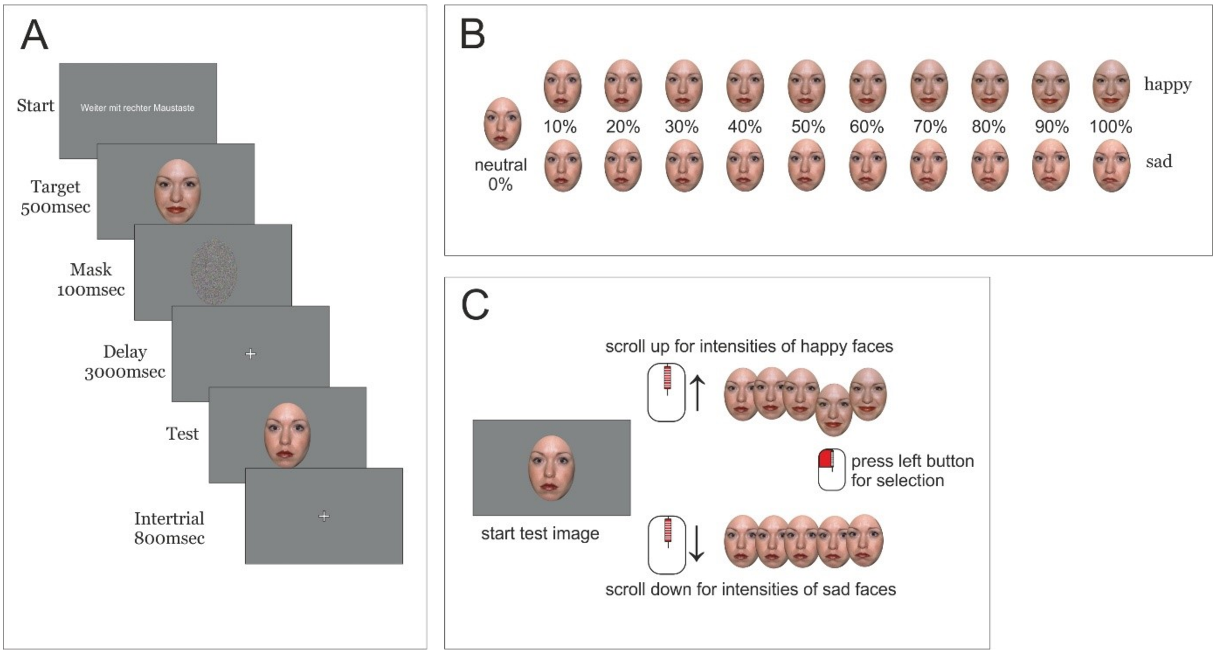

Figure 8. Task procedure of facial emotional WM task. On each trial, participants were asked to encode a target face into WM with an emotional expression (fearful or happy) with a certain emotional intensity. After a delay, participants used a mouse to adjust a facial expression to match the emotion type and intensity in memory. **(A)** Trial example. Each trial began with a starting image, present until participants push the right mouse button. The target image was displayed for 500msec followed by a mask image of 100msec. After a delay of 3000msec, the test image was shown and participants had to respond. After the response or after 11 seconds a fixation cross appeared for 800msec before the next trial started. **(B)** Target Image. The target image was either a happy or a sad emotional face at one of 11 intensity steps (neutral, 10,20,30,40,50,60,70,80,90,100% sad or happy). **(C)** Test Image. The test image always started with a neutral face. By using the mouse wheel, the participant had to adjust the remembered emotion and the intensity. Scrolling the mouse wheel changed the intensity of the emotional face continuously in steps of 1%. By pressing the left mouse button, the participant made their final selection.

Data Analysis

To investigate the influence of *facial mimicry manipulation* on emotional WM we assessed the quality of WM representations for emotional material and the systematic affective biases in perceiving and interpreting emotional material (Mok et al., 2019). Accordingly, we separately analyzed performance accuracy (categorical judgment of a happy or sad face) and emotional bias (representing information as more positive or negative) for the two pen holding conditions and the two facial emotions.

To characterize the accuracy of WM performance, we assessed the percent correct responses. A response was considered correct when participant adjusted a face to the correct emotion type (e.g., reporting a happy face as happy and a sad face as sad). To analyze the effect of ambiguity, the intensity levels were median-splitted in two equal bins of high and low ambiguity and percent correct responses were computed for each target emotion intensity bin.

The emotional bias represents the signed percentage deviation of the test image from the target image, such that negative values imply that participants remembered the emotion as less positive/more negative than the target image originally was and positive values imply that they remembered it as more positive/less negative (see *Appendix A* for formulas). Consequently, an emotional bias of -5% would indicate that a target image is remember 5% less positive/more negative than it originally was. After calculating the percentage deviation, an outlier analysis was performed on individual level for each participant separately for the two pen holding conditions (hand, teeth) and the two emotion conditions (happy, sad). Values exceeding ±2 standard deviations from the mean were excluded from further analysis.

Mean percent correct responses were entered into a repeated measures (RM) -ANOVA with the within-participant factors *Facial Muscle Manipulation* (hand vs. teeth), *emotion* (happy vs. sad) and *ambiguity* (high vs. low) and *gender* (male vs. female) as between-participant factor. Data of the emotional bias were entered into a RM-ANOVA with the within-participant factors *Facial Muscle Manipulation* (hand vs. teeth), *emotion* (happy vs. sad) and *gender* (male vs. female) as between-participant factor. If necessary, Greenhouse-Geisser adjustment was used to correct for violations of sphericity. All significant interactions were post-hoc examined by using paired *t* tests. The statistical analysis was performed by using IBM SPSS (version 26).

4.3. Results

Accuracy of WM Performance

Figure 9A illustrates the percent correct responses for each emotional intensity separately for all emotions and mimicry conditions. The RM-ANOVA revealed a significant main effect of the factor *ambiguity* ($F_{1,35}$ = 487,407, P < .001, η_p^2 = 0.933). As can be seen in Figure 9B, memory accuracy was reduced for more ambiguous faces (faces with low intensity levels, M = 0.83, SD = 0.05), i.e. more often incorrectly remembered as the opposite emotion, than faces with a more explicit emotion (high intensity levels, M = 0.98, SD = 0.02). The RM-ANOVA further revealed a significant *Facial Mimicry Manipulation* x *emotion* interaction ($F_{1,35}$ = 4.293, P = .046, η_p^2 =0.109). Post-hoc comparisons showed that compared to the hand condition the teeth condition significantly increased the accuracy of happy faces only (M_{hand} = 0.90, SD_{hand} = 0.06, M_{teeth} = 0.92, SD_{teeth} = 0.04, t(36) = -2.537, P = .016, d = -0.392) while there was no influence of *Facial Mimicry Manipulation* on correct responses to sad faces (M_{hand} = 0.90, SD_{hand} = 0.06, M_{teeth} = 0.89, SD_{teeth} = 0.08, t(36) = 0.808, P = 0.424, d = 0.141, see Figure 9C). Finally the ANOVA revealed a significant *Facial Mimicry Manipulation* x *emotion* x *ambiguity* interaction (F1,35 = 4.429, P = 0.043, η_p^2 0.112). A subsequent step-down analysis by means by the factor *ambiguity* revealed a significant *Facial Mimicry Manipulation x emotion* interaction (F1,36 = 4.447, P = 0.042, η_p^2 = 0.110) for high ambiguous emotional faces due to a significant increase of correct responses in the teeth compared to the hand condition only to happy (M_{hand} = 0.81, SD_{hand} = 0.11, M_{teeth} = 0.86, SD_{teeth} = 0.08, t(36) = -2.665, P = .011, d = -0.520) but not to high ambiguous sad faces (M_{hand} = 0.83, SD_{hand} = 0.10, M_{teeth} = 0.81, SD_{teeth} = 0.14, t(36) = 0.909, P = 0.369, d = 0.164,). In contrast, the RM-ANOVAs for the low ambiguous emotional faces revealed no significant effect of the factor FMM or its interactions (all Ps>.8).

The results were similar without grouping the intensity levels into high and low ambiguity, showing a significant main effect of the factor *intensity level* ($F_{3.907,136.737}$ = 211.870, P < .001, η_p^2 = 0.858) a significant *Facial Mimicry Manipulation* x *emotion* interaction (F1,35 = 4.293, P = .046, η_p^2 =0.109) as well as an trend for a *Facial Mimicry Manipulation* x *emotion* x *intensity level* interaction (F3.779, 132.268 = 2.323, P = .063, η_p^2 = 0.062).

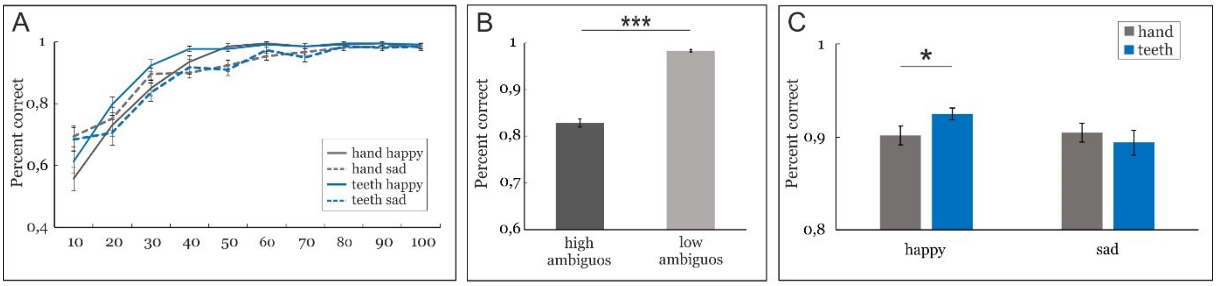

Figure 9. Accuracy of WM Performance. (**A)** Percent correct responses for each emotional intensity during the hand condition for happy (solid grey) and sad (dashed grey) faces and during the teeth condition for happy (solid blue) and sad (dashed blue) faces. (**B)** Percent correct responses for high (left) and low (right) ambiguous emotional faces. In comparison to low ambiguous faces, memory accuracy for high ambiguous faces was significantly reduced. (**C)** Percent correct responses across all intensity levels for happy (left side) and sad (right side) faces during the hand (grey) and teeth (blue) Facial Mimicry Manipulation condition. Whereas Facial Mimicry Manipulation did not influence the memory accuracy to sad faces, FMM improved the accuracy for happy faces during the teeth condition. Happy faces are more often correctly remembered as happy compared to the hand condition. Error bars represent standard errors (SE). *** $p < .001$, * $p < .05$.

Emotional Bias

Figure 10 illustrates the results for the emotional bias. The RM-ANOVA revealed significant main effects of the factors *Facial Muscle Manipulation* ($F_{1,35}$ = 5.010, P = .032, η_p^2 = 0.125) and *emotion* ($F_{1,35}$ = 7.288, P = .011, η_p^2 = 0.172) as well as a significant interaction between *Facial Muscle Manipulation* and *gender* ($F_{1,35}$ = 5.260, P = .028, η_p^2 = 0.131). The main effect of *emotion* results from a generally more negative bias for happy faces (M = -4.39, SD = 6.88) compared to sad faces (M = 1.19, SD = 7.47, t(36) = -2.738, P = .01, d = 0.778) (see Figure 10A). Thus, happy faces were remembered as less positive/more negative than their related target images initially were. The main effect of *Facial Muscle Manipulation* is shown in Figure 10B. Independent of the emotion, the teeth condition reduced the negative bias, i.e. faces were remembered more positive when participants hold the pen with the teeth (M = -0.91, SD = 4.54) compared to the hand condition (M = -2.29, SD = 3.72, t(36) = -2.057, P = .047, d = -0.333).

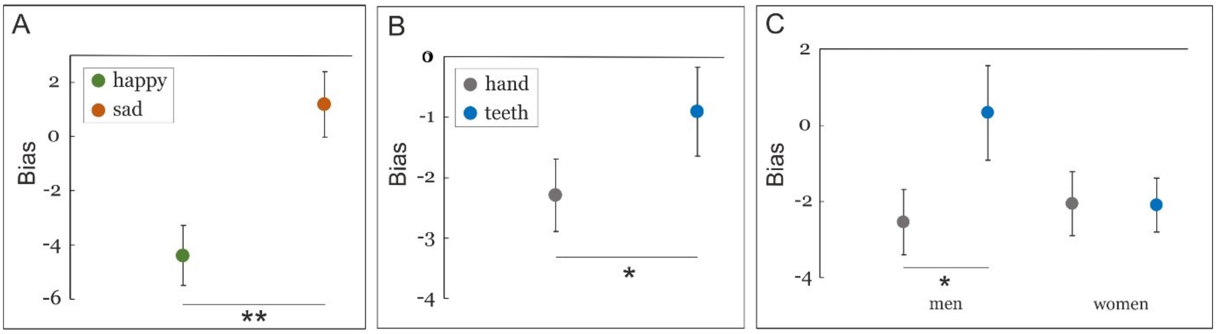

Figure 10. Emotional bias for working memory task. **(A)** Effect of emotion. Happy faces (green) are remembered as more negative compared to sad faces. **(B)** Effect of Facial Mimicry Manipulation. Independent of the emotion, emotional faces are remembered more positive/less negative during teeth (blue) than during the hand (grey) condition. **(C)** Emotional bias for male (left side) and female (right side) participants for the hand (grey) and teeth (blue) Facial Mimicry Manipulation condition. Specifically male participants remembered faces more positive during the teeth compared to the hand condition. Error bars represent standard errors (SE). * p < .05, ** p ≤ .01.

To further examine the *Facial Muscle Manipulation* x *gender* interaction post hoc comparisons between the hand and the teeth conditions were conducted separately for male and female participants. While in male participants the teeth condition significantly lowered the negative bias compared to the hand condition (M_{hand} = -2.54, SD_{hand} = 4.27, M_{teeth} = 0.22, SD_{teeth} = 5.62, t(17) = -2.473, P = 0.024, d = -0.553) there was no influence of the Facial Muscle Manipulation in female participants (M_{hand} = -2.37, SD_{hand} = 4.70, M_{teeth} = -2.16, SD_{teeth} = 3.81, t(17) = -0.295, P = 0.771, d = -0.049; see Figure 10C).

4.4. Discussion

Recently, several studies have shown that Facial Muscle - and thus Facial Mimicry Manipulation influences the conscious as well as automatic processing of emotional faces on a behavioral and electrophysiological level. However, it is still unclear whether these data can be solely attributable to influences on a perceptional level or whether other cognitive processes are directly altered as well. To investigate the impact of Facial Muscle Manipulation on memory processes for emotional faces we conducted a facial emotional WM paradigm while participants hold a pen either with the teeth or with the non-dominant hand. These two pen-holding conditions lead to a smiling mimicry manipulation (teeth) or serve as control condition (hand). Generally, our data show that the smiling mimicry condition improved the memory performance selectively for happy faces especially when high ambiguous facial expression had to be remembered. Furthermore, we found that, in addition to an overall negative bias for happy faces compared to sad faces, facial mimicry manipulation induced a general positivity bias in representing emotional facial information in WM. Finally, data demonstrate a higher vulnerability of male participants to be affected by facial mimicry manipulation; during smiling mimicry especially males remembered faces less negative.

Data of the present study are generally in line with the results of previous reports using an comparable WM design (Mok et al. (2019)). As assumed, we also showed that emotional faces of low intensity/high ambiguity are remembered more often incorrectly as the opposite emotion compared to faces with more clear emotions. According to these authors, this might be attributed to the fact that facial expressions of low intensities are generally more difficult to recognize. Accordingly, analogous recognition difficulties of low-intensity emotional expressions have already been shown by Montagne, Kessels, De Haan, and Perrett (2007) applying an emotion recognition task with morphed intensity levels.

Furthermore, our data revealed a generally stronger negative bias for happy faces as for sad faces. Such negative memory bias was also reported by Mok et al. (2019) in young participants. However, in contrast to the present study they reported that fearful faces were remembered as more fearful while there was no effect for happy faces. Negative memory bias is consistently reported in depressed and dysphoric participants with better memory performance to sad faces and inferior memory to happy faces (e.g. Jermann, van der Linden, and D'Argembeau, 2008; Linden, Jackson, Subramanian, Healy, and Linden, 2011; Ridout, Astell, Reid, Glen, and O'Carroll, 2003). However, the present results cannot be explained by subtle depressive symptoms as indexed by statistical analysis of the ADS-K questionnaire (see *Appendix B*, Influence of Depressive Symptoms).

Facial Muscle Manipulation Influence on WM

Importantly, our results demonstrate - for the first time - that Facial Muscle Manipulation systematically influences WM performance for facial emotional stimuli. In contrast to the control manipulation condition, the smiling mimicry condition improved the memory performance selectively for happy faces and induced a general positivity bias in representing information in WM independent from the emotional quality.

Numerous previous studies evidenced facial mimicry and thus facial feedback as an important factor for the processes of emotional stimuli recognition in general (Söderkvist et al., 2018) as well as recognition of facial emotional expressions in particular (e.g. A. Hennenlotter et al., 2009; Kim et al., 2014; Lobmaier and Fischer, 2015; Neal and Chartrand, 2011; Niedenthal et al., 2001; Lindsay M Oberman et al., 2007; Sel et al., 2015). It is thought that facial mimicry supports embodied simulation processes: the perception of an emotional expression results in an internal simulation of a relating affective state by the activation of corresponding motor, somatosensory, affective and reward systems which in turn helps to understand the meaning of the expression (Niedenthal et al., 2010).

To date, there is a considerable lack of research assessing the influences of facial mimicry on the emotional memory. Accordingly, we can only speculate on the memory-linked underlying processes:

It might be assumed that the observed effect of FMM is related to general mood modulation processes. Thus, the smiling mimicry manipulation might have activated the corresponding affective system in the participants and consequently resulted in a positive mood, which in turn could help to store congruent information in memory. Previous studies consistently demonstrated that facial mimicry manipulation can systematically induce and modulate mood (e.g. Kleinke, Peterson, and Rutledge, 1998; J. D. Laird, 1974; Larsen et al., 1992). Further, some evidence has been provided that mood itself can influence memory performance (Bower, 1981; James D Laird et al., 1982). A mood-congruent memory effect is additionally supported by results demonstrating a tendency for better recalling information that is congruent to the current mood in depressed and anxious participants (Ridout et al., 2003; Russo et al., 2006; Watkins, Mathews, Williamson, & Fuller, 1992). In the present study, we additionally assessed the influence of facial mimicry manipulation on the participants affect by asking them to fill out the IPANAT (Baron-Cohen & Wheelwright, 2004) before starting with the paradigm, at the middle of the testing session after smiling manipulation, and after the end of the testing block. Indeed the smiling manipulation significantly decreases the negative affect of the participants while the positive affect remained unchanged by mimicry manipulation (see *Appendix C*, Influence of Emotional State). However, as the IPANAT does not measure explicit mood but rather affective trait and state, it provides only indirect evidence for how the facial mimicry manipulation might have influence the mood of the participants.

However, one might also argue against this general mood inducing effects. There is compelling evidence that happy mood triggers a global and automatic while sad mood triggers a more local and analytic processing style in different domains (Bless et al., 1996; de Vries, Holland, & Witteman, 2008; Gasper & Clore, 2002). Following this, the smiling manipulation conditions might have caused a positive mood and, accordingly triggered a more global and automatic processing style in the participants. However, in the present task for memorizing facial emotional expressions at different intensity levels, a local, more analytical processing style might have been in favor to a more global automatic processing style to allow for the processing of more subtle differences between the intensity levels. Thus, while the present facial mimicry manipulation might evoked mood changes, these mood changes may not fully explain the observed results.

Alternatively, the influence of Facial Muscle Manipulation can also be explained on a more neural level. As mentioned above, the reactivation account of memory assumes that remembering of an information activates the same brain regions that were already engaged during the encoding phase. One might speculate that the facial mimicry manipulation in the present study primed the related brain regions which were active during a smiling expression and - most importantly - which were also active during the storage and the retrieval of related information like the memory of an smiling facial expression. In the past, few imaging studies provided information about the brain regions involved in WM processes of emotional faces (LoPresti et al., 2008; Neta & Whalen, 2011; Röder, Mohr, & Linden, 2011; Sergerie, Lepage, & Armony, 2005). These studies found frequently activation within frontal areas, especially within the dorsolateral prefrontal and orbitofrontal cortex (dlPFC, OFC), as well within the superior temporal sulcus (STS) and the amygdala. Generally, the dlPFC plays a fundamental role within the WM network (e.g. Braver et al., 1997; Cohen et al., 1994; Petrides, 2000; Rypma and D'Esposito, 1999). Both, the OFC as well as the amygdala possess face-selective neurons (Leonard, Rolls, Wilson, & Baylis, 1985; Thorpe, Rolls, & Maddison, 1983) and their connective activity is thought to be responsible for differentiation of positive and neutral facial expressions from negative ones (Liang, Zebrowitz, & Aharon, 2009). Further, it is assumed that amygdala activation is related to enhanced memory for emotional stimuli (e.g. Adolphs, Tranel, and Denburg, 2000; Dolcos, LaBar, and Cabeza, 2004; Hamann, Ely, Grafton, and Kilts, 1999; Kilpatrick and Cahill, 2003; Richardson, Strange, and Dolan, 2004) and the STS is well known structure in processing changeable features of faces such like emotional expressions (Haxby, Hoffman, & Gobbini, 2000; Winston, Henson, Fine-Goulden, & Dolan, 2004). Research investigating facial mimicry processes related the amygdala, hippocampus (especially right) and STS activity to processes of facial mimicry during the perception of emotionally expressive faces (A. Hennenlotter et al., 2009; Kim et al., 2014; T.-W. Lee, O. Josephs, R. J. Dolan, & H. D. Critchley, 2006; Likowski et al., 2012; Schilbach et al., 2008; Wild, Erb, Eyb, Bartels, & Grodd, 2003). It is thought that the activation of the right hippocampus displays the recruitment of memory contents for an improved understanding of the displayed facial expression (Schilbach et al., 2008) while STS activation presents not only the sensory representation of the visual information but also an emotional communication process (T. W. Lee, O. Josephs, R. J. Dolan, & H. D. Critchley, 2006). Thus, it might be assumed that facial mimicry manipulation primed the activation of those brain regions engaged during emotional memory processing and consequently facilitated the storage and retrieval of related information about facial expressions. With respect to future research, it would be interesting to shed further light on the activity of related brain regions during memorizing facial emotional expressions and the contribution of facial mimicry to those processes.

Gender Difference

Our data show that especially male participants were more susceptible to the Facial Muscle Manipulation. They remembered emotional expressions less negative/more positive in the teeth compared to the control manipulation condition thereby reducing the negative bias. An analogous gender dependency has already been shown recently in a study by Wood, Martin, Alibali, and Niedenthal (2019). In this study, the recognition of facial expressions and hand gestures was impaired after facial mimicry restriction in male but not in female participants. Further evidence that male participants are more vulnerable to facial mimicry manipulations comes from a study of pacifier use in childhood (Niedenthal et al., 2012). This study revealed that the duration of pacifier use is negatively correlated with the amount of facial mimicry in boys but not in girls and that this effect seems to further impact social skills of male participants in later life. Especially those skills that depend on the recognition of others' emotion.

However, women generally outperform men during emotion recognition tasks, with an more pronounced advantage for negative emotions (for review see Thompson and Voyer, 2014). This advantage can be of biological as well as cultural origin – women as caregivers are more in demand of recognizing negative emotions (Thompson & Voyer, 2014) and women as "emotion experts" profit of particular emotional stimulation in childhood (Fischer & Lafrance, 2015; Fivush, Brotman, Buckner, & Goodman, 2000). Finally, there exist some evidence that women are more responsive towards emotional facial expressions in their own facial reactions (U. Dimberg, 1990) and generally show more emotional expressions than men and tend to smile more (LaFrance & Hecht, 2000). Consequently, it might be that in the present study female participants reach a ceiling effect regarding their potential influence of facial mimicry manipulation while male participants did not exploit their facial mimicry and expressivity to its full potential and can thus still profit from the manipulation.

Since previous studies did not reveal gender differences for the influence of a smiling manipulation on emotion perception (Lobmaier & Fischer, 2015; Neal & Chartrand, 2011) one can exclude that our results relay on a influences of perceptional processes only. Additionally, a solely influence of mimicry manipulation on perceptual processes would have affected the target as well as the test image and both should have been perceived as more positive. In consequence, such general perception bias should have been itself mutual rescinded. Notwithstanding the female advantage in emotion recognition abilities, a general gender difference in memorizing abilities for facial emotional expressions remains incompletely understood and should be topic of future studies.

Limitations and Further Directions

There are limitations in this study that should be addressed in future research. First, because of the implementation of the facial mimicry manipulation (holding a pen with the non-dominant hand vs. holding it with the teeth) the manipulation was maintained during the whole duration of the testing session with alternating control and smiling blocks. For this reason, data do not allow for a detailed separation of the influence on the different stages of the WM process (e.g. storage, maintenance or retrieval). Based on the present data, future studies should apply facial mimicry manipulation more specific either during target or test image presentation.

A further limitation is related to the task specificity. In the present paradigm participants had to remember the emotional expression and the intensity of this expression of a face. This allows to investigate the influence of facial mimicry manipulation on visual WM for emotional faces. However, we cannot excluded that the manipulation might have also influenced the visual WM for more static aspects of the target such as identity or gender. Accordingly, future research of this topic should consider control tasks, e.g. where participants have to remember the facial identity of a perceived face. Finally, we did not observe a (potentially interfering) effect of our FMM on negative emotions. Accordingly, future research should considered FMM incompatible with smiling (i.e. lip holding condition) to further assess the specificity of our reported effects.

4.5. Conclusion

The present study examined the influence of facial mimicry manipulation on visual WM for emotional faces. For this purpose we applied classical mimicry manipulation where holding a pen with the teeth induced a smiling expression while holding it with the non-dominant hand served as control condition. The mimicry of the participants was manipulated while they performed a visual WM paradigm where they had to remember the intensity of either a happy or a sad facial emotional expression. Data show that that the smiling mimicry condition improved the memory performance selectively for happy faces especially when high ambiguous facial expression had to be remembered. Furthermore, we found that facial mimicry manipulation induced a general positivity bias (reduced the negative memory bias) in representing emotional facial information in WM. Finally, data demonstrate a higher vulnerability of male participants to be affected by facial mimicry manipulation.

These influences of the smiling manipulation might be attributed to the priming of activation specific brain network engaged during memory processes for emotional faces. Consequently, this priming might facilitate the storage and retrieval of congruent information (like emotional faces). While previous studies revealed that woman are generally more expressive than man, our data pointing towards a higher vulnerability to facial mimicry manipulations in male participants. Our data demonstrate that the mimicry of the observer does not only influence his recognition but also systematically alters his memory of the facial emotional expressions of our conspecifics. Since maintaining information on the emotional expressions of our conspecifics is highly important for a successful social interaction, this study constitutes a first step towards our understanding of the influence of facial mimicry on WM of emotional facial expressions.

5. Project 3

I Spy, with my Little Eye: The Detection of Changes in Emotional Faces and the Influence of Facial Feedback in Parkinson's disease

Specific aim:

In this last project, I want to investigate if the prominent emotion recognition impairment in patients with Parkinson's disease can be attributed to the existing reduced facial mimicry in these patients.

The content of this chapter has been submitted to a peer-reviewed journal.

ABSTRACT

Emotional facial expressions play an important role in our social interactions and usually lead to a congruent facial reaction in the observer (facial mimicry). It is thought that the resulting facial feedback helps to understand the emotional state of our counterparts by activating corresponding emotional representations. Several studies verified deficits in facial emotion recognition in patients with Parkinson's disease (PD). Additionally, recent studies revealed reduced facial mimicry and consequently reduced facial feedback while PD patients observed emotional faces, suggesting that this reduction might contribute to the prominent emotion recognition deficits.

In the present study, I investigated whether the reduced facial mimicry is responsible for these emotion recognition deficits and whether they can be diminished by means of facial mimicry manipulation. For this purpose, 20 PD patients and 20 healthy controls underwent a classical facial mimicry manipulation by different pen holding conditions (holding the pen with the lips, the teeth or the non-dominant hand) while performing an emotional change detection task with faces. While the change detection ability was significantly influenced by facial mimicry manipulation in healthy controls, the manipulation had no influence on the performance in PD. These results suggest that not only facial mimicry is impaired in Parkinson patients, but that the whole process of facial feedback is fundamentally disturbed in Parkinson patients.

5.1. Introduction

Parkinson's disease is a progressive neurodegenerative disorder. During the course of the disease, the loss of dopaminergic neurons in the substantia nigra pars compacta causes the prominent motor symptoms comprising bradykinesia, rigidity, postural instability and rest tremor (Jankovic, 2003). These motor symptoms result in difficulties and limitations in daily routines. Among these motor symptoms, facial bradykinesia circumscribes impairments in emotional, spontaneous as well as voluntary facial movements due to basal ganglia dysfunction (Bologna et al., 2013). Facial bradykinesia is often perceived as masked face (hypomimia) and significantly influences the quality of life and social well-being (S. Argaud, 2018; Gunnery et al., 2016). Apart from these impairments in self-expressing emotions by facial movements, patients with Parkinson's disease (PD) experience difficulties in perceiving and recognizing emotional expressions (Peron et al., 2012). Previous studies reveal that, in contrast to healthy controls, PD patients are impaired in the explicit categorization of emotional expressions in faces (Sprengelmeyer et al. (2003); Wagenbreth, Wattenberg, Heinze, and Zaehle (2016), for a review see S. Argaud (2018)). These difficulties in facial emotion recognition have been associated with problems of facial mimicry as a result of facial bradykinesia (Prenger & MacDonald, 2018)

The link between facial emotional expressiveness of the observer and recognition of facial expressions of others plays an important role in theories of embodied simulation. According to such theories, emotional expressions are decoded, processed, interpreted and finally understood by simulating them. Thus, when observing an emotional expression of others, facial and body gestures are adapted by contracting the corresponding musculature. This simulation occurs automatically and by feedback processes that trigger the simulation of the equivalent motor, somatosensory and affective state (Niedenthal et al., 2010). This link was affirmed by U. Dimberg (1982) who showed that facial muscle activity of participants, measured by electromyography (EMG), corresponds to observed facial emotional expressions and that these facial muscles are even activated when facial emotions are presented only subliminally (U. Dimberg et al., 2000). A more direct relation is offered by studies measuring EMG while participants rated the observed facial emotional expressions. These studies provide evidence that facial mimicry predicts accuracy ratings in emotion classification of facial expressions (Künecke et al., 2014), as well as authenticity ratings of smiles

(Korb et al., 2014) and valence of emotional experiences to dynamic facial expressions, which in turn predicts valence ratings for recognized emotions (Sato et al., 2013)

The inter-relation between mimicry and emotional face processing has also been investigated by manipulating the process of mimicry. By doing this, several studies demonstrate that facial mimicry influences the perception accuracy of facial expressions on a behavioral (Neal & Chartrand, 2011), as well as on an electrophysiological level (Sel et al., 2015). Further, facial mimicry manipulation affects the change detection of facial expressions (Lobmaier & Fischer, 2015; Niedenthal et al., 2001) and even the automatic unconscious processing of emotional faces (Kuehne et al., 2019).

In patients with PD the embodied simulation account was supported by Marneweck et al. (2014) who showed that the discrimination as well as the recognition of facial expressions of emotions positively correlated with voluntary facial muscle control. A positive relation between facial expressivity and facial emotion recognition in PD patients as well as in a healthy control group was further strengthened by Ricciardi et al. (2017).

Hence ,the present study investigates whether the reduced facial mimicry in those patients is responsible for the prominent emotion recognition impairment and if so, to what extent a facial mimicry manipulation can reduce this impairment. For this purpose a classical mimicry manipulation was implemented by different pen holding conditions, as described by Strack et al. (1988) while participants performed an emotional change detection task with faces. During the mimicry manipulation. Holding the pen with the teeth should activates the Musculus zygomaticus major, which is activated while posing a smiling expression. In contrast, holding the pen with the lips should activate the M. orbicularis oris and is incompatible with smiling. Holding the pen with the non-dominant hand allows free mimicry and thus serves as control condition.

In accordance with previous studies, we expect to find a general deficit of detecting changes in emotional expressions in patients with PD. Further, we assume that facial mimicry manipulation should influence change detection in both healthy controls (HCs) and patients with PD. Comparable to the study of Lobmaier and Fischer (2015) happy facial expressions should be perceived sooner (change from neutral expression) and longer (change to neutral expression) while participants hold the pen with the teeth compared to the control hand-condition. Accordingly, while holding the pen with the lips, participants should detect sad faces earlier (changes from neutral expressions) and perceive them longer (changes to neutral expressions). Further, we expect that the deficit of change detection of PD patients will improve with emotion-congruent facial mimicry manipulation. These results would support the embodied simulation accounts where facial mimicry plays a crucial role in the process of facial emotion recognition. Further, these results would provide a first evidence that the reduced or the non-existing facial mimicry in PD patients highly contributes to the prominent emotion recognition impairments. On the contrary, if the results will reveal no influence of facial mimicry manipulation on the emotional change detection performance in PD patients, then it might be suspected that not only facial mimicry itself is impaired in those patients but the whole process of facial feedback starting with the facial muscle activation going over to the neuronal processing of the produced facial muscle signal and ending with the understanding of the observed emotional expression.

5.2. Methods

Participants

Forty-six participants (24 PD patients, 22 HCs) took part in the study. All participants were recruited from the Department of Neurology at the University of Magdeburg. Groups were matched for sex, age and educational level. PD patients were diagnosed with idiopathic PD by a neurologist of the department. All participants completed the Beck Depression Inventory-II (BDI, Hautzinger et al. (2006)) and the German version of the Snaith-Hamilton-Pleasure Scale (SHAPS-D, Franz et al. (1998)). Exclusion criteria for the present study included any reported psychiatric or neurological disease other than PD, BDI scores above 19 and SHAPS-D scores above two. Six participants were excluded from analysis due to scores exceeding the BDI cutoff threshold for mild depressive symptom (1 control, 3 PD) and high deviations from the mean level of the group during the main task (1 control, 1 PD). This resulted in 20 participants for each group. Table 4 shows demographic and clinical characteristics for both groups. All participants had normal or corrected to normal vision. The local Ethical Committee of the University Magdeburg approved the experimental procedures. All participants were naïve to the aim of the study and provided informed consent. The study was conducted in accordance with the Declaration of Helsinki (1991; p.1194).

Table 4. Sample Characteristics of PD patients (PD) and Healthy Controls (HCs)

	PD (*n = 20, 10 female*)	*HCs* (*n = 20, 10 female*)
Age (years)	70.85 ± 6.7	69.75 ± 5.02
BDI	8.7 ± 4.59	5.7 ±4.46
SHAPS-D	0.45 ±0.80	0.11 ± 0.31
Disease duration (years)	13.3 ± 16.83	
LED (mg)	543.75 ± 222.35	

BDI = Beck Depression Inventory, SHAPS-D = German version of the Snaith-Hamilton-Pleasure-Scale, LED = daily levodopa equivalent dose.

Stimuli and Procedure

Visual stimuli consisted of 24 different characters (12 female, 12 male) each displaying 3 different emotional expressions (neutral, happy, sad) taken from the Karolinska face data-base (Lundqvist, 1998). To control for low-level visual influence the hair regions were cut off and the background of all images was gray scaled. Additionally, mean luminance and contrast of all images was equalized with the SHINE toolbox for MATLAB (Willenbockel et al., 2010). For each character 6 different emotional change sequences were created with java psychomorph (version 6, Tiddeman et al. (2001)). These emotional change sequences included morphs with 40 frames from neutral to happy, happy to neutral, neutral to sad and sad to neutral facial expressions for quantitative changes and changes from happy to sad and sad to happy facial expressions for the qualitative changes. Accordingly, the experimental procedure consisted of 144 different morph sequences. Visual stimuli were presented on a computer screen (Samsung SyncMaster SA450, 22') located in front of the observer at a viewing distance of 90cm.

Facial mimicry manipulation was conducted in compliance with the study by Strack et al. (1988) by applying 3 different pen holding conditions. Holding a pen with the teeth innervates facial muscles activated while smiling, while holding the pen with lips inhibits those facial muscles. Holding the pen with the non-dominant hand allows free mimicry and serves as a control condition.

After experimental instructions and completing questionnaires, participants sat in a comfortable chair in dimmed room. To investigate the influence of facial mimicry on the detection of emotional changes, participants underwent the different pen holding conditions in pseudorandomized order in three separate blocks. Each block consisted of a familiarization task and the emotional change detection task. Within the familiarization task, emotional faces were introduced to the observer to exclude any novelty effects during the emotional change detection task. For this purpose, eight different characters (4 female) were randomly presented, each displaying all three emotional expressions resulting in 24 trials. Participants had to indicate the emotional expression of a face by pressing one of three colored keys that matched one of the displayed labels under the face (three-forced-choice response format, see Figure 11). The subsequent emotional change detection task consisted of 48 morph sequences (6 possible emotional changes, 8 characters), where the order of morph sequences within each block was randomly selected. The playback of these sequences was self-paced – by pressing the space bar participants navigated forwards through the morph sequences. One morph sequence comprised 40 frames and with every button press the initial emotion changed stepwise into another one. As soon as a change of the initial emotional expression was detected participants pressed the enter button. Subsequent to this change detection, participants had to indicate the initial and the end emotion of the previously displayed morph sequence by pressing one of the three corresponding colored keys. After this, the next trial started (see Figure 11).

The familiarization task and the emotional change detection task were available in four different versions, pseudorandomly assigned between the participants (A,B,C,D). The versions of the familiarization and the emotional change detection task differed in colored key allocations to the emotional labels and the assignment of characters to the different blocks.

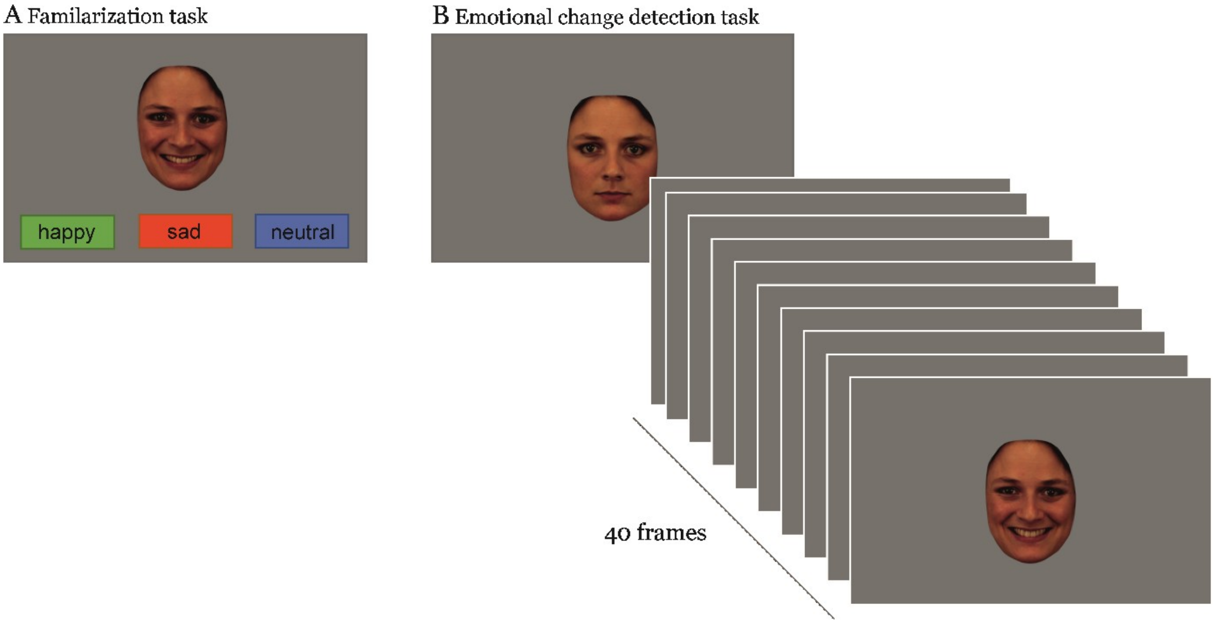

Figure 11. Trial procedure for one block. Each block started with a familarization task (A). During this task, facial stimuli were introduced to the participants, which had to indicate the presented emotion by pressing one of three colored keys of the keyboard. The familarization task was followed by the emotional change detection task (B). Here participants saw a face whose emotion slightly changed into another emotion by each pressing of the space bar. Whenever the initial emotion changed into another one they should press enter and the next trial would start.

Data Analysis

The statistical analysis was performed with IBM SPSS-Software 26. In order to investigate the differential influence of facial mimicry manipulation (FMM) on the ability to detect changes of facial emotional expressions between PD patients and the control group, the results of the quantitative and qualitative morph sequence changes were analyzed separately. Results of quantitative morph sequences were entered into a repeated measures (RM)-ANOVA with within-participant factors *FMM* (hand vs. lips vs. teeth) and *morph sequence* (neutral – happy vs. happy – neutral vs. neutral – sad vs. sad – neutral) and the between-participant factor *group* (controls vs. PD patients). Analogously, results of qualitative morph sequence were analyzed with the within-participant factors *FMM* (hand vs. lips vs. teeth) and *morph sequence* (happy – sad vs. sad – happy) and the between-participant factor *group* (controls vs. PD patients). In case of sphericity violations, data were Greenhouse-Geisser adjusted. Significant interactions were further examined using paired *t* tests. In addition, in order to further confirm the absence of an effect we provide confidence intervals (CI) for the differences between the tested means for the emotional change detection task. The CIs provide information whether H_0 can be rejected or whether it should be retained. Granted that the CI did not entail the value of zero effect (0) H_0 can be rejected, conversely, if the calculated CI includes 0 we can assume that the treatment has no effect of practical importance (Aberson, 2002; Quertemont, 2011).

5.3. Results

Quantitative Morph Sequences

The results of the quantitative emotion changing morph sequences are depicted in Figure 12. RM-ANOVA of the quantitative changes revealed a significant *group* effect ($F_{1,38}$ = 21.674, P < .001, η_p^2 = 0.363) due to more sequences required for change detection for PD patients (M = 26.54, SE = 0.84) compared to the control group (M = 20.93, SE = 0.86, t(19) = -4.073, P = .001, d = -1.247, 95%CI = -8.491 <= μ_1 - μ_1 <= -2.727) as well as a significant main effect of the factor *morph sequence* (F2.356,89.539 = 115.762, P < .001, η_p^2 = 0.753). Post-hoc comparisons between the different morph sequences revealed that all of them significantly differ among each other (see Table 5 for overview of statistical results). Generally, changes to neutral faces were detected the latest (happy – neutral: M = 29.13, SE = 0.78; sad – neutral: M = 27.21, SE = 1.03) while changes from neutral to happy faces were detected the earliest (M = 14.83, SE = 0.81) (see Figure 12B). Furthermore, the ANOVA revealed a significant *Facial Muscle Manipulation (FMM)* x *morph sequence* interaction ($F_{3.502,133.062}$ = 5.735, P = .001, η_p^2 = 0.131) as well as a significant *FMM* x *morph sequence* x *group* interaction ($F_{3.502,133.062}$ = 4.849, P = .002, η_p^2 = 0.113). Overall, while holding the pen with the lips happy faces were recognized later when changing from a neutral face (neutral – happy: M = 15.98, SE = 0.93) compared to the control condition (neutral – happy: M = 14.26, SE = 0.85, t(39) = -2.541, P = .015, d = -0.305, 95%CI = -3.092 μ_1 - μ_1 <= -0.351) and the change to neutral was detected sooner (happy – neutral: M = 27.8, SE = 1.02) compared to the control (happy – neutral: 29.90, SE = 0.85, t(39) = 2.463, p = .018, d = 0.352, 95%CI = 0.375 <= μ_1 - μ_1 <= 3.827) and teeth condition (happy – neutral: M = 29.68, SE = 0.82, t(39) = -2.291, p = .027, d = -0.32, 95%CI = -3.536 <= μ_1 - μ_1 <= -0.220). Similarly, during the lips condition, sad faces were perceived longer when changing to neutral faces (sad – neutral: M = 28.19, SE = 1.10) compared to the teeth condition (sad – neutral: M = 26.28, SE = 1.33, $t(39) = 2.195$, $p = .034$, $d = 1.088$, 95%CI = $0.149 <= \mu_1 - \mu_1 <= 3.663$)(see Table 6).

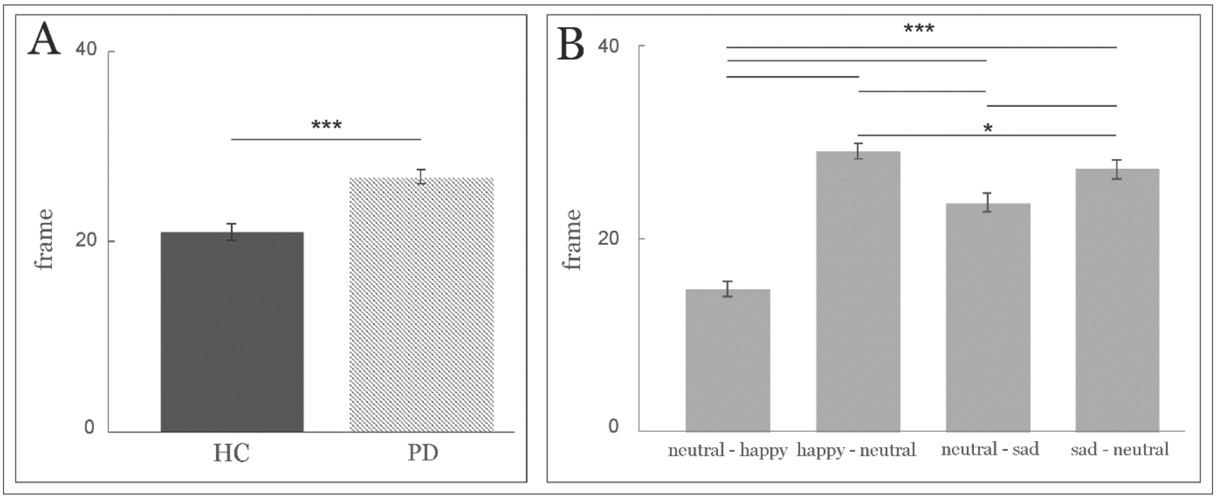

Figure 12. Mean and SEM for quantitative morph changes. (A) Group effect. PD patients need significantly more frames to detect emotional change. (B) Main effect of morph sequence. Generally, all morph sequences differ significantly from each other. Emotional changes were detected fastest in neutral – happy and latest in happy – neutral morph sequences. *** p ≤ .001, * p < .05.

Table 5. Significant Results of Post-hoc Comparisons between Different Morph Sequences by Paired t-Tests. P-values <= .05 are marked in bold

Morph sequences			**t(39)**	**P**	**Cohen's d**	**95% CI**
neutral - happy	vs.	happy - neutral	-14.427	**<.001**	-2.847	[-16.304, -12.295]
neutral - happy	vs.	neutral - sad	-10.937	**<.001**	-1.586	[-10.599, -7.291]
neutral - happy	vs.	sad - neutral	-12.534	**<.001**	-2.109	[-14.379, -10.383]
happy - neutral	vs.	neutral - sad	6.798	**<.001**	0.966	[3.761, 6.948]
happy - neutral	vs.	sad - neutral	2.405	**<.021**	0.332	[0.305, 3.532]
neutral - sad	vs.	sad - neutral	-6.661	**<.001**	-0.544	[-4.480, -2.393]

Table 6. Significant Results of Post-hoc Comparisons between FMM Conditions of Different Morph Sequences by Paired t-Tests. P-values <= .05 are marked in bold

Morph sequence	FMM conditions			t(39)	P	Cohen's d	95% CI
neutral - happy	control	vs.	lips	-2.541	**.015**	-0.305	[-3.092, -0.351]
	lips	vs.	teeth	2.055	**.047**	0.289	[0.027, 3.473]
happy – neutral	control	vs.	lips	2.463	**.018**	0.352	[0.375, 3.827]
	lips	vs.	teeth	-2.291	**.027**	-0.32	[-3.536, -0.220]
sad - neutral	lips	vs.	teeth	2.195	**.034**	1.088	[0.149, 3.663]

In order to further examine the significant *FMM* x *morph sequence* x *group* interaction two additional 3 (*FMM*) x 4 (*morph sequence*) RM-ANOVAs were conducted for HCs and PD patients separately. In both groups, the ANOVA revealed a significant main effect of *morph sequence* (HCs: $F_{3,57}$ = 37.000, P <.001, η_p^2 = 0.661, PDs: $F_{3,57}$ = 111.899, P < .001, η_p^2 = 0.855) where changes to neutral faces were detected latest (controls: $M_{happy-neutral}$ = 26.59, SE = 1.01; $M_{sad-neutral}$ = 24.03, SE = 1.49; PD patients = $M_{happy-neutral}$ = 31.66, SE = 0.88; $M_{sad-neutral}$ = 30.39, SE = 1.04) and changes from neutral to happy faces were detected fastest (controls: M = 12.66, SE = 0.94; PD patients: M = 16.99, SE = 1.15) (for more details see Table 7). Notably, HCs showed a significant interaction between *FMM* and *morph sequence* ($F_{2.181,41.432}$ = 8.341, P = .001, η_p^2 = 0.305), while this interaction effect was absent for PD ($F_{6,114}$ = 0.672, P = 0.672, η_p^2 = 0.034). For neutral – happy morph sequences, holding the pen with the lips (M = 14.99, SE = 1.08) significantly increased the detection time for happy faces compared to the control (M = 12.39, SE = 0.94, t(19) = -2.804, P = .011, d = -0.573, 95%CI = -4.541 <= μ_1 - μ_1 <= -0.659) and teeth condition (M = 10.62, SE = 1.15, t(19) = 4.684, P < .001, d = 0.876, 95%CI = 2.417 <= μ_1 - μ_1 <= 6.321), while holding the pen with the teeth significantly decreased detection time of happy faces compared to control condition (t(19) = 2.563, P = .019, d = 0.376, 95%CI = 0.325 <= μ_1 - μ_1 <= 3.213). In contrast, when happy faces changed to neutral faces the lip condition (M = 24.29, SE = 1.32) significantly decreased change detection time compared to control (M = 27.76, SE = 1.28, t(19) = 2.835, P = .011, d = 0.597, 95%CI = 0.909 <= μ_1 - μ_1 <= 6.041) and teeth condition (M = 27.73, SE = 0.97, t(19) = -2.766, p = .012, d = -0.663, 95%CI -

6.038 <= $\mu_1 - \mu_1$ <= -0.837). Further, change detection for sad – neutral morph sequences was significantly increased while participants held the pen with the lips (M= 25.89, SE = 1.53) compared to holding the pen with the teeth (M = 22.17, SE = 1.83, $t(19) = 2.786$, $P = .012$, $d = 0.493$, 95%CI = 0.926 <= $\mu_1 - \mu_1$ <= 6.524) (see Figure 13A). In contrast, as shown in Figure 13B, facial feedback manipulation was absent in the PD group (see Table 8).

In summary, HCs showed the expected effect of facial muscle manipulation on the emotional change detection for the presented quantitative morph sequence, while there was no effect in patients with PD (see Figure 13 and Table 8).

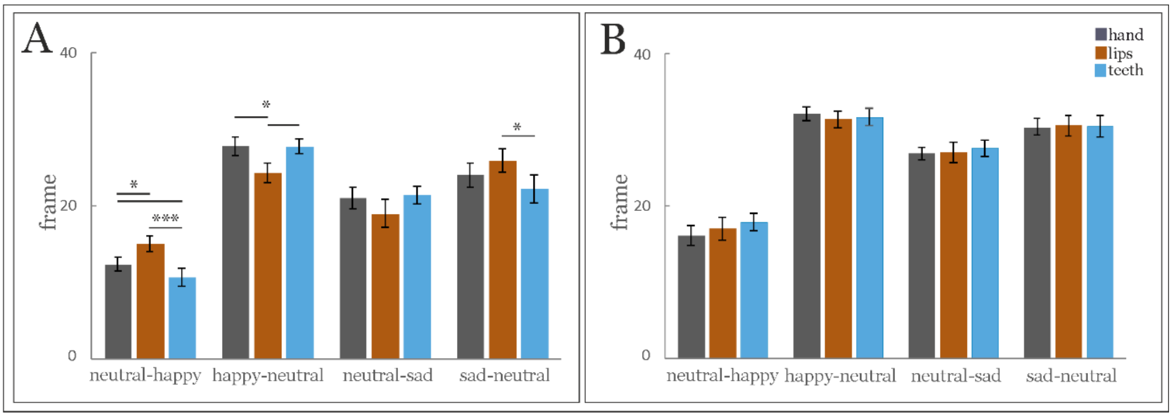

Figure 13. Mean and SEM of quantitative morph sequences for HCs (A) and PD patients (B). (A) The ability to detect changes in facial emotional expressions was significantly influenced by the different mimicry conditions. (B) Facial mimicry manipulation did not influence the detection change of facial emotional expressions in PD patients. grey – hand, orange – lip, blue – teeth condition, *** $p \leq .001$, * $p < .05$.

Table 7. Significant Results of Post-hoc Comparisons between Different Morph Sequences by Paired t-Tests separately for HCs and PD Patients. P-values <= .05 are marked in bold

HCs

Morph sequences			**t(19)**	**P**	**Cohen's d**	**95% CI**
neutral - happy	vs.	happy - neutral	-8.698	**<.001**	-3.189	[-17.278, -10.576]
neutral - happy	vs.	neutral - sad	-5.920	**<.001**	-1.492	[-10.518, -5.023]
neutral - happy	vs.	sad - neutral	-7.020	**<.001**	-2.042	[-14.748, -7.973]
happy - neutral	vs.	neutral - sad	4.214	**<.001**	1.15	[3.099, 9.214]
neutral - sad	vs.	sad - neutral	-3.910	**.001**	-0.564	[-5.511, -1.668]

PD patients

Morph sequences			**t(19)**	**P**	**Cohen's d**	**95% CI**
neutral - happy	vs.	happy - neutral	-12.166	**<.001**	-3.196	[-17.196, -12.148]
neutral - happy	vs.	neutral - sad	-10.801	**<.001**	-2.184	[-12.080, -8.158]
neutral - happy	vs.	sad - neutral	-11.858	**<.001**	-2.723	[-15.768, -11.037]
happy - neutral	vs.	neutral - sad	7.747	**<.001**	1.14	[3.323, 5.783]
neutral - sad	vs.	sad - neutral	-6.600	**<.001**	-0.751	[-4.324, -2.242]

Table 8. Results of Post-hoc Comparisons between FMM Conditions of Quantitative Morph Sequences by Paired t-Tests separately for HCs and PD Patients. P-values <= .05 are marked in bold

HCs

Morph sequence	FMM conditions			t(19)	P	Cohen's d	95% CI
neutral - happy	control	vs.	lips	-2.804	**.011**	-0.573	[-4.541, -0.659]
	control	vs.	teeth	2.563	**.019**	0.376	[0.325, 3.213]
	lips	vs.	teeth	4.684	**<.001**	0.876	[2.417, 6.321]
happy - neutral	control	vs.	lips	2.836	**.011**	0.597	[0.909, 6.041]
	control	vs.	teeth	0.044	0.965	0.007	[-1.745, 1.820]
	lips	vs.	teeth	-2.766	**.012**	-0.663	[-6.038, -0.837]
neutral - sad	control	vs.	lips	1.47	.158	0.27	[-0.856, 4.893]
	control	vs.	teeth	-0.418	.681	-0.06	[-2.180, 1.455]
	lips	vs.	teeth	-1.833	.083	-0.34	[-5.100, 0.338]
sad - neutral	control	vs.	lips	-1.626	0.12	-0.267	[-4.303, 0.540]
	control	vs.	teeth	1.321	.202	0.238	[-1.077, 4.765]
	lips	vs.	teeth	2.786	**.012**	0.493	[0.926, 6.524]

PD patients

Morph sequence	FMM conditions			t(19)	P	Cohen's d	95% CI
neutral - happy	control	vs.	lips	-0.868	.396	-0.133	[-2.877, 1.190]
	control	vs.	teeth	-1.386	.182	-0.155	[-4.299, 0.874]
	lips	vs.	teeth	-0.738	.47	-0.145	[-3.333, 1.595]
happy - neutral	control	vs.	lips	0.641	.529	0.158	[-1.647, 3.103]
	control	vs.	teeth	0.331	.745	0.085	[-2.179, 2.997]
	lips	vs.	teeth	-0.326	.748	-0.061	[-2.367, 1.730]
neutral - sad	control	vs.	lips	-0.102	.92	-0.029	[-2.950, 2.675]
	control	vs.	teeth	-0.617	.544	-0.151	[-2.964, 1.614]
	lips	vs.	teeth	-0.585	.565	-0.095	[-2.459, 1.384]
sad - neutral	control	vs.	lips	-0.112	.912	-0.031	[-3.561, 3.198]
	control	vs.	teeth	-0.056	.956	-0.016	[-3.620, 3.433]
	lips	vs.	teeth	0.089	.93	0.014	[-1.964, 2.139]

Qualitative Morph Sequences

Figure 14 and 15 illustrate the results for qualitative morph sequences. As for the quantitative morph sequences, analysis of the qualitative morph sequences revealed a significant *group* effect ($F_{1,38}$ = 8.275, P = .007, η_p^2= 0.179), due to longer change detection rates for PD patients (M= 25.49, SE = 0.79) compared to HCs (M = 22.21, SE = 0.82, t(19) = -2.838, P= .011, d = -0.91, 95%CI = -5.705 <= μ_1 - μ_1 <= -0.862) (see Figure 14A). Furthermore, there was a significant main effect of the factor *morph sequence* ($F_{1,38}$ = 109.488, P < .001, η_p^2 = 0.742) with longer change detection rates to happy – sad morph sequences (M = 27.68, SE = 0.71) compared to sad – happy morph sequences (M = 20.01, SE = 0.73, t(39) = 10.391, P < .001, d = 1.677, 95%CI = 6.176 <= μ_1 - μ_1 <= 9.161) (see Figure 14B). Additionally, the interaction between *FMM* x *morph sequence* x *group* reached significance ($F_{2,76}$ = 4.018, P = .022, η_p^2 = 0.096). In order to examine this interaction effect, two separate ANOVAs with *FMM* and *morph sequence* as within-subject factors were conducted, separately for HC and PD participiants. In both groups, ANOVAs revealed a significant main effect of the factor *morph sequence* (HCs: $F_{1,19}$ = 36.167, P < .001, η_p^2 = 0.656, see Figure 15A; PD: $F_{1,19}$ = 83.103, P < .001, η_p^2 = 0.841, see Figure 15B) with longer change detection rates for happy – sad morph sequences (controls: 25.59, SE = 0.95; PD patients: M = 29.78, SE = 0.85) compared to sad – happy morph sequences (controls: M = 18.83, SE = 1.04, t(19) = 6.014, P < .001, d = 1.519, 95%CI = 4.406 <= μ_1 - μ_1 <= 9.110; PD patients: M = 21.2, SE = 0.99, t(19) = 9.116, P < .001, d = 2.082, 95%CI = 6.609 <= μ_1 - μ_1 <= 10.549). Again, while an interaction effect was absent for PD ($F_{2,38}$ = 0,792, P = 0.460, η_p^2 = 0.040), there was a significant interaction between *FMM* and *morph sequence* in the control group ($F_{2,38}$ = 3.529, P = .039, η_p^2 0.157). This interaction effect was driven by the influence of *FMM* on happy – sad morph sequences: compared to the lips condition (M = 24.14, SE = 1.18) emotional changes from happy to sad faces are detected later in the teeth condition (M = 26.97, SE = 1.20, t(19) = -2.812, P = .011, d = -0.53, 95%CI = -4.940 <= μ_1 - μ_1 <= -0.724)(see Table 9 and Figure 15A).

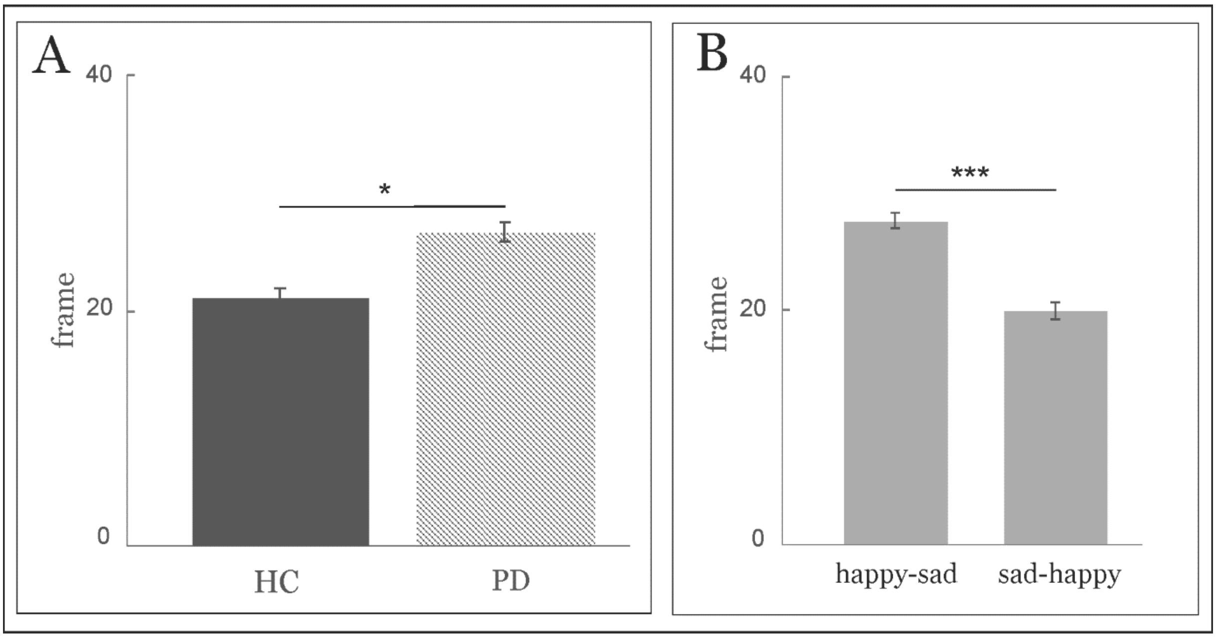

Figure 14. Mean and SEM for qualitative morph sequences. (A) Group effect. PD patients need significantly more frames to detect emotional changes in faces. (B) Morph sequence effect. Happy – sad emotional changes were significantly detected later than sad – happy changes. *** p < .001, * p < .05.

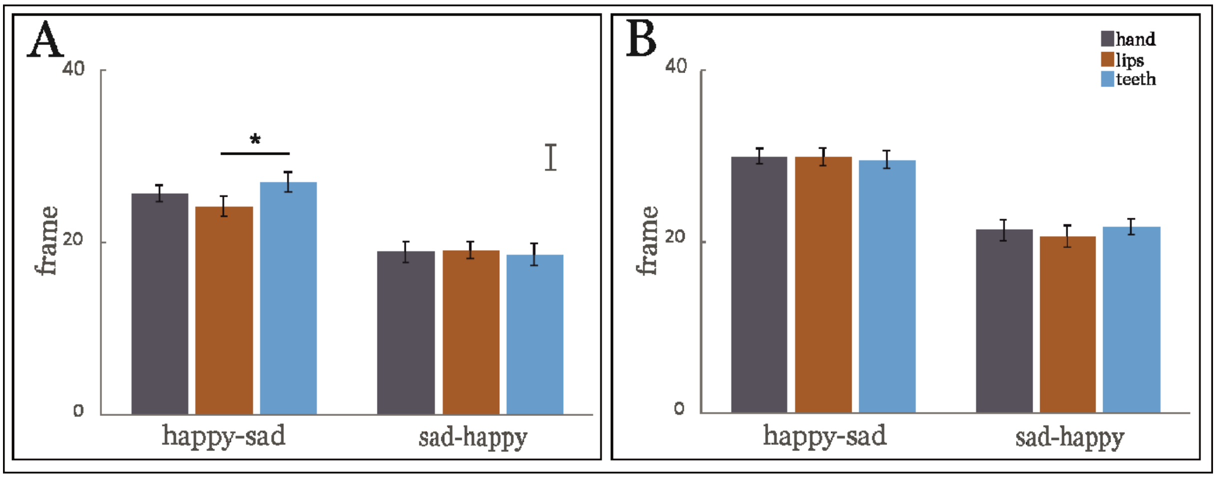

Figure 15. Mean and SEM of qualitative morph sequences for HCs (A) and PD patients (B). (A) The teeth condition significantly increased the perception of happy faces compared to the lip condition. There was no influence of facial mimicry manipulation for sad – happy morph sequences. (B) PD patients did not have any influence of facial muscle manipulation during the emotional change detection task of qualitative morph sequences. *p < .05.

Table 9. Results of Post-hoc Comparisons between FMM Conditions of Qualitative Morph Sequences by Paired t-Tests separately for HCs and PD Patients. P-values <= .05 are marked in bold

HCs

Morph sequence	FMM conditions			t(19)	P	Cohen's d	95% CI
happy - sad	control	vs.	lips	1.363	.189	0.309	[-0.811, 3.838]
	control	vs.	teeth	-1.195	.247	-0.266	[-3.629, 0.992]
	lips	vs.	teeth	-2.812	**.011**	-0.53	[-4.940, -0.724]
sad - happy	control	vs.	lips	-0.151	.881	-0.037	[-2.691, 2.328]
	control	vs.	teeth	0.526	.605	0.067	[-1.136, 1.898]
	lips	vs.	teeth	0.506	.619	0.109	[-1.766, 2.891]

PD patients

Morph sequence	FMM conditions			t(19)	P	Cohen's d	95% CI
happy - sad	control	vs.	lips	0.059	.954	0.014	[-1.946, 2.059]
	control	vs.	teeth	0.423	.677	0.087	[-1.504, 2.266]
	lips	vs.	teeth	0.335	.741	0.07	[-1.704, 2.354]
sad - happy	control	vs.	lips	0.542	.594	0.113	[-1.879, 3.192]
	control	vs.	teeth	-0.289	.776	-0.077	[-3.250, 2.462]
	lips	vs.	teeth	-1.164	.259	0.206	[-2.938, 0.838]

In summary, results demonstrate that emotional change detection in HCs is influenced by facial muscle manipulation. During the lip-condition, changes from neutral to happy and sad to neutral were detected later, while changes from happy to neutral facial expression were detected earlier. Analogously, during the teeth condition changes from neutral to happy were detected earlier and changes from happy to sad facial expressions later. In contrast, patients with PD generally detected emotional changes in facial expressions later and -importantly- their emotional change detection was not influenced by facial mimicry manipulation.

5.4. Discussion

The correct reading of emotions in facial expressions represents a main column in social interaction. This reading is partially implemented by simulating the perceived emotional expression within the own face (facial mimicry). The resulting facial feedback activates related affective and cognitive mental states (Stel, 2016). However, this process of facial feedback seems to be impaired in patients with PD as previous studies had revealed a possible link between a reduced facial mimicry and impaired emotional expression recognition (Marneweck et al., 2014; Ricciardi et al., 2017). As the facial mimicry as well as the emotion recognition impairments make a deep negative impact on PD patients' quality of life, we wanted to further examine the possible role of the reduced facial mimicry to the emotion recognition impairments. For this reason, we examined the influence of facial mimicry manipulation on the detection of emotional changes in facial expressions in patients with PD and HCs. The mimicry manipulation was conducted in conformity with Strack et al. (1988) where holding a pen with the teeth activates the Musculus zygomaticus major (which is contracted while smiling), and holding the pen with lips activates Musculus orbicularis oris (contracted during frowning). Holding the pen with the non-dominant hand served as control condition, enabling free facial mimicry. During an emotion change detection task, PD patients and HCs indicated as soon as they detected a change from an initial facial emotional expression into another. These changes could be quantitative (neutral – happy/sad, happy/sad – neutral) or qualitative (happy – sad, sad – happy). As hypothesized, facial mimicry manipulation systematically influenced the detection of emotional changes in HCs. However, the performance of PD patients was not modulated by mimicry manipulation: the facial mimicry manipulation influenced the change detection only in HCs, but not in PD patients.

Healthy Controls

The influence of mimicry manipulation in HCs is in accordance with the findings of Lobmaier and Fischer (2015). Paralleling the findings of Lobmaier & Fischer (2015), the lip condition (preventing smiling) had the greatest impact on the detection of quantitative emotional changes, while the detection of qualitative changes was only influenced by the teeth condition. When participants adopted a frowning facial expression they detected the change from happy to neutral facial expressions earlier and detected the change from neutral to happy expressions later compared to free mimicry (hand) and smiling (teeth) manipulation condition. In contrast, sad facial expressions were perceived longer during the lip condition. Accordingly, while posing a smile, happy facial expressions were perceived longer (happy –sad) and detected earlier (neutral – happy). We hence confirmed the finding of Lobmaier and Fischer (2015) that facial feedback generally influences the detection of emotional changes in facial expressions.

In contrast to Lobmaier and Fischer (2015), the present study revealed that the facial feedback manipulation additionally influenced the perceived quality of emotion (qualitative emotion changes). In both studies, each quantitative and qualitative morph sequence consisted of 40 frames. However, in contrast to Lobmaier & Fischer (2015) who used 4 identities, we used 12 different identities (6 female/6 male) to generate the morph sequences, and the identities were not repeated over the different pen holding conditions. Thus, it might be that due to the identity repetitions in the study by Lobmaier and Fischer (2015) over the different pen holding conditions participants could more easily remember the frames where they detected the emotion changes. This may be particularly true for qualitative emotion changes where the changes are more obvious and thus could be easier to remember than changes between a neutral and an emotional face. Additionally, we presented 8 different trials per morph sequence and per facial mimicry condition, thus twice as much trials as the preceding study which should increase the reliability of the study.

Further, in contrast to the previous study in which mainly the teeth condition influenced the change detection, in the present study both the lips and the teeth condition similarly influenced emotional change detection of healthy controls. However, by mere observation of the data, the lips and the teeth manipulation similarly modulated the change detection in both studies. Possibly, the increased trial numbers in the present study accentuated these results.

Finally, while Lobmaier and Fischer (2015) observed a congruency effect between facial mimicry manipulation condition and the morph sequences, the present study additionally revealed an incongruency effect. Previous studies demonstrated a congruency effect for quantitative emotional changes, reflected by a longer (for changes from emotional to neutral faces) and earlier (for changes from neutral to emotional faces) perception of mimicry congruent emotions. That is, when mimicry was manipulated to expressing a smile, happy faces were perceived longer when changing to neutral and changes were detected earlier when changing from neutral to happy. Likewise, sad faces were perceived longer and detected earlier when participants adopted a frowning expression by holding the pen with the lips (Lobmaier & Fischer, 2015). This congruency effect was also observed by Niedenthal, Halberstadt, Margolin, and Innes-Ker (2000) who modified the emotional state of participants either to happy or sad. In the present study, we observed this congruency effect for the teeth condition in neutral-to-happy morph sequences and for the lip condition in sad-to-neutral morph sequences. However, we additionally found an incongruency effect. This incongruency effect appeared during the lip condition where happy faces were perceived shorter and changes to happy faces were detected later when changing to or from neutral facial expressions. Such an incongruency effect of facial feedback on the processing of emotional faces has already been observed in a previous study (Kuehne et al., 2019). There, we investigated the effect of the different facial mimicry conditions on the automatic processing of facial emotional expressions measured electrophysiologically as emotional mismatch negativity (eMMN) during an oddball paradigm. While the teeth condition attenuated the eMMN to rare unattended happy faces, it increased the eMMN to rare unattended sad faces. Thus, on a neural level, facial feedback seems to influence not only congruent but also incongruent facial emotional expressions. Therefore, it can be assumed that, in the present study, posing a smiling facial expression enhanced the processing of happy and simultaneously diminished the processing of sad facial expressions.

PD Patients

While the current data on healthy controls confirm and extend previous knowledge, the main objective of the present study was to investigate the influence of facial feedback in emotion recognition especially in patients with PD. As those patients show a reduced facial mimicry to - and are impaired in the recognition of - emotional expressions they represent a promising model to investigate facial feedback processes. For this reason, we applied the different facial mimicry manipulation conditions to patients with PD. Generally and independent of the facial mimicry manipulation condition, patients with PD detected emotion changes later than HCs, regardless whether these changes were quantitative or qualitative. These results are consistent with several studies showing that PD patients have deficits in the recognition and processing of emotional stimuli especially of facial emotional expressions (for reviews see Assogna, Pontieri, Caltagirone, and Spalletta, 2008, Peron et al., 2012, S. Argaud, 2018).

Further, our data suggest no specific morph sequence effect in PD: PD patients seem to show an overall deficit in detecting emotional changes in facial expressions. Despite ambivalent results on the reported impairments in the recognition of facial emotional expressions (Peron et al., 2012), this finding is in line with several previous studies. A recent review by S. Argaud (2018) implies that PD patients show a deficit in recognizing all 6 basic emotions, particularly when recognizing facial expressions (Peron et al., 2012). Most importantly, impaired emotion recognition in PD patients has been shown to be related to reduced facial emotional expressivity (spontaneous as well as controlled) (Livingstone et al., 2016; Marneweck et al., 2014; Ricciardi et al., 2015; Ricciardi et al., 2017). Thus, the emotion recognition impairments observed in patients with PD might partially result from missing facial feedback. If this were the case, the specific facial mimicry manipulation used in the present study should enhance facial feedback in PD patients and by this improve their recognition of facial emotions. Present results confirmed that PD patients have difficulties to detect emotional changes in facial expressions, however, we found no evidence that facial mimicry manipulation influences the emotional change detection in PD patients.

A potential reason for this finding might be that the facial feedback signal cannot be forwarded in patients with PD. This would imply a breakdown of the facial feedback loop. Apart from the classical brain regions involved in the processing of facial expressions of emotions (e.g., amygdala, insula and limbic system, Haxby et al., 2000) it is thought that the simulation process activates a network of multiple neural regions. A possible mechanism of this simulation process is provided by a specialized mirror neuron system. Studies in monkeys found that mirror neurons in area F5 of the premotor cortex discharge both during action execution and action observation (di Pellegrino, Fadiga, Fogassi, Gallese, & Rizzolatti, 1992; Gallese, Fadiga, Fogassi, & Rizzolatti, 1996; Rizzolatti, Fadiga, Gallese, & Fogassi, 1996). Neurophysiological and brain-imaging studies suggest that the human mirror neuron system is located within the rostral part of the inferior parietal lobule and the ventral premotor area within the inferior frontal gyrus. Further activity was observed within the primary motor cortex as well as in pre- and supplementary motor areas (for a review see Rizzolatti and Craighero, 2004), where the superior temporal sulcus posits the main visual input to the human MNS (Iacoboni & Dapretto, 2006). Studies support the idea that a similar system is activated during the observation and expression of facial emotions with the function to understand the emotional state of others. Several neuroimaging studies confirmed a shared neural network of observing and executing/imitating facial expressions of emotions compromising among others the premotor cortex and pars opercularis of the inferior frontal gyrus, primary and secondary somatosensory cortex, rostral part of posterior parietal cortex, anterior insula, amygdala, hippocampus, cerebellum and visual areas (sulcus temporal superior and middle temporal gyrus) (Carr, Iacoboni, Dubeau, Mazziotta, & Lenzi, 2003; Andreas Hennenlotter et al., 2005; Leslie, Johnson-Frey, & Grafton, 2004; van der Gaag, Minderaa, & Keysers, 2007; Wicker et al., 2003). Recently, Pohl and colleagues (2017) demonstrated that PD patients show impaired activation of the mirror neuron system during the processing of facial expressions. Specifically, compared to controls, patients with PD showed reduced activation within the pars opercularis of the right inferior frontal gyrus, inferior parietal lobule and the supplementary motor area during the observation of facial expressions (Pohl et al., 2017). Consequently, the decreased activity within the fronto-parietal MNS network in PD patients might be responsible for the impaired emotion recognition.

Besides the involvement of the MNS, lesion, imaging and neuromodulation studies confirm that the somatosensory cortex (especially the right) is involved in facial expression recognition processes (see e.g. Adolphs, Damasio, Tranel, Cooper, and Damasio, 2000; Pitcher, Garrido, Walsh, and Duchaine, 2008; Winston, O'Doherty, and Dolan, 2003). Consequently it is assumed that the generated proprioceptive feedback is transmitted to and processed within the somatosensory cortex (Niedenthal et al., 2016). The somatosensory cortex allegedly plays an important role in understanding the facial expressions of others. It is thought that the somatosensory cortex is important for simulating emotional expressions and experiencing the emotional states of others (Adolphs, 2002). One assumptions is that while observing facial emotional expressions the activation of congruent facial muscles may lead to an activation of somatosensory representation of the emotional states related to those facial movements (Goldman & Sripada, 2005). Only a few studies so far have investigated the involvement of the somatosensory cortex in PD patients during facial emotion recognition (Wabnegger et al., 2015; Yoshimura, Kawamura, Masaoka, & Homma, 2005). Yoshimura et al. (2005) found that in PD patients, brain potentials to fearful faces were not generated within amygdala and visual cortex as they are in healthy controls, but within the somatosensory cortex. The extraordinary recruitment of somatosensory areas was also reported by Wabnegger et al. (2015), who found a positive association between somatosensory cortex activation and performance in facial expression recognition. Because there were no differences in the recognition of negative emotional expressions between HCs and PD patients the authors assume that the increased activation within somatosensory area displays a compensatory mechanisms. The interpretation of the recruitment of the somatosensory cortex as compensatory structure would also explain results by Wieser et al. (2012). Here again, results reveal no impairments of emotion recognition in PD patients. However, the authors report diminished early visual discrimination while late cortical evaluative processes are intact. The unimpaired emotion recognition with simultaneous compromised early visual discrimination could be suggestive of compensatory functions of the somatosensory, premotor and prefrontal areas. Altogether, these studies are in favor for an intact functioning or rather an overfunctioning of the somatosensory cortex in patients with PD. Consequently, the missing facial mimicry manipulation effect in PD patients in the present study is probably not a result of an absent processing of the facial feedback signal within the somatosensory cortex and might be attributed to a mal-functioning of other brain structures. However, in contrast to the present research, the studies by Yoshimura et al. (2005) and Wabnegger et al. (2015) investigated only negative emotions and the latter study only included patients in the OFF dopaminergic state. Additionally, both studies report no impairments of emotion recognition in their patient group whereas we found a clear impaired performance in the detection of emotional changes in PD patients. Thus, further studies are necessary to investigate the processing within the somatosensory cortex during facial emotion recognition.

Another reason for the missing effect of the facial mimicry manipulation in PD patients on the detection of emotional changes might rely on later processing stages where the integration of the visual information and the facial feedback information takes place. The process of multisensory integration involves the integration of complex sensory information of different modalities into a unique percept (Stein & Meredith, 1990). It has been demonstrated that basal ganglia play a pivotal role in this integration process (Nagy, Eördegh, Paróczy, Márkus, & Benedek, 2006). As basal ganglia undergo considerable structural changes due to loss of dopaminergic neurons in substantia nigra in PD (Jankovic, 2003) it is not surprising that PD patients have difficulties in multisensory integration processes (Adamovich, Berkinblit, Hening, Sage, & Poizner, 2001; Fearon, Butler, Newman, Lynch, & Reilly, 2015; Ren et al., 2018). Additionally, several studies revealed abnormal visual processing in patients with PD (Armstrong, 2017; Weil et al., 2016), which might further contribute to the present emotional change detection impairment of PD patients. Related to the present study, it is conceivable that the degeneration of dopaminergic neurons in the basal ganglia results in a modified integration process of the facial feedback and the possibly distorted visual information of the emotional expression, potentially explaining the lacking influence of facial feedback on emotional change detection in PD. However, future studies are needed with focus on this assumption.

5.5. Conclusion

In order to investigate the involvement of the missing facial mimicry on impaired emotion recognition processing in PD we conducted a behavioral study where facial expressions were manipulated to a smiling, frowning or neutral expression in participants with PD and healthy controls. While the mimicry manipulations considerably influenced the ability to detect emotional changes in healthy controls, the change detection ability was unaffected in PD patients. As the supportive facial mimicry in the present study did not change the emotion recognition in PD patients one has to conclude that it is not the missing or reduced facial mimicry but possibly the transmission and the neural processing of the resulting facial feedback which leads to this prominent deficit in those patients. As the reduced facial mimicry as well as the impairment of emotion recognition considerably influence the social well-being and the quality of life of those patients further studies are indispensable to investigate the facial feedback process in PD patients.

6. General Discussion

Social interaction is, among others, characterized by manifold nonverbal communication – where facial expressions take a special positon. These facial expressions can be of high complexity – making it difficult to decode and correctly react towards them. A natural tool for this difficult task is provided by our own facial mimicry. According to the embodied simulation account, we automatically simulate or mimic the observed emotional expressions of others and the resulting facial feedback facilitates the subsequent processing of the observed facial emotion.

The present thesis focused on the influence of facial mimicry on facial emotion recognition. Particularly, I wanted to investigate whether the automatic processing of emotional expressions is influenced by facial mimicry (Project 1), whether facial mimicry also influences the memory for emotional expressions (Project 2) and if the impaired emotion recognition in patients with PD can be attributed to the reduced or missing facial mimicry of those patients (Project 3).

Generally, results of the present thesis highlight the impact of facial mimicry on the automatic processing of emotional facial expressions as well as on memory processes towards emotional expressions in healthy individuals and show that in PD patients facial mimicry cannot longer influence facial emotion recognition. The findings of the three projects will be presented and discussed in more detail in the following.

Results of the Project 1 confirmed my hypothesis that facial mimicry does influence the automatic processing of emotional expressions. Particularly, electrophysiological data reveal that the activation of facial muscles responsible for smiling increased eMMN to sad while simultaneously decreasing eMMN to happy faces. As previous studies have confirmed that facial mimicry can influence the emotional experience (e.g. Finzi and Rosenthal, 2014; Finzi and Wasserman, 2006; J. D. Laird, 1974) it can be assumed that the smiling mimicry manipulation induced a positive mood. Consequently, the perceived facial expressions might constitute a more or less large mismatch to the induced positive mood or this positive mood might act as a priming effect, thereby influencing the subsequent processing of the emotional faces. Alternatively, it might also be possible that the facial mimicry manipulation influenced the memory for the emotional faces. This assumption complies with a study by James D Laird et al. (1982) showing that emotions can facilitate the encoding of emotion-congruent information in memory. Further, it is thought that the MMN reflects a prediction error signal based on memory comparison processes (I. Czigler, 2014; Näätänen et al., 2007). As a result, the smiling mimicry manipulation condition might have primed the activation of positive emotional information thereby facilitating the subsequent encoding and retrieval of happy facial expressions and leading to a more effective storage of happy expressions in memory and hence a smaller eMMN signal towards them. In contrast, sad facial expressions are stored less effectively in memory under the smiling condition and thus pose a greater mismatch with increased eMMN signal. In a following step, I implemented a second project to investigate whether facial mimicry impacts memory processes to emotional facial expressions.

Project 2 confirmed my hypothesis that facial mimicry and the resulting facial feedback influences memory to emotional expressions. More specifically, the data show that the induction of a smiling expression improved the memory performance selectively for happy faces. This improvement was even more pronounced for high ambiguous happy faces. Additionally, the results further confirm the hypothesis that facial mimicry manipulation differently influences the memory performance between male and female participants – male participants are more vulnerable to the facial mimicry manipulation, during the smiling condition they remembered faces as more positive/less negative. However, a discussion of the present results is impeded as a comprehensive research on working memory processes for emotional expressions is lacking. Analogously to the first project, the results might be explained by a mood induction effect of the facial mimicry manipulation. As a consequence, a happy mood, as it might have been induced by the smiling mimicry condition, would have primed the activation of positive emotional information and consequently facilitated the storage and retrieval of happy facial expressions. Today, there exist some evidence that mood itself can influence memory (Bower, 1981; James D Laird et al., 1982) and is additionally further supported by mood-congruent storage of information in memory in anxious and depressed participants (Ridout et al., 2003; Russo et al., 2006; Watkins et al., 1992). Furthermore, collected data of the IPANAT slightly confirm that the applied facial mimicry manipulation reduced the negative affect. However, an argument against the assumption that the facial mimicry manipulation modified mood, which in turn influences the memory for emotional expressions comes about by studies investigating the influence of mood on processing styles. These studies demonstrated that happy mood triggers a more global while sad mood triggers a more local, analytical processing style (Bless et al., 1996; Gasper & Clore, 2002). In the present study, a more local, analytical processing style would be preferable to correctly store and retrieve emotional low intensity facial expressions. However, assuming that the smiling condition would have elicit a happy mood, a global processing style would have been exist which consequently would have impaired the memory for such low intensity emotional expressions. Thus, it seems likely that the facial mimicry manipulation directly primed the activation of the related brain regions which are active during the execution of a smiling expression and the storage and retrieval of related information in memory, like the dlPFC, amygdala and STS. Particularly interesting was the gender dependence of the present results, as there exists only little evidence for the different influence of facial mimicry on emotional processing by gender (Niedenthal et al., 2012; Wood et al., 2019).

In the third project, I demonstrated that facial mimicry manipulation cannot influence emotion recognition in patients with PD. Thus, contrary to my hypothesis the facial mimicry manipulation did not change the detection of emotional changes in facial expressions in PD patients in comparison to healthy controls which showed an influence on their emotional change detection ability analogously to a previous study (Lobmaier & Fischer, 2015). As recent research revealed that PD patients show a reduced facial mimicry to – and an impaired recognition of - facial emotional expressions, the assumption emerged that the reduced or rather the missing facial mimicry might be responsible for the impaired emotion recognition processes in those patients (S. Argaud, 2018; Prenger & MacDonald, 2018). However, the present results could not confirm this assumption. Therefore, it might be speculated that not only the reduced facial mimicry, but rather the whole flawed facial feedback process contributes to the prominent impairments of emotion recognition. This assumption is in accordance with a study by Pohl et al. (2017) showing an impaired activation within the MNS during the processing of facial expressions in PD patients. Further, it has been revealed that the process of multisensory integration is, among others, performed within the basal ganglia (Nagy et al., 2006). As this brain area undergoes considerable structural changes during the course of the disease in PD (Jankovic, 2003) it might be suspected that the integration of the visual information and the facial feedback is disturbed in individuals with PD.

The results of my thesis implicate that facial mimicry is considerably involved in the recognition of emotional expressions as well as in their storage and retrieval from memory. In the past, a study on facial paralysis raised concerns about the necessity of facial mimicry for the correct recognition of emotional expressions (Rives Bogart & Matsumoto, 2010). This study compared participants with Moebius syndrome, characterized by congenital bilateral facial paralysis, with a healthy control group in their ability to recognize facial expressions. As the authors found no difference between both groups in their emotion recognition accuracy, they concluded that facial mimicry is not necessary to recognize emotional facial expressions. However, in a subsequent study, Bogart, Tickle-Degnen, and Ambady (2012) compared participants with congenital against acquired facial paralysis in their compensation of the impoverished facial expression. Results of this study demonstrate that individuals with congenital facial paralysis use more expressive verbal and nonverbal behavior to compensate for their missing facial expressions in contrast to individuals with acquired facial paralysis. These results might explain the findings of the first study and further moderate the claim that facial mimicry is not necessary for emotion recognition. Accordingly, although facial mimicry is not inevitably necessary for the intact processing of emotional expressions it is irrefutably an important facilitative component in this process. This is considerably confirmed by the present findings showing that the manipulation of the facial mimicry and consequently the facial feedback influences the automatic processing of emotional expressions (Project 1), the memory to emotional expressions (Project 2) as well as the ability to detect emotional expression changes (Project 3) in healthy participants.

Furthermore, the presented thesis demonstrates that the classical facial mimicry manipulation initially introduced by Strack et al. (1988) is an appropriate method to study the influence of facial mimicry on cognitive processes. However, a recently conducted replication study raised doubts about this method. In an attempt, 17 laboratories aimed to replicate the results of Strack et al. (1988) and failed by finding any effect of the facial mimicry manipulation on cartoon ratings, consequently questioning the validity of the former study (Wagenmakers et al., 2016). However, a re-replication study by Noah et al. (2018) counteracts this concern by demonstrating that results of facial mimicry manipulation can itself be modulated by the presence or absence of a monitoring camera. The authors replicated the facial feedback effect in the absence of the camera, while there was no effect when participants were monitored, as it was the case in the study by Wagenmakers et al. (2016). This study and several other studies including the presented projects clearly demonstrate that facial mimicry can be effectively manipulated by the different pen holding conditions.

Limitations and Future Perspectives

While the present thesis provides an important contribution to the research on the influence of facial mimicry on the processing of facial emotional expressions in healthy as well as in a clinical subgroup, the projects presented within this thesis underlie some methodological limitations. These limitations and additional incentives for future directions are the topic of this last section.

Although the here applied facial mimicry manipulation of different pen holding conditions was introduced by Strack et al. (1988) in order to prevent that participants are aware of the link between the contraction of certain muscles and the corresponding emotional meaning behind it, I cannot completely exclude that participants get the truth behind the different pen holding conditions. However, in the presented projects I have tried to exclude any effect of the notice of the study aim by applying a cover story explaining the different pen holding conditions. In all three projects, participants were told that they display a control group to patients suffering from facial paralysis after stroke. Further, at the end of each experiment they were asked about the possible function of the different pen holding conditions, showing that they were consistently unaware of the underlying manipulation. Nevertheless, participants might have been additionally distracted from the different pen holding conditions. For this reason, future studies might apply a more passive facial mimicry manipulation method. Such promising facial mimicry manipulation methods are represented by (i) the injection of BOTOX to certain facial regions thereby artificially paralyzing the underlying muscles, (ii) the application of a black mask, thereby establishing a resistance to facial muscle contractions which improves the facial feedback or (iii) by the electrical stimulation of facial muscles (Ilves et al., 2019; Neal & Chartrand, 2011; Zariffa, Hitzig, & Popovic, 2014). Especially the method of facial muscle stimulation exhibits a promising tool of facial mimicry manipulation as in this way it is possible to pose a variety of emotional expressions.

Further, the possible influence of mood on the present findings occurs throughout the discussion. Several studies have revealed that facial mimicry can influence the mood of the participants (Kleinke et al., 1998; J. D. Laird, 1974; Larsen et al., 1992). Therefore, it cannot be established unequivocally whether the here applied facial mimicry manipulation influences the mood of the participants which in turn influences the processing of emotional expressions or whether the facial mimicry manipulation directly activates corresponding brain regions and thereby facilitating or worsening facial emotion processing. In the present thesis, mood of participants was only recorded within Project 2 by means of the IPANAT with the result that during the smiling condition the negative affect was reduced while there was no effect on the positive effect. To shed further light on this question, further studies could additionally measure the mood of the participants before and after facial mimicry manipulation application. Another option would be to directly compare the effects of facial mimicry manipulation with those of mood induction methods on, e.g. the recognition of emotional expressions.

A last methodological limitation refers to the second project. Here, facial mimicry manipulation was implemented in alternating blocks of holding the pen with the teeth vs. holding the pen with the non-dominant hand over the whole duration of the experiment. Thus, it is unclear which level of memory process was influenced by the manipulated facial feedback – the storage, maintenance or the retrieval of the emotional expression. Future studies could use other facial mimicry manipulation methods (like the mentioned electrical facial muscle stimulation) to more specifically manipulate facial mimicry during the different stages of memory processing. For more specificity, it would also be possible to ask participants to react towards the target image with a corresponding facial expression or to indicate the remembered facial expression first with an equivalent posing of the facial expression before reporting the observed intensity level.

With respect to the findings of the influence of facial mimicry manipulation on the recognition of emotional expressions in PD patients it would also be interesting to compare neural activity of PD patients with healthy controls during voluntary and automatic facial mimicry. Especially neuroimaging studies might shed light on the question whether the whole facial feedback process is disturbed in those patients causing the prominent emotion recognition impairments.

Conclusion

In this thesis, I have investigated the influence of facial mimicry on the processing of emotional expressions by means of facial mimicry manipulation. The findings of my projects show that the automatic processing of facial expressions is influenced by facial mimicry and that facial mimicry impacts the memory for emotional expressions. Therefore, these findings further demonstrate the importance of facial mimicry for our social interaction. In everyday life, emotional expressions frequently occur outside the focus of our attention and a continuous renewal of the memory for the emotional expressions of our counterparts plays an important role in our social communications. Especially the role of facial mimicry and the resulting facial feedback in a subgroup of patients like those with Parkinson's disease deserves special consideration as those patients suffer from deficits of automatic facial mimicry – showing that facial mimicry is highly important for our quality of life and deserves special consideration.

Therefore, I hope that my present research will serve as an incentive for future studies on the influence of facial mimicry on cognitive processes.

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8. Appendices

Appendix A: Project 2, Emotional Bias Formulas

- Happy target face correctly remembered as happy face

$\boldsymbol{Happy_{correct}} = \%\ test\ image - \%\ target\ image$

Example Target image: 40% happy Test image: 30% happy

Emotional bias: 40% - 30% = 10%

- Happy target face incorrectly remembered as sad face

$\boldsymbol{Happy_{wrong}} = -(\%\ target\ image + \%\ test\ image)$

Example Target image: 40% happy Test image: 30% sad

Emotional bias: -(40% + 30%) = -70%

- Sad face correctly remembered as sad face

$\boldsymbol{Sad_{correct}} = \%\ target\ image - \%\ test\ image$

Example Target image: 30% sad Test image: 40% sad

Emotional bias: 30% - 40% = -10%

- Sad face incorrectly remembered as sad face

$\boldsymbol{Sad_{wrong}} = \%\ \text{target}\ image + \%\ test\ image$

Example Target image: 30% sad Test image: 20% happy

Emotional bias: 30% + 20% = 50%

Appendix B: Project 2, Influence of Depressive Symptoms

The ADS-K (Allgemeine Depressionsskala, short-version) is a self-report questionnaire measuring impairments caused by depressive symptom of the last weeks. The present data show that participants exhibited an overall negative bias for happy faces compared to sad faces. To exclude any influence of depressive symptomatic on this negative bias we conducted an additional statistical analysis. For this purpose, a RM-ANOVA with *Facial Muscle Manipulation* and *emotion* as within- and gender as between-participant factors and *ADS-K* as covariate was conducted. Analogously to the main results, this ANOVA revealed a significant main effect of *Facial Muscle Manipulation* ($F_{1,34}$ = 4.148, P = 0.05, η_p^2 = 0.109). Further the interactions of *emotion* x *ADS-K* as well as *Facial Muscle Manipulation* x *emotion* x *ADS-K* did not reach significance (all Ps > 0.8) and there was no main effect of *ADS-K* (F1,34 = 0.131, P = 0.720, η_p^2 = 0.004). Consequently, it can be excluded that the apparent negative bias is caused by the influence of any depressive symptoms of the participants.

Appendix C: Project 2, Influence of Emotional State

The IPANAT (Implicit Positive and Negative Affect Test) is a self-report questionnaire of measuring the negative and positive affect (Quirin et al., 2009). To control for the impact of our facial mimicry manipulation on the emotional state of the participants we performed an additional statistical analysis. For this purpose, two separate paired t-Tests were calculated to directly compare the positive affect between the hand and the teeth condition as well as the negative affect between the two different facial mimicry manipulation conditions. This analysis revealed a significant difference for the negative affect between the manipulation conditions where the negative affect was significantly decreased after the teeth (M = 1.68, SD = 0.42) compared to the control condition (M = 1.82, SD = 0.51, t(36) = 2.326, P = 0.026, d = 0.3). However, the positive affect of the participants did not differ between the two Facial Muscle Manipulation conditions (M_{hand} = 2.15, SD_{hand} = 0.40, M_{teeth} = 2.24, SD_{teeth} = 0.41, t(36) = -1.501,P = 0.142, d = -0.222). Thus during the smiling condition the negative affect was significantly decreased compared to hand condition indicating that the emotional affect of the participants was modulated by our facial muscle manipulation.

Publications

2019

Wagenbreth, C., **Kuehne, M.**, Voges, J., Heinze, H.-J., Galazky, I. & Zaehle, T. (2019) 'Deep Brain Stimulation of the Subthalamic Nucleus Selectively Modulates Emotion Recognition of Facial Stimuli in Parkinson's Patients', Journal of clinical medicine, 8(9), p. 1335.

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Erklärung zur Dissertation

Hiermit bestätige ich, dass ich die Dissertation (Titel):

Facial Mimicry and the Processing of Facial Emotional Expressions

im Fach

Psychologie

unter der Leitung von PD Dr.

Janek Lobmaier

ohne unerlaubte Hilfe ausgeführt und an keiner anderen Universität zur Erlangung eines akademischen Grades eingereicht habe. Ich habe keine anderen als die angegebenen Quellen verwendet. Alle Stellen, die wörtlich oder singgemäß aus Quellen entnommen wurden, habe ich als solche gekennzeichnet. Mir ist bekannt, dass andernfalls der Senat gemäss Artikel 36 Absatz 1 Buchstabe r des Gesetzes vom 5. September 1996 über die Universität zum Entzug des auf Grund dieser Arbeit verliehenen Titels berechtigt ist. Für die Zwecke der Begutachtung und der Überprüfung der Einhaltung der Selbständigkeitserklärung bzw. der Reglemente betreffend Plagiate erteile ich der Universität Bern das Recht, die dazu erforderlichen Personendaten zu bearbeiten und Nutzungshandlungen vorzunehmen, insbesondere die schriftliche Arbeit zu vervielfältigen und dauerhaft in einer Datenbank zu speichern sowie diese zur Überprüfung von Arbeiten Dritter zu verwenden oder hierzu zur Verfügung zu stellen.

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