# A SPARK OF EMOTION: THE IMPACT OF ELECTRICAL FACIAL MUSCLE ACTIVATION ON EMOTIONAL STATE AND AFFECTIVE PROCESSING

Themis Nikolas Efthimiou

Department of Psychology

University of Essex

This thesis is submitted for the degree of Doctor of Philosophy

November 2023

# ABSTRACT

Facial feedback, which involves the brain receiving information about the activation of facial muscles, has the potential to influence our emotional states and judgments. The extent to which this applies is still a matter of debate, particularly considering a failed replication of a seminal study. One factor contributing to the lack of replication in facial feedback effects may be the imprecise manipulation of facial muscle activity in terms of both degree and timing. To overcome these limitations, this thesis proposes a non-invasive method for inducing precise facial muscle contractions, called facial neuromuscular electrical stimulation (fNMES). I begin by presenting a systematic literature review that lays the groundwork for standardising the use of fNMES in psychological research, by evaluating its application in existing studies. This review highlights two issues, the lack of use of fNMES in psychology research and the lack of parameter reporting. I provide practical recommendations for researchers interested in implementing fNMES. Subsequently, I conducted an online experiment to investigate participants' willingness to participate in fNMES research. This experiment revealed that concerns over potential burns and involuntary muscle movements are significant deterrents to participation. Understanding these anxieties is critical for participant management and expectation setting. Subsequently, two laboratory studies are presented that investigated the facial FFH using fNMES. The first study showed that feelings of happiness and sadness, and changes in peripheral physiology, can be induced by stimulating corresponding facial muscles with 5–seconds of fNMES. The second experiment showed that fNMES-induced smiling alters the perception of ambiguous facial emotions, creating a bias towards happiness, and alters neural correlates of face processing, as measured with event-related potentials (ERPs). In summary, the thesis presents promising results for testing the facial feedback hypothesis with fNMES and provides practical guidelines and recommendations for researchers interested in using fNMES for psychological research.

# TABLE OF CONTENTS

# ACKNOWLEDGEMENTS

First, I would like to extend my deepest gratitude to my PhD supervisor, Dr Sebastian Korb, for his unwavering support, guidance, and mentorship throughout my research journey. His profound insights, encouragement, and dedication have been instrumental in shaping my academic trajectory. I am grateful to my team members, Dr Marc Mehu, Dr Arthur Elsenaar, and Dr Joshua Baker, for their priceless feedback, collaborative energy, and excitement. Collaborating with Joshua has been an honour and an inspiring experience that has greatly enriched the quality and profundity of my research.

I would like to express my gratitude to the University of Essex staff as well. I am especially thankful to my co-supervisors, Professor Reinhold Scherer for guidance and Dr Alex Sel, for her insights, support, and guidance. My sincere appreciation goes to Steven Fowles for his indispensable technical assistance during the project and friendship. Finally, a thank you to my collaborators, Dr Paul Hanel and Dr Alasdair Clarke, for their contributions. I am grateful to Dr Tom Foulsham and Dr Helge Gillmeister for overseeing my supervisory panels and to Trudi Day for her assistance and support with the technical aspects of my doctoral research.

My deepest gratitude goes to my family for their endless support and unwavering faith in me. To my two sisters, I appreciate your constant encouragement. A special thanks to my mum, whose love and guidance have been pivotal in my journey, offering strength and solace in difficult times. Your collective roles have been fundamental to my path, and for that, I am profoundly thankful.

Lastly, I would like to express my heartfelt appreciation to my girlfriend, Georgia. Your belief, patience, and unwavering love have been my anchor. I am truly grateful for every moment, conversation, and gesture of kindness that you have shared with me.

# COVID IMPACT STATEMENT

The COVID-19 pandemic had a significant impact on my PhD thesis. The pandemic began two months after I started my PhD, which meant that I had to start my research in a different environment than I had planned.

One of the biggest challenges I faced was the delay in constructing the laboratory. The laboratory required significant upgrades, which involved the installation of new equipment, including electrical stimulators, a new computer, webcams, monitors, and the synchronisation of the electroencephalography amplifier with the new PC to eliminate input lag, and the pandemic caused delays in the delivery/setup of equipment and testing of the equipment. This meant that I was unable to start my experiments until several months later than I had planned. In addition, the pandemic made it difficult to conduct experiments. We had to take several precautions to protect ourselves and our participants from COVID-19; we implemented safety measures that consequently delayed the pace of our research process. For example, we had to disinfect the laboratory regularly and always wear personal protective equipment. We also had to limit the number of people in the laboratory at any given time, which made it difficult to conduct large-scale experiments. Finally, the pandemic made it difficult to recruit participants for my study. Many people were reluctant to participate in research studies because of the risk of catching COVID-19. In addition, many students were not returning to campus because of the pandemic, which made it difficult to find participants from the university community.

Overall, the COVID-19 pandemic had a significant impact on my PhD thesis. It caused delays in the construction of the laboratory, the conduct of experiments, and the recruitment of participants. However, I was able to overcome these challenges and complete my research. I am confident that my thesis is still of high quality and that it makes a significant contribution to the field.

# LIST OF PUBLICATIONS BY CANDIDATE

## Published in peer-reviewed journals:

Efthimiou, T. N., Hernandez, M. P., Elsenaar, A., Mehu, M., & Korb, S. (2023). Application of facial neuromuscular electrical stimulation (fNMES) in psychophysiological research: Practical recommendations based on a systematic review of the literature. *Behavior Research Methods*. https://doi.org/10.3758/s13428-023-02262-7

Efthimiou, T. N., Hanel, P. H. P., & Korb, S. (2022). Volunteers' concerns about facial neuromuscular electrical stimulation. *BMC Psychology*, 10(1), 117. https://doi.org/10.1186/s40359-022-00827-3

## Under review and published as pre-prints:

Efthimiou, T. N., Baker, J., M., Clarke, Elsenaar, A., Mehu A., & Korb, S. (2023). Zygomaticus activation through facial neuromuscular electric stimulation (fNMES) induces happiness perception in ambiguous facial expressions and affects neural correlates of face processing. *PsyArXiv*. https://doi.org/10.31234/osf.io/38whf

Efthimiou, T. N., Baker, J., Elsenaar, A., Mehu, M., & Korb, S. (2023). Smiling and frowning induced by facial neuromuscular electrical stimulation (fNMES) modulate felt emotion and physiology. *PsyArXiv*. https://doi.org/10.31234/osf.io/vec8f

# LIST OF FIGURES

# LIST OF TABLES

# List of Abbreviations and Acronyms

| | |
|---|---|
| ANOVA | Analysis of variance |
| AQ | Autism spectrum quotient |
| AU | Action Unit |
| BICI | Body Image Concern Index |
| CNS | Central nervous system |
| DAO | Depressor anguli oris |
| DOSPERT | Domain-Specific Risk-Taking Scale |
| EEG | Electroencephalography |
| EMG | Electromyography |
| EQ | Empathy quotient |
| ERP | Event-related potential |
| FACS | Facial action coding scheme |
| FES | Functional Electrical Stimulation |
| FFH | Facial feedback hypothesis |
| fNMES | functional Neuromuscular Electrical Stimulation |
| GLMM | Generalised linear mixed effects model |
| Hz | Hertz |
| ICNIRP | International Commission on Non-Ionizing Radiation Protection |
| IEC | International Electrotechnical Commission |
| IPIP | International Personality Item Pool |
| LMM | Linear mixed effects model |
| LOTP | Likelihood of taking part |
| LPP | Late positive potential |

| | |
|---|---|
| MAIA | Multidimensional assessment of interoceptive awareness |
| MBS | Moebius syndrome |
| MMN | Mismatch negativity |
| MRI | Magnetic Resonance Imaging |
| MP | Motor point |
| MT | Motor threshold |
| NAQ | Need for affect questionnaire |
| NMES | Neuromuscular electrical stimulation |
| OASIS | Open Affective Standardised Image Set |
| OO | Orbicularis Oculi |
| PANAS | Positive negative affect schedule |
| PRISMA | Preferred Reporting Items for Systematic Reviews and Meta-Analysis |
| PWM | Pulse Width Modulation |
| RMS | Root Mean Square |
| tACS | transcranial altering current stimulation |
| tDCS | transcranial direct current stimulation |
| TENS | Transcutaneous Electrical Stimulation |
| ZM | Zygomaticus major |

# THESIS STRUCTURE

This thesis introduces a novel approach for activating facial muscles through facial neuromuscular electrical stimulation (fNMES). The contention is that fNMES is an effective way to engage facial muscles and provide proprioceptive feedback to the brain. This section outlines the structure of the forthcoming chapters and the thesis format to help readers understand and navigate the content. The thesis is organised into six chapters: two of them are dedicated to reviewing the literature on facial feedback effects and providing guidelines for testing them with fNMES. The subsequent three chapters detail one online and two laboratory experiments. The thesis concludes with a final chapter that discusses the overall findings.

The thesis comprises six chapters, beginning with two comprehensive literature reviews. Chapter 1 acquaints the reader with the concept of facial feedback effects, exploring existing research methodologies, their limitations, and the controversies in the field, as well as describing the feedback mechanism from muscles to the brain. Chapter 2 offers a systematic review of the fNMES literature across various fields and presents itself as a guide for researchers interested in utilising fNMES.

The following chapters—3, 4, and 5—detail individual experiments. Chapter 3 describes an online experiment examining participants' concerns at the prospect of receiving fNMES in a lab setting. Chapters 4 and 5 each report a laboratory test about an aspect of the facial feedback hypothesis introduced earlier. These chapters are structured as journal articles as they are either published or under review at the time of writing. However, an additional summary is included at the end summarising the experiments and their conclusions.

Chapter 6 synthesises the insights from each experimental chapter, discussing the significance of the observed effect sizes and evaluating the practicality of fNMES as a method for probing facial feedback effects.

# 1 Introduction

*'The free expression by outward signs of an emotion intensifies it. On the other hand, the repression, as far as this is possible, of all outward signs softens our emotions... Even the simulation of an emotion tends to arouse it in our minds'* – Charles Darwin (1872, p. 366)

I begin my overview of the interplay between the face and emotion processing with the conjectures of Charles Darwin. Darwin's initial thoughts laid the groundwork for future work theorising about the role of the body and emotional experience. He suggested that emotions and their influence on physical states are the cause of physical changes, not just outcomes of these emotions. However, Darwin's work was centred around his theory of evolution, comparing human facial expressions to those of other great apes and the shared function of facial expressions (for review, see Kavanagh et al., 2022a). Thus, his work never developed this idea further, only foreshadowing what today are theories of embodied cognition.

Greater prominence of the role between physiological sensations and emotion lay in the writings of William James (1884) and Carl Lange (1885), leading to the creation of the James-Lange theory of emotion[1]. This theory suggests that feelings are caused by their physiological responses, in other words, physiological responses precede the emotional

[1]The James-Lange theory was also referred to as the James–Lange–Sergi theory of emotion (Ruckmick, 1936) as the ideas were expressed by Giuseppe Sergi (1894). As noted by Coles et al (2019b), Giuseppe Sergi is often omitted, potentially due to the fact his work was not translated into English.

experience. Interestingly as noted by Tourangeau and Ellsworth (1979), Lange's writings were restricted to visceral physiological changes, for example, heart rate and stomach contractions. It was only in James's writing that muscular feedback of posture and facial expressions were included. However, when discussing the James-Lange theory these two distinctions are overlooked and often grouped. The James-Lange theory received mainstream consensus until the work of Cannon, which provided a critical examination of the James-Lange theory, proposing an alternative framework, in which visceral changes are in reaction to (instead of before) stimuli (Cannon, 1927). Nonetheless, Canon's critique neglected the distinctive muscular element of James's writings, which is a vital part of modern theories about facial muscle feedback.

The debates on how the body and face interact during emotional experiences have given rise to numerous theories, collectively referred to as the theories of embodied cognition. In the broadest sense, these theories can be summed up as the position that the body has a role in shaping our thoughts, feelings, and experiences. It rejects the traditional view of the mind as a disembodied entity that is separate from the body. Instead, embodied cognition theorists argue that the mind is embodied in the sense that it is inextricably linked to the body and its interactions with the world (Barsalou, 2008, 2010; Foglia & Wilson, 2013; Niedenthal, 2007; Semin & Cacioppo, 2008). Narrowing the scope to the human face, it is proposed that generating a facial expression[2] results in facial feedback which exerts influence on behaviour and physiology.

Facial feedback encompasses a wide scope; broadly, it can include the influence of facial movement on an area of interest, such as racial bias (Ito et al., 2006). To narrow down

[2]I use "facial expression" to denote movements typically linked to emotions like happiness or sadness, while "facial movement" refers to expressions without implied emotional intent.

the effect, two related concepts come to the forefront. Firstly, the Facial Feedback Hypothesis (FFH) suggests that facial expressions directly influence our emotions – a smile might induce happiness and a frown sadness. Secondly, sensorimotor simulation occurs when a facial expression observed by an individual is internally simulated in the brain, activating related sensorimotor regions. This process can result in the mirroring/recreation of the observed expression on one's face. As demonstrated by Wood et al. (2016a), the imitation of an observed face can trigger related memories or affect the processing of emotional information. This influences our perception of stimuli, such as faces and voices, making them appear more positive or negative in accordance with the imitated expressions. This distinction is made for clarity: the FFH focuses on felt emotion, while sensorimotor simulation focuses on the recreation of an observed expression on judgment. However, it is important to note that some might assume changes in judgment are due to feeling happier; this is not the case. Simulation approaches emphasise matching rather than actual emotional changes, underscoring the importance of this distinction. In practice, this distinction is less important when considering studies like Strack (1988), which explored facial feedback on judgements of cartoons rather than personal emotional states. For simplicity, this thesis will group these views under the facial feedback hypothesis, acknowledging their mutual relevance in understanding human emotions.

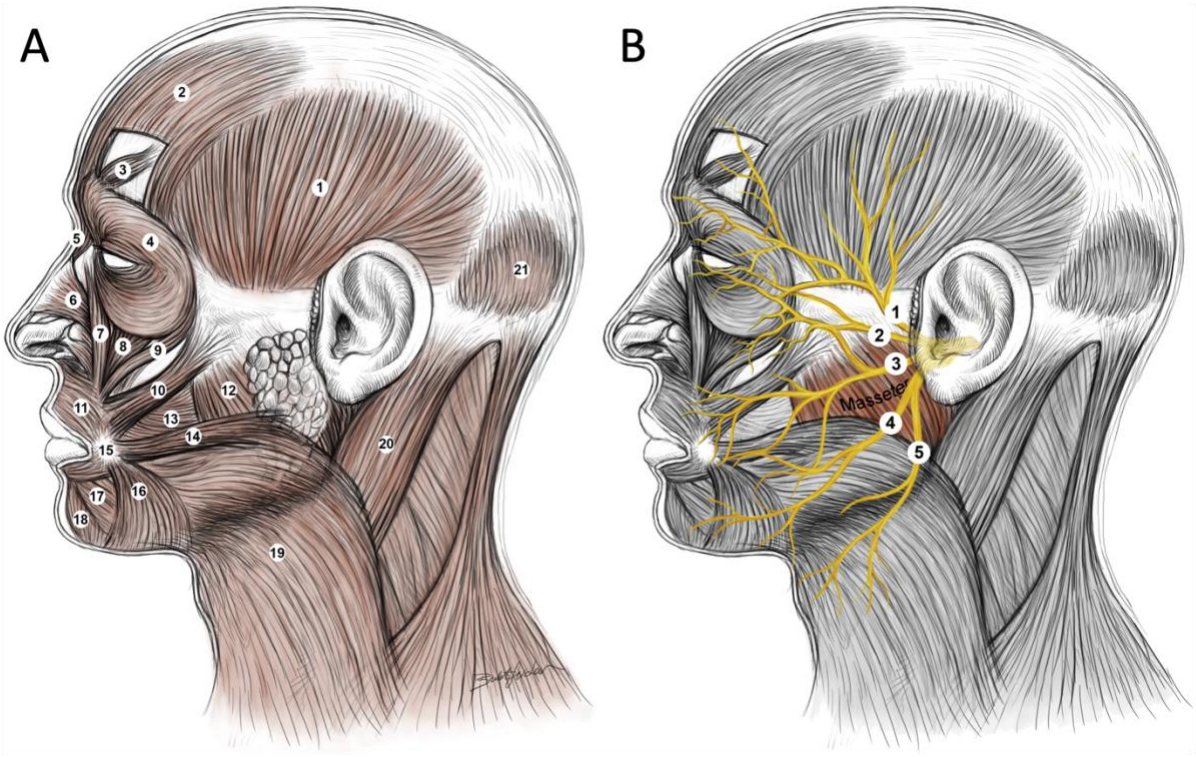
## 1.1 Anatomy of the Human Face

Before delving deeper into the intricacies of the facial feedback effect, it is essential to first explore the anatomy of the human face, providing a foundational understanding of the structures which the feedback results from. The human face consists of approximately 17 paired skeletal muscles (see Figure 1), with a large inter-subject, and partly intra-subject (lateralisation) variability (Pessa et al., 1998). Importantly, the major muscles producing the most common facial expressions (happiness, sadness, fear, anger, surprise, disgust), are

universally and bilaterally present in all subjects (Waller et al., 2008). The facial muscles are divided into two groups: mimetic and masticatory (Marur et al., 2014). Masticatory muscles (i.e., the masseter, temporalis, lateral and medial pterygoid) are engaged during mastication and movement of the lower jaw. They are mostly irrelevant for facial expressions of emotion. In contrast, mimetic muscles can visibly change the shape of the face. They form the basis for emotional facial expressions and are the focus of this thesis.

**Figure 1**

*Illustration of the human face from a profile view*



*Note.* Panel A delineates the facial mimetic and masticatory muscles: 1. temporalis, 2. frontalis, 3. corrugator supercilii, 4. orbicularis oculi, 5. procerus, 6. nasalis, 7. levator labii superioris aleque nasi, 8. levator labii superioris, 9. zygomaticus minor, 10. zygomaticus major, 11. orbicularis oris, 12. masseter, 13. buccinator, 14. risorius, 15. modiolus, 16. depressor anguli oris, 17. depressor labii inferioris, 18. mentalis, 19. platysma, 20. sternocleidomastoid, 21. occipitalis. Panel B shows the terminal branches of the facial nerve as: 1. temporal branch, 2. zygomatic branch, 3. buccal branch, 4. marginal mandibular branch, 5. cervical branch (Marur et al., 2014).

Mimetic muscles are interwoven, mainly due to their common embryologic origin from the second brachial arch's mesoderm (Som et al., 2012). Early in development, the face is composed of a single muscular sheet that quickly differentiates into individual muscles as the embryo grows (Gasser, 1967). There is difficulty in disentangling the muscles, one atlas separates the face into six sections and identifies the muscles based on their common insertion sites using Magnetic Resonance Imaging (MRI) scans of cadavers before and after dissection (for review see, Hutto & Vattoth, 2015). An alternative atlas groups them based on muscle activity, using surface electromyography (EMG; Schumann et al., 2021). Mimetic muscles perform various functions that collectively shape facial expressions. These functions include acting as sphincters and dilators (like the orbicularis oculi, responsible for blinking) or as elevators and depressors (such as the zygomaticus major, which lifts the corners of the lips).

The production of facial expressions involves five cortical areas (the primary motor cortex, ventrolateral premotor cortex, supplementary motor area, and the rostral and caudal cingulate motor cortices) and several subcortical areas (e.g., the basal ganglia), which all project to the facial nuclei located in the brainstem (Korb & Sander, 2009; Morecraft et al., 2001; Müri, 2016). The right and left facial nuclei are in the ventrolateral region of the inferior pons and contain the cell bodies of the neurons forming the facial nerve (Cranial Nerve VII: CNVII; Cattaneo & Pavesi, 2014; Marur et al., 2014). The facial nerve contains sensory, parasympathetic, and motor components. However, only the motor components

innervate the mimetic muscles and the stapedius muscle, emerging from the brainstem at the pontomedullary junction and splitting into five major branches (Rinn, 1984; Wilson-Pauwels, 2010).

Skeletal muscles are constructed of fibres, which can be categorised by their biological characteristics, there are different types but of interest are type 1 ‘slow-twitch’ and type 2 ‘fast-twitch’ (for review see, Scott et al., 2001). When producing a voluntary facial expression, type 1 fibres are recruited first, followed by type 2 fibres. The fibres are present in all skeletal muscles but the difference in proportion is indicative of the muscle's function. For example, type 1 fibres are fatigue-resistant and are dominant in larger muscles used for prolonged periods, such as the leg muscles. Whereas type 2 fibres are dominant in smaller muscles, such as the triceps, and are recruited for fast movements. Cattaneo and Pavesis' (2014) review of the human facial musculature details the percentage of type 1 vs. type 2 facial muscles. The frontalis, corrugator supercilii, and depressor labii inferioris contain mainly (about 50%) type 1 fibres. In contrast, the mentalis, the depressor anguli oris, the orbicularis oris, the levator anguli oris, the zygomatici, and the levator labii superiori are type 2 dominant, as they contain approximately 66% of type 2 fibres. Thus, facial muscles can vary widely in their composition of fibre types, which explains their speed and resistance. For example, the orbicularis oris muscle can contract very quickly, to support eye closure and blinking, and unsurprisingly is made up to 90% of type 2 fibres.

Interestingly, facial muscles differ from other skeletal muscles. First, for skeletal muscles of the trunk and limbs, the skin and subcutaneous tissue are physically separated from the musculature by a layer of fascia. In contrast, facial muscles originate from the bone but insert directly into the dermis through an intricate structure called the superficial musculoaponeurotic system (Ghassemi et al., 2003). Second, every individual fibre of a skeletal muscle is typically innervated by a single motor axon and fibres innervated by the

same motor axon form a motor unit. Innervation occurs at the motor end plate or the neuromuscular junction, where the axon of a motor neuron releases acetylcholine into the synaptic cleft. This release of acetylcholine leads to depolarisation of the muscle cell membrane, which then triggers an action potential. In skeletal muscles, the motor end plates are in the middle of the muscle fibres. This is not the case for facial muscles. In an investigation of ten facial muscles (zygomaticus major and minor, levator labii superioris, levator labii superioris alaequenasi, levator anguli oris, depressor anguli oris, depressor labii inferioris, buccinator, orbicularis oculi, and orbicularis oris), multiple motor end plates were found, often away from the centre of the muscle, with exception of the orbicularis oris and oculi, where motor end plates were evenly distributed (Happak et al., 1997).

The facial nerve and its branches (for review, see Myckatyn and Mackinnon, 2004) are complex due to their arborisation style and the branches cross many areas of the face (Balagopal et al., 2012; Saylam et al., 2007). Indeed, four possible types were identified for the facial nerve based on where the buccal branch first emerges (Kwak et al., 2004). Moreover, the differences extend to the muscles innervated by the branches of the facial nerve, specifically the buccal and zygomatic branches. It was thought that the zygomatic branches mainly innervate the zygomaticus major and the orbicularis oculi and that buccal branches innervated the buccinator, levator labii superioris, levator labii superioris alequenasi, nasalis, orbicularis oris and levator angulioris (Waldeyer, 2011). However, a recent study by (Kehrer et al., 2018) demonstrated that the zygomaticus major is innervated by the zygomatic branches in 83% of cases and by the buccal branches in 17%, concluding that it is difficult to determine which branch innervates the zygomaticus major due to unclear definitions and boundaries between the facial nerve branches.

To conclude, this section has summarised the anatomy of the human face, detailing its muscles, cranial nerves, and fibre types. Understanding these elements is crucial when

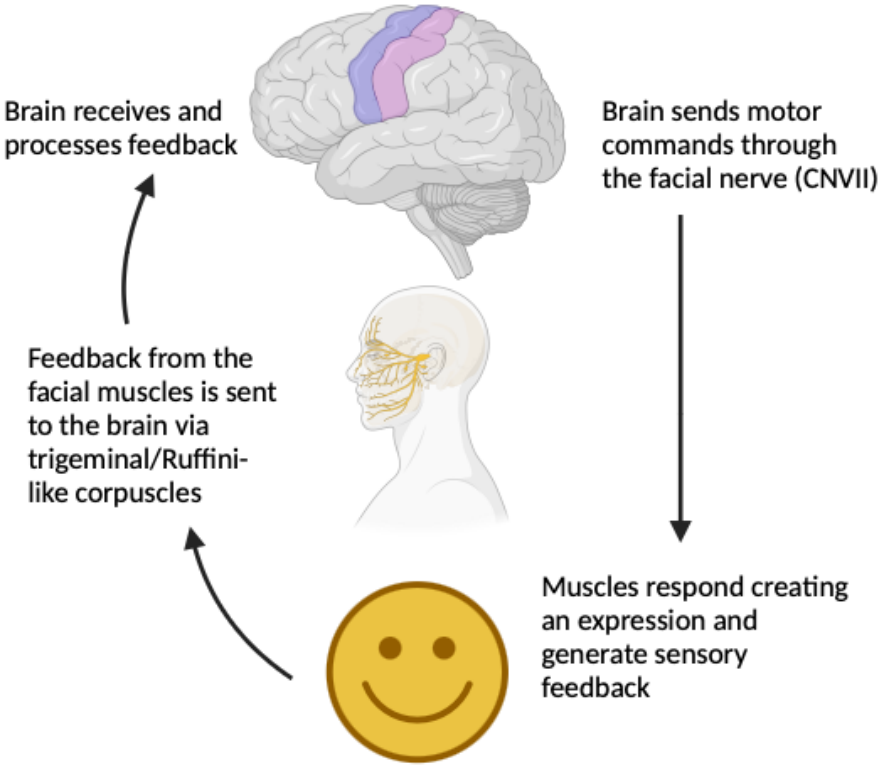
considering facial manipulation. It is important to recognise the differences from skeletal muscles, which necessitate specific considerations. Notably, facial muscles are predominantly small, fast-twitch fibres, making them well-suited for short-term activities that require high demand, but they also fatigue quickly. Furthermore, they directly attach into the dermis with multiple branches of the cranial nerves surrounding and innervating them.

## 1.2 The Facial Feedback Hypothesis (FFH)

Many different viewpoints on the FFH have emerged from the literature (Adelmann & Zajonc, 1989; McIntosh, 1996; Rutledge & Hupka, 1985). In essence, the FFH posits that the feedback from generating a facial expression can influence emotional state. Therefore, if emotions are rooted in physiology, then by modifying physiological factors, such as facial expressions, it is possible to trigger changes in emotional state (see Figure 2). However, what was and is still debated is the extent of these effects. For example, Tourangeau and Ellsworth (1979) summarised the different views of the FFH in three distinct hypotheses. Firstly, the necessity hypothesis posits that an emotional facial expression is necessary for an emotional experience. In other words, you cannot feel an emotion without making the corresponding facial expression. Secondly, there is the sufficiency hypothesis, which posits that facial expressions alone can be adequate to elicit an emotional experience. This suggests that the act of producing a facial expression can trigger a specific emotion, independent of whether that emotion is experienced in that moment. Lastly, the monotonicity hypothesis focuses on the intensity of the expression, proposing the strength of a facial expression will have a positive, monotonic (unchanging) correlation with the intensity of the subjective emotion. In other words, the more intense the facial expression, the more intense the subjective emotion will be.

**Figure 2**

*Illustration of the bidirectional communication between the brain and facial muscles in the facial feedback process*




*Note.* The brain sends motor commands to the facial muscles via facial nerve (Cranial Nerve VII: CNVII), leading to the creation of an expression. This facial movement generates sensory feedback, which is relayed back to the brain through the trigeminal/Ruffini-like corpuscles for processing. This loop exemplifies the interconnectedness of facial expressions and neural processes.

Later, an updated classification was proposed in a literature review by Adelmann and Zajonc (1989). These were then developed by McIntosh (1996) who put forth four research questions. The first question is whether distinct facial expressions correspond to specific emotions. There is some consensus around this question, termed the common view[3] (for a

[3]This consensus is steadily changing, as facial expressions can have multiple meanings (Martin et al., 2017; Niedenthal et al., 2010). But for research purposes, this has been the dominant paradigm.

more comprehensive discussion and critique of this view, see Barrett et al., 2019), driven by the work of Ekman (1973) and the development of the Facial Action Coding System (FACS; Ekman et al., 2002; Friesen & Ekman, 1978). According to FACS, facial movements are categorized into units known as Action Units (AUs), resulting in the classification of 33 facial muscle movements and 25 head and eye movements in a non-theoretical manner (Waller et al., 2020).

The second question addresses whether facial expressions are necessary for the experience of emotion, as posited by the necessity hypothesis. However, research on clinical groups with facial paralysis, such as those with Moebius syndrome (Rives Bogart & Matsumoto, 2010) or idiopathic facial paralysis (Keillor et al., 2002), suggests that this hypothesis might not hold. These groups can experience emotion despite lacking facial expressions. Although McIntosh (1996), discusses some nuances to this idea, the necessity hypothesis is generally considered to have been dismissed.

The last two ideas have been the most tested. One is that facial feedback can initiate an emotional experience, even in the absence of an emotional stimulus. The other is that it can modulate an ongoing emotional experience that was induced by an emotional stimulus. These two effects have been distilled from much debate and research as the main tenets of the FFH and have been at the centre of most research (Coles et al., 2019b; Coles et al., 2022).

## 1.3 The FFH today

The purpose of the previous section(s) was to introduce the reader to the FFH and the rich history behind it. Indeed, the idea can be considered widespread through commonly used phrases such as "grin and bear it" (Kraft & Pressman, 2012), and "when you smile, the world smiles back" (Sel et al., 2015), as well as expressions such as "fake it until you make it", "smile until you make it", and "turn that frown upside down". While the FFH has been interpreted in various ways by different scholars over the years, a century of writings and

experiments have converged on a broad consensus: the peripheral nervous system plays a significant role in shaping emotional experiences (for review, see Moors, 2009).

The facial feedback effect is more than just theoretical; it has tangible real-world implications. For example, the act of smiling can enhance physical well-being (for review, see Cross et al., 2023) and aid in stress reduction (Ansfield, 2007; Kraft & Pressman, 2012). Moreover, there are clinical applications. Restricting frown-associated muscles, specifically the corrugator supercilii and procerus, with Botox injections has been shown to alleviate symptoms of depression. This is supported by several studies (Finzi & Rosenthal, 2014, 2016; for review, see Coles et al., 2019a). Efforts have been made to restore muscle activity in individuals with idiopathic facial paralysis, aiming to restore their diminished emotion recognition abilities (Rantanen et al., 2016; Storbeck et al., 2019). Additionally, interventions have been developed for Parkinson's patients to target tremors, thereby improving their emotional recognition abilities (Argaud et al., 2018; Balconi et al., 2016; Kuehne et al., 2023).

However, recent research tends to support the idea that these effects are not very strong. A recent study that looked at 134 research papers found that facial feedback effects are small (Coles et al., 2019b). However, even these seemingly minor cumulative effects may carry significance in the short term (Funder & Ozer, 2019). With this understanding in mind, we will now delve into an overview of the methodologies employed to investigate these facial feedback effects and their impact on an individual's emotional state and cognitive processes.

## 1.4 Techniques for Manipulating Facial Muscles

Facial manipulation techniques can be divided into two types: those that activate muscles by causing them to engage from a resting state (as discussed in the “Activation studies” section), and those that restrict or paralyse muscle activation (refer to the “1.4.2 Restriction studies” section). To quantify the effects of these techniques, participants’ emotional states are often measured. This approach tests the first tenet of the Facial Feedback

Hypothesis (FFH), which posits that facial feedback modulates emotional state. To examine the second tenet — that facial feedback alters perception — participants may be exposed to emotional stimuli (such as faces, words, videos) and asked to rate or categorise their content.

### 1.4.1 Activation studies

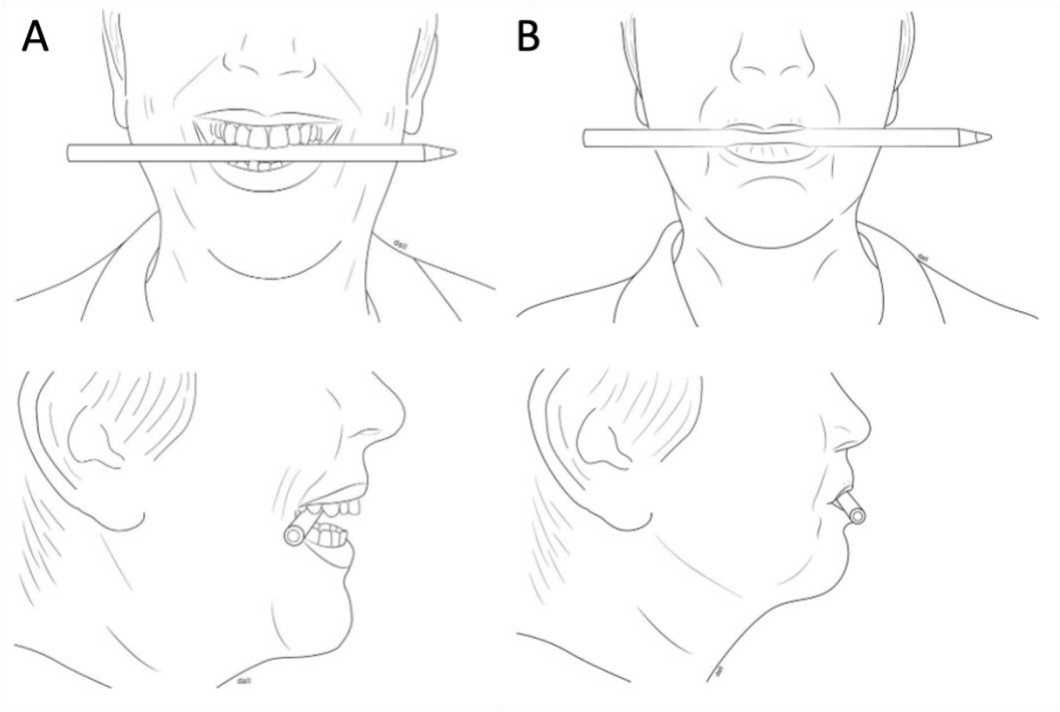
In a series of early experiments, the FFH was explored by having participants voluntarily pose a facial expression (Duclos et al., 1989; Duncan & Laird, 1980; Laird, 1974; Tourangeau & Ellsworth, 1979). Laird (1974) conducted two studies, in which electrodes were placed on the corners of the mouth or between the eyebrows. Participants were instructed to contract the muscles beneath the electrodes, producing either a smile or a frown, respectively. In the first experiment, participants viewed emotional images, then completed a mood questionnaire related to these images while posing a smile or frown. The authors found that mood scores for aggression, but not for social affection, were higher when frowning. Conversely, when participants posed a smile, scores for social affection were higher than for aggression. The second experiment employed the same technique for inducing a smile or frown. Participants viewed humorous cartoons, then completed a mood questionnaire, assessing their feelings and rating the funniness of the cartoons. In line with the FFH, those who produced a smile reported greater feelings of happiness and gave higher funniness ratings compared to those instructed to frown. However, this technique faced criticism, notably from Buck (1980), who argued that demand characteristics might have influenced the results, as it could induce cognitive expectancies associated with the explicitly mentioned facial expression.

To overcome the issue of demand characteristics, a seminal study by Strack et al. (1988) had participants watch cartoons while producing a smile or pout. This was achieved by holding a felt-tip marker sideways between their teeth, without touching it with their lips (resulting in facial muscle activation resembling a smile), or lengthwise between their pouting

lips (hindering them from smiling, as shown in Figure 3). In a control condition, participants held the marker in their hand. Importantly, a cover story was used, and participants were not explicitly asked to produce facial expressions. The study found that participants reported being more amused and finding the cartoons funnier when smiling by holding the marker between their teeth, compared to when holding it between their lips or in their hand. These results suggest that activating facial muscles modulates humour perception. Incidental methods have been extensively used to explore facial feedback effects. The pen-in-mouth technique (or similar methods using other objects such as pencils, chopsticks, and devices) has been the most common. Others have employed chewing gum (Oberman et al., 2007), applying tape to the face (Mori & Mori, 2009), and using golf tees (Larsen et al., 1992). A common finding across these studies is that facial feedback modulates the visual perception of affective stimuli and emotional experience.

**Figure 3**

*Depiction of the 'pen-in-mouth' technique shown from both front and side views*



*Note.* Column A showcases the smile induction method, with the pen held between the teeth. Column B demonstrates how the pen can be used to limit facial movement. Taken from Marmolejo-Ramos et al. (2020) and image copyright ©Daniela Alvarez, 2020.

Evidence suggests that incidental techniques also influence the neural processing of affective stimuli. This has been explored using electroencephalography (EEG), a non-invasive method that records the brain's electrical activity through electrodes placed on the scalp (Biasiucci et al., 2019). EEG studies often focus on event-related potentials (ERPs), which are used to examine changes in neural activity. ERPs are obtained by time-locking the analysis window to a sensory, cognitive, affective, or motor event, and then averaging these data to produce a waveform. This waveform reflects the average ongoing post-synaptic activity (Luck & Kappenman, 2011).

One study by Sel et al. (2015) investigated the impact of the pen-in-mouth technique on early visual processing using EEG. Participants were asked to maintain a neutral facial expression while holding a pen either between their teeth, causing muscle contraction resembling a smile, or between their pursed lips, which inhibits smiling. They then rated the intensity of faces expressing either happy or neutral expressions. The study found that this manipulation of facial muscle activation modulated an early visual brain response known as the N170 component. The N170 is a negative potential that appears around 170 ms after the presentation of a visual stimulus, primarily over the visual-temporal cortices. It is associated with structural facial encoding (Eimer, 2011). Typically, the N170 is larger in response to faces than other objects and is sometimes larger for emotional compared to neutral faces (Bentin et al., 1996; Eimer & Holmes, 2007). In Sel et al.'s study, when participants smiled, their N170 responses to neutral faces increased, reaching similar amplitudes to those elicited by happy faces. These findings suggest that producing a smile, and thus receiving

corresponding facial feedback, results in perceiving neutral faces as more akin to happy faces, thereby modulating early visual processing.

A study conducted by Davis et al. (2015) demonstrates the effects of facial feedback on the processing of affective language. The researchers simultaneously recorded EMG and EEG while participants read emotion-related sentences and words. Smiles were facilitated or inhibited using the pen-in-mouth technique. Interestingly, the authors found no modulation of ERP components when processing valence-related words, suggesting facial feedback is not valence-based. Conversely, by inhibiting smiling a larger N400 (an ERP component associated with semantic processing) was observed. Thus, by inhibiting facial feedback when processing affective words, additional cognitive resources are required for semantic retrieval.

A final EEG-ERP study that will be discussed, examined the influence of facial feedback on the automatic processing of emotional facial expressions, using an oddball task. In this study, the pen-in-mouth technique was used to produce or inhibit a smile while participants attended to a central fixation cross and paired faces (neutral, sad, or happy) were presented bilaterally. The authors found that the activation of facial muscles resembling smiling increases the mismatch negativity (MMN) ERP to sad faces, and decreases the MMN to happy (Kuehne et al., 2019).

The three studies presented demonstrate the influence of facial feedback on the neural processing of affective stimuli. Specifically, facial feedback modulates different ERP components, with Sel et al. (2015) demonstrating the influence of facial feedback on early visual processing (N170), Davis et al. (2015) on semantic processing (N400), and Kuehne et al. (2019) on automatic processing (MMN).

Previous EEG studies have often overlooked the detailed measurement of facial muscle engagement. As a result, there is a notable gap in the literature regarding the systematic activation of facial muscles and its influence on the brain processing of facial

emotional expressions. Incidental methods fall short because they do not stimulate the facial musculature as robustly as deliberate posing of a facial expression does. A recent study by Cross et al. (2019) compared smiles produced by posing to the pen-in-mouth technique and a smiling stick, which is a reusable, blue cylindrical oral device made of FDA-approved nontoxic material, designed specifically to manipulate smiles comfortably and effectively, offering a more professional and hygienic alternative to pens and chopsticks in research settings. The authors report greater muscle activation in ZM (by 40%) and OO (by 15%) during posed smiles, compared to smiles produced by holding a pen or smile stick between the teeth.

### 1.4.2 Inhibition of facial feedback

Spontaneous facial mimicry refers to the unconscious and automatic tendency of individuals to mirror or imitate the facial expressions of others. This phenomenon has been manipulated using cosmetic treatments, which can alter or restrict facial muscle movements, thereby potentially affecting the natural occurrence of such mimicry. For example, Wood et al (2016a) applied a facial gel mask, which restricts large voluntary facial movements to inhibit facial mimicry. The authors found that by restricting the movement of facial muscles the participant's accuracy in discriminating between emotional facial expressions was reduced. However, it is unclear how the gel mask interferes with facial feedback – whilst it restricts movement, there may be an increase in muscle activity to overcome the restriction, thereby amplifying the facial mimicry effect, as was speculated by Neal and Chartrand (2011).

Researchers have explored the effects of botulinum toxin (Botox) injections, commonly used cosmetically to diminish eye wrinkles, on mood and the processing of emotional stimuli. Botox acts by blocking the release of acetylcholine at the neuromuscular junction, leading to muscle paralysis (Nigam & Nigam, 2010). It's theorised that facial muscle paralysis can impact mood and emotional processing (Finzi & Rosenthal, 2016). For example,

injections to the corrugator, procerus, and orbicularis oculi muscles resulted in increased reaction times and more errors when identifying emotional stimuli (e.g., faces and sentences) compared to neutral stimuli (Baumeister et al., 2016; Bulnes et al., 2019; Lewis, 2018). Besides inhibiting facial feedback to the brain, the paralysis of facial muscles also modulates neural responses to emotional stimuli. For example, amygdala responses to angry faces were reduced following Botox injections into the corrugator muscle (Hennenlotter et al., 2009; M. J. Kim et al., 2014).

Evidence for the FFH comes from an array of research using different techniques to manipulate facial muscles. Nevertheless, all methods currently discussed are limited in testing the FFH. The techniques discussed introduce facial manipulations before the onset of the stimuli, and the muscles are continuously engaged or paralysed for most/or the entire experimental procedure. This is problematic because the FFH assumes that stimulus-congruent facial feedback follows early visual processing (Halberstadt et al., 2009; Niedenthal, 2007). However, the current techniques introduce facial feedback first, and the visual stimulus second.

## 1.5 Debates around the FFH

The literature on the FFH is broad, with several controversies that will be discussed. First, the pathways that facial muscles utilise to signal their state to the brain are unclear and rarely discussed. Second, a recent concern in the field is the failed replication of the seminal study by Strack and colleagues (1988) by a pre-registered multi-lab study (Wagenmakers et al., 2016). Recently, there has been a revived discussion about the necessity of a simulation process for effective emotion recognition. The following section will outline and address these controversies.

### 1.5.1 Facial Feedback pathways

The facial muscles are unusual when compared to the other skeletal muscles of the body, due to the absence of typical proprioceptive organs. This is problematic for the FFH and the studies manipulating facial muscles, as the mechanism underlying the effects of facial feedback is unknown. The medical literature suggests several alternative pathways unique to the face. Firstly, it has been suggested that alternative mechanisms of proprioception operate in the face, such as mechanoreceptors in the skin, which can capture changes in muscle contraction through the stretching of the overlying skin (Collins et al., 2005; Macefield, 2005; Pilurzi et al., 2013). Yet, it seems unlikely that mechanoreceptors in the skin constitute the sole mechanism of facial proprioception, as these receptors could only detect strong and widespread muscle activation.

Secondly, the trigeminal nerve (Cranial Nerve V: CNV), which provides sensory innervation to the muscles of the face, could also provide feedback about the static and dynamic condition of facial muscles to the central nervous system (CNS). According to initial evidence, CNV and CNVII are interconnected at numerous facial locations, allowing for additional exchange mechanisms between motor output and sensory feedback (Cobo et al., 2017; Hwang et al., 2015).

Lastly, a recent study suggests atypical proprioceptors in the facial muscles themselves. Cobo and colleagues (2017) examined the cheeks of cadavers, specifically the zygomaticus major and buccal muscles. The authors confirmed the absence of muscle spindles in these muscles but reported that they contain sensory formations similar to Ruffini's corpuscles – a mechanoreceptor of the skin (Feher, 2012). These atypical proprioception organs are likely to play a major role in facial feedback, that is, in delivering to the brain information about the state of muscle contraction in facial muscles. It should be noted that these findings are limited to only two of the facial muscles.

The reviewed evidence suggests that there are three possible pathways through which proprioceptive information can nevertheless be delivered to the CNS. Firstly, the trigeminal nerve, a pure sensory nerve, exhibits complex interbranching with the facial nerve and may carry feedback signals via its connection to the pons. Secondly, muscle movements stretch the skin and thus activate mechanoreceptors. Thirdly, atypical proprioceptors were recently discovered in cheek muscles – additional research is required to establish whether they exist in other muscles of the face or are limited to the cheek. To date, the precise mechanism through which facial muscles signal their state of activation/relaxation to the CNS remains unclear. Nevertheless, there is little doubt that the brain must receive constant feedback about the state of activation and stretch of the facial muscles, to allow fine-tuned facial control.

### 1.5.2 The failed replications of Strack et al. (1988)

The recently failed replication of Strack et al's (1988; described in section '1.4.1 Activation studies') seminal study by 17 labs has renewed debate regarding the FFH. Specifically, the concern of participants modifying their behaviour to align with the experimenter's expectations, a phenomenon known as "demand characteristics". The failed replication by Wagenmakers et al. (2016) has been criticised for deviating from the original study in several ways (Strack, 2016). A significant deviation was the use of video cameras to monitor participants, which has been suggested as an explanation for the failed replications. It is argued that when a person knows they are being observed, they are less reliant on internal bodily cues, resulting in altered behaviour. To examine the effect of video cameras on facial feedback effects, Noah et al. (Noah et al., 2018) repeated the procedure used by Wagenmakers et al (2016) but compared facial feedback effects when a video camera was present vs. absent. The authors reported that facial feedback effects were diminished when the video camera was used, but the effect was present when there was no video camera, suggesting facial feedback effects are sensitive to social context.

A second explanation of the failed replication is that the original task may not have been suitable for detecting the facial feedback effect, specifically the use of cartoons which were positive in valence. There is a growing body of work suggesting that facial feedback effects are prominent during the processing of emotionally ambiguous stimuli (Beffara et al., 2012). A recent multi-lab study by Marmolejo-Ramos et al. (2020) supports this notion. In the study's first experiment, participants either held a pen between their teeth to induce a smile or held nothing for a control condition. The second experiment replaced the control with a condition where participants held a pen between their lips, restricting facial movement (refer to Figure 3). The study employed both dynamic stimuli, which were point light displays of biological motion, and static stimuli, which were facial expressions, to depict happiness and sadness at various intensities. Across both experiments, the researchers observed that participants who induced a smile (by holding a pen between their teeth) had a reduced threshold for recognizing 'happy' expressions in both facial and body stimuli compared to those without any device.

### 1.5.3 Facial paralysis and the role of facial feedback

The second controversy is regarding research that has recruited individuals with Moebius syndrome (MBS), a rare congenital neurological disorder. Individuals with MBS have maldeveloped cranial nerves, primarily CNVI and CNVII, resulting in unilateral or bilateral facial paralysis. Therefore, individuals with MBS are considered an ideal population to test whether facial mimicry is necessary for emotion recognition. A recent study conducted by Vannuscropts et al., (2020) tested the performance of adults with MBS on five facial expression recognition tasks, two facial identity recognition tasks, and an emotional speech recognition task. Across all tasks, the participants performed above chance and similar to the control group, despite their congenital facial paralysis. The authors conclude that efficient recognition of facial expressions does not require sensorimotor simulation.

However, this conclusion has several limitations that I outline below. First, a recent study by Schiano Lomoriello et al. (2023) proposed that deficits in the visual processing of emotions may only emerge when facial expressions are of low emotional intensity. They recruited individuals with MBS and an age-matched control group and asked them to rate the intensity of the emotion expressed in images of faces containing a mixture of neutrality and emotionality, specifically the six basic emotions (anger, disgust, happiness, sadness, surprise, and fear). The authors report that the MBS patients' ratings of emotion intensity for sadness, fear, anger, and disgust were lower than those of the healthy control group. Additionally, multidimensional scaling maps revealed that these negative emotions were closely clustered, suggesting that MBS patients confused them with each other.

Secondly, adults with MBS may not be an ideal population to study, because they may have developed coping strategies, such as using contextual bodily cues (Rives Bogart & Matsumoto, 2010; Stefani et al., 2019). Instead, more might be learned by studying children with MBS, who have not yet developed such coping strategies. In a recent study by Nicolini et al. (2019), children with MBS and a control group identified the emotions expressed by static drawings of facial expressions. In line with the FFH, the authors reported that the MBS group performed worse than the control group. Alternatively, it seems more fruitful to focus on individuals who develop facial paralysis after birth, such as individuals with idiopathic facial paralysis. This form of facial paralysis is an abrupt disorder of the facial nerve with an unknown cause; thus, this population would not have the same time to develop alternative emotion recognition strategies. A recent study compared individuals with IFP to a control group on two tasks, face recognition and emotional face recognition. The authors reported that the facial paralysis group took longer to identify emotional facial expressions compared to the control group, while emotion recognition accuracy was not affected (Storbeck et al., 2019).

## 1.6 Summary

Chapter 1 explored the relationship between facial expressions and emotion processing, beginning with Charles Darwin's early conjectures. Darwin theorised that emotions influence physical states and vice versa, laying the groundwork for future theories of embodied cognition. The chapter then discussed the James-Lange theory of emotion, proposed by William James and Carl Lange, suggesting that physiological responses, including facial expressions, precede emotional experiences. Moreover, the chapter delved into the anatomy of the human face, explaining the role of facial muscles in emotional expressions. It highlighted the distinction between mimetic and masticatory muscles, emphasising the role of mimetic muscles in forming emotional facial expressions. The chapter also described the neural pathways involved in producing facial expressions and the different types of muscle fibres that contribute to facial movements.

At the heart of chapter 1 lies the FFH, a brief overview was provided as the FFH developed, concluding on two contemporary tenets of the FFH. The first is that facial expressions can generate or alter our own reported or experienced emotions. The second tenet posits that facial expressions can affect how we judge visual stimuli. This hypothesis is corroborated by numerous studies, employing various techniques to manipulate facial muscles and expressions such as the 'pen-in-mouth' method. An overview of these techniques was provided, highlighting their limitations in testing the FFH.

The chapter also addressed debates around FFH, including the pathways through which facial muscles communicate with the brain and the replication issues of foundational studies. It discussed the role of facial mimicry in emotion recognition and the impact of facial paralysis as occurring in Moebius syndrome, on emotional processing.

In conclusion, the chapter presented a comprehensive overview of the interplay between facial expressions and emotion, drawing on historical theories, anatomical insights,

and contemporary research. It highlighted the complexity of this interplay and the ongoing debates in the field.

# 2 Application of facial Neuromuscular Electrical Stimulation (fNMES) in psychophysiological research – practical recommendations based on a systematic review of the literature

Themis Nikolas Efthimiou[1], Monica Perusquia Hernandez[2], Arthur Elsenaar[3], Marc Mehu[4], Sebastian Korb[1,5]

[1]Department of Psychology, University of Essex, Colchester, United Kingdom

[2]Nara Institute of Science and Technology, Ikoma, Japan

[3] ArtScience Interfaculty, Royal Academy of Art, Royal Conservatory, The Hague, Netherlands

[4] Department of Psychology, Webster Vienna Private University, Vienna, Austria

[5] Department of Cognition, Emotion, and Methods in Psychology, University of Vienna, Austria

## 2.1 Abstract

Facial neuromuscular electrical stimulation (fNMES), which allows for the non-invasive and physiologically sound activation of facial muscles, has great potential for investigating fundamental questions in psychology and neuroscience, such as the role of proprioceptive facial feedback in emotion induction and emotion recognition, and may serve for clinical applications, such as alleviating symptoms of depression. However, despite illustrious origins in the 19th-century work of Duchenne de Boulogne, the practical application of fNMES remains largely unknown to today's researchers in psychology. In addition, published studies vary dramatically in the stimulation parameters used, such as stimulation frequency, amplitude, duration, and electrode size, and in the way they reported them. Because fNMES parameters impact the comfort and safety of volunteers, as well as its physiological (and psychological) effects, it is of paramount importance to establish recommendations of good practice and to ensure studies can be better compared and integrated. Here, we provide an introduction to fNMES, systematically review the existing literature focusing on the stimulation parameters used and offer recommendations on how to safely and reliably deliver fNMES, and on how to report the fNMES parameters to allow better cross-study comparison. In addition, we provide a free webpage, to easily visualise fNMES parameters and verify their safety based on current density. As an example of a potential application, we focus on the use of fNMES for the investigation of the facial feedback hypothesis.

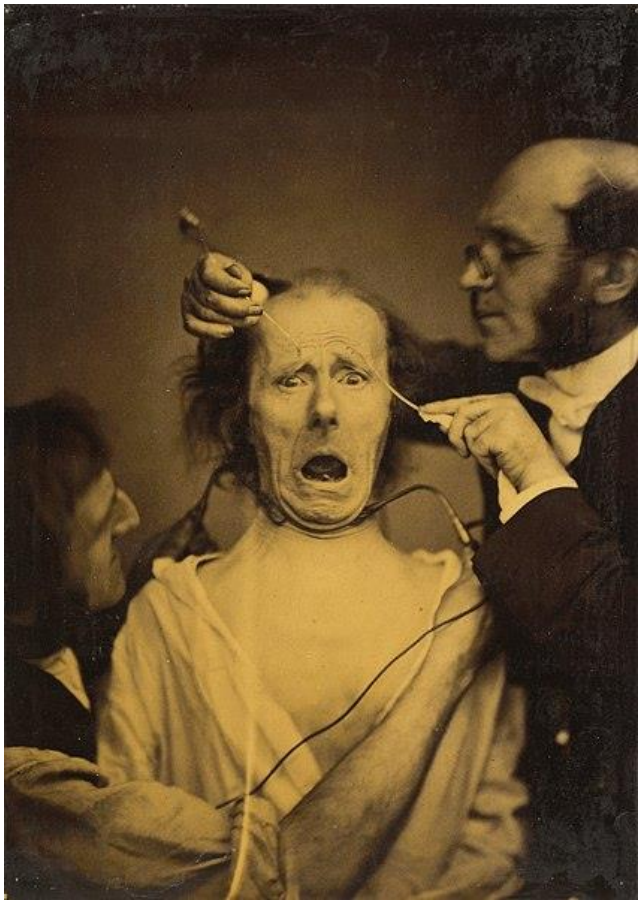
Keywords: NMES, facial muscles, emotion, facial feedback, electrical stimulation

## 2.2 Introduction

Facial Neuromuscular Electrical Stimulation (fNMES) has a long and fascinating history that can be traced back to the pioneering work of 19th-century French electrophysiologist Duchenne de Boulogne. In his book "Mécanisme de la physionomie humaine", Duchenne (1862) documented the use of faradic currents to elicit different types of facial expressions (see Figure 4). Charles Darwin recognised the significance of Duchenne's use of electrical stimulation for the study of facial expression and included drawings made after Duchenne's photographs in his book "The Expression of the Emotions in Man and Animals" (Darwin & Prodger, 1998).

**Figure 4**

*A mid-18th century photograph depicting Duchenne de Boulogne applying fNMES to his patient, from Duchenne (1862)*



More recently, fNMES (also called functional electrical stimulation, FES, or transcutaneous electric nerve stimulation, TENS, although these terms refer to partly different frequencies and stimulation parameters) has evolved into a versatile technique with a broad range of applications in both clinical and non-clinical domains. For example, it has been utilised as a therapeutic intervention to reduce pain (Johnson et al., 2022), and to support recovery from idiopathic facial nerve paralysis (Hyvärinen et al., 2008; Fargher & Coulson, 2017; Puls et al., 2020), where it is often paired with electromyography (EMG) to develop facial 'pacing' technology that matches the activation of paralysed muscles with that of the unaffected half of the face (Rantanen et al., 2016; Ilves et al., 2019). Non-invasive cosmetic procedures have also been explored with fNMES to improve muscle thickness and reduce age-related reductions in muscular mass and collagen (Kavanagh et al., 2012b; for review see, Abe & Loenneke, 2019). Moreover, fNMES has emerged as a promising medium for artistic expression. For example, Arthur Elsenaar's performances involve the real-time control of facial movements through the use of electrical stimulation, often paired with a computer-generated voice, resulting in a surreal and interactive performance experience (Elsenaar & Scha, 2002). In addition, researchers have explored the integration of fNMES with virtual reality applications to enhance realism through combinations of visual, mechanical, and electrical feedback (Kono et al., 2018; Khamis et al., 2019).

Despite the ground-breaking and influential nature of Duchenne's early work and its many clinical, cosmetic, and artistic applications that have since emerged, fNMES has however not been employed by modern-day psychologists – with notable exceptions, such as the replication of Duchenne's work in humans and its extension to chimpanzees, albeit using invasive needle electrodes (Waller et al., 2006), and the reduction of symptoms of depression through fNMES over smiling muscles (Kapadia et al., 2019). This is regrettable, as fNMES holds considerable potential for the investigation of many aspects of human cognition, such as

the facial feedback hypothesis' (FFH) proposal that proprioceptive feedback from facial muscles to the brain can generate and/or modulate felt and perceived emotion (Hatfield et al., 1993; Coles et al., 2019b; Coles et al., 2022). Indeed, in combination with surface electrodes, fNMES offers a non-invasive means of selectively activating specific facial muscles, at precise points in time, and for variable durations. Due to this anatomical and temporal precision, fNMES may be regarded as a methodological advancement, compared to other means that have so far been used to test the FFH, e.g., asking healthy participants to voluntarily pose facial expressions (Ekman et al., 1983), or to hold a pen between the lips or teeth (Strack et al., 1988; Wagenmakers et al., 2016), or investigating felt emotion and emotion recognition in individuals presenting temporary (i.e., Botox, see Baumeister et al., 2016; Davis et al., 2010; Neal & Chartrand, 2011) or long-term (Moebius' syndrome, see Rives Bogart & Matsumoto, 2010; Sessa et al., 2022) facial paralysis.

To encourage the use of fNMES to investigate aspects of cognition and emotion, we provide an introduction to the method, as well as detailed recommendations on how to safely and reliably deliver fNMES using surface electrodes. These recommendations are based on a systematic review of the literature (published until November 2022) about fNMES applied using surface electrodes to live humans, as well as on our experience in the artistic (Elsenaar, 2010; Elsenaar & Scha, 2002) and laboratory setting (Baker et al., 2023). We also provide a Shiny App to easily calculate current density based on a handful of stimulation parameters, allowing researchers to verify the safety of their methodology, and allowing the field to better compare parameters between and analyse findings across fNMES studies. As an example of a potential application of fNMES, we focus on its use for the investigation of the FFH. We hope that these recommendations will contribute to introducing fNMES to a wider audience of psychologists and neuroscientists, thus enlarging and enriching the toolset of techniques

allowing the investigation of the role of proprioceptive feedback and other peripheral physiology signals in the formation and modulation of affective and perceptive phenomena.

## 2.3 Delivering fNMES

From many points of view, the administration of electrical stimulation to the face is no different than to the body (Maffiuletti, 2010; Doucet et al., 2012). As a result, the same underlying principles can be used with fNMES as well. Two electrodes are placed over a facial muscle of interest and a current is delivered which depolarises the muscle's cell membranes; once a threshold is passed, a motor action potential is induced. However, despite its name, fNMES typically targets the facial nerve innervating a muscle, rather than individual muscles themselves, as the former can be depolarised with lower electrical intensities (Peckham & Knutson, 2005).

Reducing or limiting users' discomfort and muscular fatigue should be a top priority while using fNMES. To achieve this, electrode placement over selected muscles should be guided by careful consideration of muscle anatomy and physiology (Cattaneo & Pavesi, 2014; Korb & Sander, 2009; Pessa et al., 1998; Rinn, 1984), as well as electrical stimulation parameters (pulse width, frequency, intensity, waveform; see Table 1 for an extensive list). In addition, it is advisable to take into consideration and manage volunteers' concerns about the comfort of fNMES, and its possible side effects in terms of pain induction and loss of muscle control (Efthimiou et al., 2022). The following section will provide an overview of the electrical parameters, hardware, and safety considerations when using fNMES.

Once the electrodes have been positioned and fNMES is applied at intensities of motor threshold (MT, i.e., inducing visible muscle contractions), participants typically report no pain and low to medium discomfort levels. For example, in a recent experiment (manuscript in preparation) 58 participants received 5–seconds of fNMES at MT (current density 0.96) and

were asked to report their level of discomfort scale ranging from 0 ('no discomfort at all') to 100 ('extremely uncomfortable'). When fNMES was applied to the zygomaticus major muscle the average discomfort was 34.31 (*SD* = 28.57) and when it targeted the *depressor anguli oris* muscle it was 34.81 (*SD* = 28.37). Similarly, Safi (2020) found that fNMES delivered at MT was well-tolerated over 12 sessions by eight patients, who on average rated its level of discomfort as 47.8 out of 100. It is thus clear that although there is large variability in the amount of discomfort reported by participants and depending on which facial muscle is targeted, fNMES delivered at MT is normally well tolerated and only mildly uncomfortable.

### 2.3.1 Stimulation device

The stimulation device is an important component of a safe and effective fNMES, and it should follow the IEC 60601-1 Medical Electrical Equipment Guidelines (bit.ly/3YVpbFz). To administer fNMES a simple handheld TENS unit may suffice (Warren, 2021), which typically allows for the stimulation of two face areas at the same time and costs approximately £30 – £100. For greater control over stimulation parameters, it is however recommended to use a computer-controlled current density stimulator per muscle – they cost in the range of £7,000. It is worth noting that while these costs may surpass those associated with alternative facial manipulation techniques, these devices are reusable and serve diverse research purposes, including pain research and the identification of motor-evoked potentials (Pilurzi et al., 2013; Vanden Bulcke et al., 2013).

The strength of fNMES is determined by electrical resistance (or impedance), which varies primarily by tissue type, tissue health, tissue cleanliness, electrode quality, and electrode application quality. The electric conductivity between the skin and the electrode may decrease over time as the conductive gel covering the electrode dries or the electrode

partially detaches from the skin. The electric stimulator automatically following Ohms law (Prutchi & Norris, 2005) can account for changes in electrode impedance.

Two types of stimulators exist: Constant-current stimulators maintain current by adjusting to changes in impedance by increasing or decreasing the voltage. Voltage-regulated stimulators, on the other hand, maintain a constant voltage while changing the current as the impedance changes following Ohms law. Because it tackles the issue of charge balancing, constant-current stimulation is a safer technique of electrical stimulation – but eventual changes in electrode attachment/impedance can result in unwanted current density increases. Furthermore, when subjects receive constant-current rather than constant-voltage stimulation, they report lower levels of discomfort (Nag et al., 2015; Washburn et al., 2014). Therefore, constant-voltage stimulators such as BIOPAC's STM200 (bit.ly/3Fa3xGh) may be better suited for research investigating pain induction. In contrast, we have been using the DS5 isolated bipolar constant-current stimulator by Digitimer (bit.ly/3OXyLDL), in combination with an Arduino-controlled digital-to-analogue converter. Nearly identical stimulators have also been used for fNMES by others (Paracampo et al., 2017; Pilurzi et al., 2013, 2020; Ramalho et al., 2022), and descriptions of similar control modules have been presented elsewhere (Pfeiffer et al., 2016).

### 2.3.2 Muscle Selection

The human face comprises 17 - 20 paired muscles (depending on how they are counted; for a comprehensive review, see Cattaneo & Pavesi, 2014). The intricate and often subtle movements of these facial muscles can be systematically classified into distinct "action units" (AUs) through the use of the Facial Action Coding System (FACS; Friesen & Ekman, 1978). Individual AUs, or specific combinations of AUs, correspond to prototypical emotional facial expressions. For instance, AU12, represented by the zygomaticus major

muscle, consists in the pulling of the mouth corners upwards and backwards and is typically associated with happiness, especially if it occurs together with AU6, represented by the orbicularis oculi and results in the lifting of the cheeks. Therefore, when researchers are tasked with selecting specific facial expressions to generate or target particular facial muscles, FACS serves as an invaluable research tool. It offers guidance to researchers by providing a clear framework for understanding the general location and expected movements of the facial muscles, facilitating the precise depiction of emotions and expressions in their studies. Finally, it has been used to guide researchers in several studies applying fNMES to the face (Baker et al., 2023; Kapadia et al., 2019; Warren, 2021; Zariffa et al., 2014). We note that an advantage of fNMES, compared to the more commonly used facial EMG technique, is that correct electrode placement can be verified through immediate visual inspection.

### 2.3.3 Electrodes

Surface fNMES can be delivered with adhesive, plate, conductive rubber, or vacuum electrodes – although adhesive single-use electrodes may be preferred, as they also do not require the application of a conductive gel. A current flow requires at least two electrodes, namely a positive (anode) and a negative (cathode) pole. Smaller electrodes provide greater precision, but increase the danger of skin burns, as they lead to greater current density. When using fNMES in pulsed patterns, the total current delivered into the body over a given period must be taken into account. Experimenters should be cautious when calculating the heat generated by their parameters, as this could result in skin burns (see section ‘2.5 Safety recommendations for fNMES’). To increase adherence of the electrodes, male participants should be clean-shaven, and the skin of all participants where the electrodes are to be placed should be gently cleansed with alcohol wipes. Furthermore, individual differences should be

considered, for example, participants who have high levels of subcutaneous fat over the muscle requiring larger electrodes (Doheny et al., 2008, 2010).

The configuration of electrodes determines where they are to be placed. In a monopolar configuration, the cathode is placed on the muscle of interest, and the anode is put on the neighbouring fascia or tendon. As a result, the monopolar arrangement is more suited to stimulating a wider surface area – but this configuration can nevertheless lead to highly effective and circumscribed muscle activations (Elsenaar, 2010). In contrast, both electrodes are situated closer to each other in the bipolar design, around the targeted muscle, and specifically near the motor point (MP), where the motor nerve enters the muscle (Mortimer & Bhadra, 2018; Peckham & Knutson, 2005). As a result, the current from the negative electrode is more concentrated and reaches the closest positive electrode. The bipolar design is more effective for localised stimulation, as it is the most used for fNMES (see Table 1).

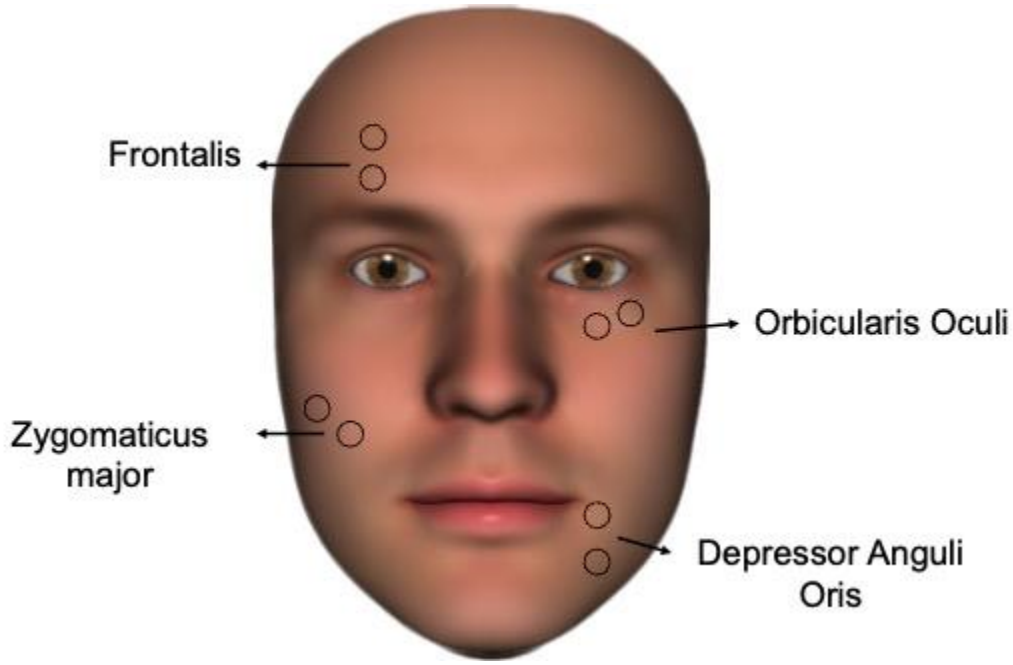
### 2.3.4 Motor Point Identification

It is recommended that experimenters target the muscle motor point (MP), which is where the nerve innervates the muscle belly, to minimise discomfort and promote maximal muscular contraction (Peckham & Knutson, 2005). This is because the muscle has a higher threshold than the nerve, requiring a higher current/voltage to elicit action potentials (Gilman & Arbor, 1983). With the smallest stimulation input, activation of the skin area corresponding to the MP induces the strongest contraction. Gobbo et al. (2014) proposed a reliable approach for locating the MP on trunk and limb muscles, which involved applying low-frequency and low-intensity stimulation to different parts of a muscle using a pen electrode and visually inspecting and identifying the spot with the highest visible contraction – targeting the MP will also increase current, compared to adjacent areas of the skin, when using a constant-voltage stimulator. However, it may be difficult to detect a specific MP in facial muscles, since they

have complex over- and under-lapping in the nerve branches and neuromuscular junctions, that also vary in clusters among the different muscles (Happak et al., 1997; Kehrer et al., 2018; Lapatki et al., 2006). In case the MP cannot be located – due to a lack of a pen electrode, lack of preparation time, or unusual anatomical configuration – the recommended position for surface EMG recording may be used instead, as it should generally correspond to the MP. For information on how to position electrodes for EMG, see Fridlund and Cacioppo (1986), and Figure 5. Bear in mind, however, that electrode positions and distances between electrodes might have to be changed slightly due to intra- and inter-individual differences in face anatomy, age (D'Souza & Ng, 2020), and gender differences (Paes et al., 2009), as well as depending on the electrode size. For example, the positioning on the left side of the face will not exactly replicate on the right side as the muscle size and nerve innervation may differ (Waller et al., 2006, 2008).

**Figure 5**

*Ideal electrode positions for bipolar fNMES*




*Note.* Locations are similar to those for facial EMG (see guidelines by Fridlund and Cacioppo, 1986). For a monopolar configuration, the active (cathode) electrode should be placed in the centre of these ideal locations (on the motor point), while the reference (anode) is placed distally.

The correct placement of fNMES electrodes can be determined by gradually increasing stimulation intensity until twitches of the intended muscle are seen – this can easily and rapidly be done by visual inspection by the experimenter, for example at the beginning of an experiment. Another solution is to video record the participant's face (e.g., with a webcam) and to analyse the video with automatic facial action coding, for which several software packages – including some open source ones – exist (Baltrusaitis et al., 2018; Cheong et al., 2021; Dupré et al., 2020). Finally, additional electrodes might be placed near the fNMES electrodes to record EMG – however, this can be a challenge given the small facial area and will require cleaning the signal from the important fNMES-induced artefacts (Rantanen et al., 2018; Baker et al., 2023).

## 2.4 fNMES Parameters

In the following section, we introduce some of the fundamental parameters that affect the efficacy and safety of fNMES, and that should always be reported in the NMES literature (Maffiuletti, 2010): waveform shape, frequency, pulse width, and intensity. These parameters were then extracted, when they were reported, from published studies and collected in a systematic review (see section Systematic Review and Table 1). It will be followed by our recommendations to help the inexperienced user.

In the following section, we introduce some of the fundamental parameters that affect the efficacy and safety of fNMES, and that should always be reported in the NMES literature (Maffiuletti, 2010): waveform shape, frequency, pulse width, and intensity. These parameters were then extracted, when they were reported, from published studies and collected in a systematic review (see section Systematic Review and Table 1). It will be followed by our recommendations to help the inexperienced user.

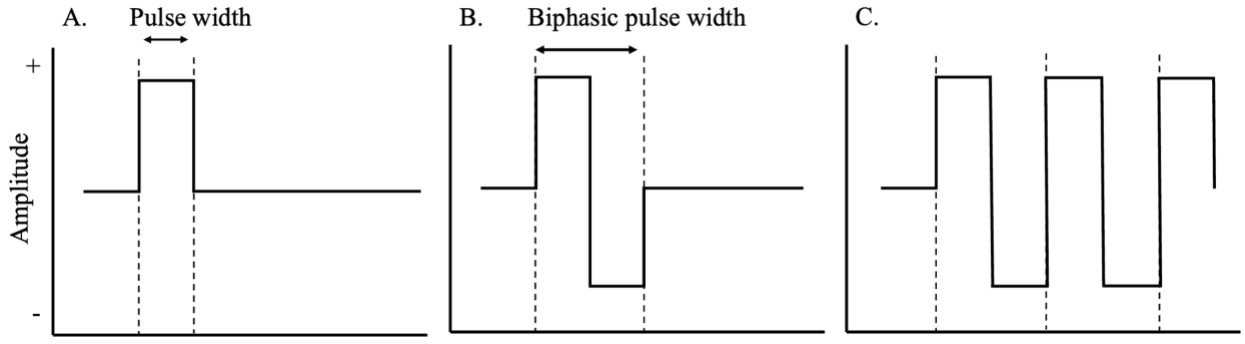
### 2.4.1 Waveform

Three types of currents are typically used to deliver charge to organic tissue (see Figure 6): direct (unidirectional, or monophasic), alternating (bidirectional or biphasic), and polyphasic (repeated uni- or bidirectional). The choice of current influences the effectiveness and tolerability of the stimulation. Monophasic waveforms stay in a single phase with a unidirectional pulse from baseline to positive or negative - although this resembles direct current, periodic interruptions can be included. Biphasic waveforms, on the other hand, are bidirectional with one positive and one negative phase. Lastly, polyphasic waveforms are similar to biphasic waveforms but have three or more phases in a burst. Monophasic and biphasic waveforms have been reported to induce stronger muscle contractions and to be less fatiguing, compared to polyphasic ones (Laufer et al., 2001). In addition, the biphasic

waveform is considered safer than the monophasic one, as the charge gets balanced, and the chance of tissue damage due to reverse electrolysis is minimised (Nag et al., 2015). Biphasic waveforms should therefore be preferred over monophasic ones for fNMES.

**Figure 6**

*An example of a square wave in three different phases*




*Note.* A. Monophasic, B. Biphasic, C. Polyphasic.

The waveform can be sinusoidal, rectangular (i.e., square; both symmetrical or asymmetrical are possible in the case of bi- and polyphasic stimulation), or of sawtooth shape (Laufer et al., 2001). However, few studies have investigated this issue with facial muscles. Ilves et al. (2020) investigated four waveforms (square wave, square wavelet, sine wave, and sinusoidal wavelet) on the frontalis muscle in terms of subjective comfort and magnitude of forehead movement. The authors report that all waves performed equally well and did not significantly differ in terms of reported comfort – other facial regions may differ due to anatomical differences, such as the amount of subcutaneous fat (Petrofsky, 2008). Another study from the same group also found no differences between a square wave and a sinusoidal wavelet in movement production, and perceived discomfort (Makela et al., 2020). To date, square wave signals are the most used, as they can be implemented by most commodity NMES devices (Pfeiffer et al., 2016).

### 2.4.2 Frequency

The frequency of NMES describes the number of pulses per second and is measured in Hertz (Hz) for alternating current. Frequency is an important parameter for comfort, quality of muscle contraction, and rate of muscle fatigue. The choice of frequency depends on the targeted muscle, the type of fibres, and fNMES stimulation parameters. High frequencies (> 50 Hz) are typically more comfortable and produce stronger and smoother contractions but can lead to faster muscle fatigue (Lynch & Popovic, 2008; Reed, 1997). Low frequencies (< 20 Hz) should be avoided, as they lead to greater discomfort (Sluka & Walsh, 2003) and the pulses can be individually perceived by the participant – low frequencies induce transient tension (twitches). Recently, there has been growing interest in very-high-frequency NMES outside of the face, such as the trunk and limbs of the body, using 100 - 250 Hz (Doucet & Mettler, 2018; Grosprêtre et al., 2017; Papcke et al., 2018) as well as frequencies in the kilo-Hertz range (Vaz & Frasson, 2018), as they may evoke greater central nervous system (CNS) changes by primarily recruiting sensory axons (Mang et al., 2010). To date, there is no consensus on the best frequency for fNMES, with studies using 25 Hz (Pilurzi et al., 2013, 2020), 60 Hz (Zariffa et al., 2014), and up to 250 Hz (Ilves et al., 2019), see Table 1. Based on the literature and personal experience, we recommend frequencies in the 50-100 Hz range, as they are well-studied, and elicit a smooth visible motor contraction.

### 2.4.3 Pulse width

To depolarise the axons of the facial nerve, a minimum amount of current must be delivered over time. This is defined by the pulse duration, also called the pulse width. The pulse width is the time a pulse is ‘on’ delivering the current, which is visualised as an increase from baseline to maximum amplitude (Figure 6). In monophasic stimulation, the pulse duration is the on-time for a single pulse in the positive phase, whereas for biphasic

stimulation the pulse duration combines both positive and negative phases (referred to as 'biphasic pulse width' below). Pulse width varies across studies but typically ranges between 50–400 microseconds (us), which is considered a short pulse width. Outside of the face, short-pulse widths are thought to mainly recruit motor axons, whereas wide-pulse widths (> .400) are thought to primarily recruit sensory axons and therefore engage the CNS to a larger extent, and more accurately mimic voluntary muscle movement (Arpin et al., 2019; Bergquist et al., 2011; Lagerquist & Collins, 2008; Maffiuletti, 2010). Further, there is an interest in pairing wide pulses with high frequencies (Baldwin et al., 2006; Blouin et al., 2009; Neyroud et al., 2019). How this applies to facial muscles remains unknown as this research has been conducted on skeletal muscles outside of the face, therefore it is currently unclear if and how its results apply also to facial muscles. In addition, one should be careful to combine wide pulse widths with high stimulation frequencies, as this also increases current density and therefore can quickly lead to exceeding safety limits (see below).

### 2.4.4 Intensity

The intensity of NMES is generally reported in milliamperes (mA). Three levels of intensity are of particular interest: 1) at low intensities subjects report tingling sensations when their sensory threshold is reached; 2) higher intensities result in visible muscle twitching, which marks the motor threshold; and 3) the functional threshold is reached at even higher intensities leading to full muscle contractions and (depending on the site of stimulation) limb movement (Insausti-Delgado et al., 2021; Smith et al., 2003). The greater the intensity of NMES, the more motor units are recruited, leading to stronger muscle contractions and stronger afferent feedback (Carson & Buick, 2019; Insausti-Delgado et al., 2021).

For fNMES, between 3 and 9 mA are typically employed (Zariffa et al., 2014), although higher intensities have been used, e.g., Safi et al. (2017) used up to 78 mA. The intensity of fNMES largely depends on other parameters, such as waveform, pulse width, duration, and electrode size. In line with this, Ilves et al. (2019) investigated the tolerability, perceived sensation, and visible muscle contraction of fNMES at different intensities. fNMES was applied to four different facial muscles (orbicularis oculi, frontalis, zygomaticus major, and orbicularis oris), and intensity was increased in steps of 0.5 mA to a maximum of 10 mA. Participants started to perceive the stimulation at 1 - 1.5 mA (sensory threshold) and did not begin to experience discomfort until 7 mA was reached. Further, muscle contractions were observed in the forehead, cheek, and mouth at 2, 4, and 3 mA respectively. In our research (Baker et al., 2023), we have applied fNMES at the motor threshold level, typically in the range of 10 to 35 mA (current density 0.39 - 1.36), which were well-tolerated and resulted in low to medium levels of discomfort.

## 2.5 Safety Recommendations for fNMES

In this section, we summarise the main risks to participants when receiving fNMES. In appendix A, we provide the necessary formulas to compute current density as the root mean square of instant current per $cm^2$, as international guidelines recommend not exceeding a waveform power of RMS 2 $mA/cm^2$. Finally, we provide a webpage (bit.ly/3lv78Z1) that allows users to rapidly verify, by entering a handful of parameters (pulse amplitude, width, and frequency, as well as electrode area), how much current is injected by a specific NMES procedure, and whether it follows safety guidelines.

fNMES is a technique that poses certain risks, as is the case with any technique applying an electrical current to the body (Kono et al., 2018). First, to ensure safety, it is recommended to abstain from using fNMES on individuals who are pregnant, have implanted

electrical devices such as pacemakers, have a history of epilepsy, have recently undergone facial surgery, or have sensitive or broken skin. Second, the parameters, i.e., the voltage/current amplitude, pulse width, waveform shape, and duration of the conduction must be carefully considered to provide safe and comfortable stimulation.

The most common risk associated with fNMES is the potential to induce skin irritation resulting in temporary marks due to heating. From our experience and the literature, the most common side effect of fNMES is skin irritation. Indeed, when using fNMES, Kavanagh and colleagues (2012b) reported redness of the skin (under the electrode) in all subjects, which faded and disappeared completely within 20 minutes. Whereas other electrical stimulation techniques, such as transcranial altering/direct current stimulation, have been known to induce phosphenes, skin lesions, and contact dermatitis (for review, see Matsumoto & Ugawa, 2017). Therefore, fNMES may be considered safer than other electrical stimulation techniques.

In extreme cases there may be burns, due to joule heating: when electricity meets resistance to flow, the area begins to heat, thereby causing electrical burns (Balmaseda et al., 1987; Walls et al., 2018). To minimise this risk, an appropriate electrode should be considered (see below). Given that the concern for burns is significant to participants (Efthimiou et al., 2022), it should also be addressed early in the laboratory session to ensure that participants feel at ease.

To ensure participants' safety, one must follow the general guidelines that have been proposed by the International Electrotechnical Commission (IEC) and the International Commission on Non-Ionizing Radiation Protection (ICNIRP). Specifically, that a waveform does not exceed a power of RMS 2 $mA/cm^2$. The root mean square (RMS) per electrode area of fNMES should be calculated to stay within safety parameters (2 $mA/cm^2$, as described by the safety guidelines, EN 60601-2-10:2000), and to allow better comparison across studies. See the app below, and appendix A for corresponding formulas. As an example, a researcher

may utilise disposable electrodes of Ag/AgCI measuring 1.6 x 1.9 cm (3.04 $cm^2$ surface area) to administer fNMES. During each trial, a 500 ms long pulse train of 30 biphasic pulses of a square waveform is delivered at 60 Hz, with a symmetrical pulse width of 50 us (biphasic pulse width 100 us), and an off period of 17 ms between each biphasic pulse. The total input for the stimulation period at the motor threshold (25 mA, averaged over participants) will then be .64 RMS $mA/cm^2$. Increasing the frequency to 70 Hz will result in 35 biphasic pulses with shorter off periods of 14 ms and a greater current density of 0.69 RMS $mA/cm^2$. As a rule of thumb, human fNMES research aiming to produce visible muscle movements should use electrodes with a surface area of at least 2.5 $cm^2$. This is because most fNMES applications will use a minimum pulse width of 50 us, a frequency of 50 to 100 Hz, and amplitudes between 10 and 50 mA. For these parameters electrodes should have a surface area of 0.36 $cm^2$ (up to 10 mA at 50 Hz) to 2.5 $cm^2$ (up to 50 mA at 100 Hz) – within that range, we recommend the larger electrodes for safety reasons. Most importantly, current density levels should be below the RMS 2 $mA/cm^2$ threshold and verified using the provided Shiny App (see below).

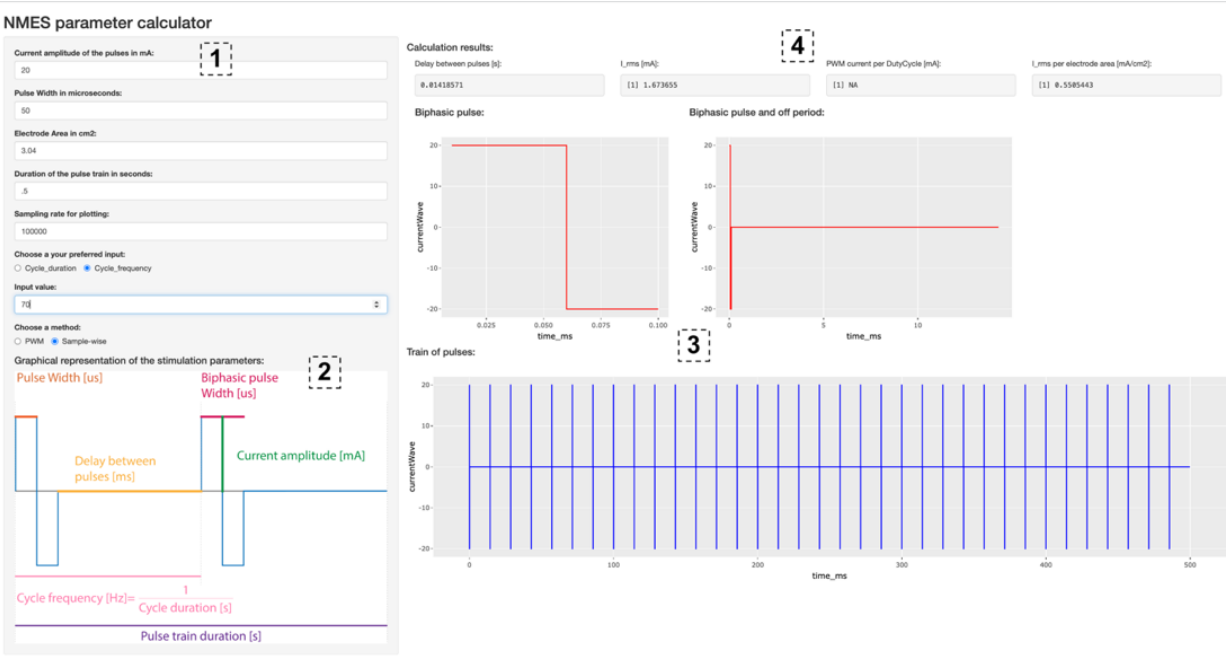
Note that since the RMS of a waveform is the root square of the mean of the square of each sample, adding more pulses with the same characteristics does not affect the RMS value. Therefore, the RMS will remain constant independently of the number of pulses in a train. Nevertheless, care should be taken when estimating the safety of fNMES applied for long periods, as Joule Heating (see Formula 1 in Appendix A) might occur. Therefore, the total duration of the stimulation should be multiplied by the Power of the waveform as described by its RMS. The IEC standard also provides a useful guideline for the safety zones according to stimulation time and current applied to the skin. Following these guidelines provides an initial account of the most common risks and to stay within international guidelines.

## 2.6 A Shiny App for designing and visualising safe fNMES parameters

To facilitate the computation of the current density as RMS mA/cm$^2$, and to help visualise a train of fNMES pulses, we have created a user-friendly app running in Shiny, an open-source R package. The app (see Figure 7) can be accessed under this link: bit.ly/3lv78Z1 and the source code of the app is available on GitHub (bit.ly/3JPvOou).

**Figure 7**

*A screenshot of the Shiny App allowing to compute current density and to visualise stimulation waveform*




On the top left-hand side of the Shiny App [1], enter the stimulation intensity in mA; the pulse width in us; the electrode area in cm$^2$; the duration of the pulse train in seconds; the sampling rate for plotting (the default is 100000); pick between cycle duration and cycle frequency and enter the corresponding value; pick between the PWM and sample-wise method (PWM should be preferred, although either method will give the same mA rms/cm$^2$). The bottom left-hand [2] shows a graphical representation of the stimulation parameters – be

aware of the difference between pulse width and biphasic pulse width. As soon as you enter your parameters, the plots on the centre of the app [3] will visualise the form of a biphasic pulse with and without the off period, as well as the whole train of pulses. Finally, the top right part of the app [4] outputs the calculation results: the delay between biphasic pulses; the root mean square (rms) of the current in mA; the current per duty cycle; and most importantly the rms of the current per electrode area. The latter output is the current density – be aware that if this exceeds 2 mA rms/$cm^2$ extra attention should be paid not to cause damage to the skin. Be aware that the app assumes a mono- or biphasic square waveform – it does not work for other waveforms, like the square wavelet and sinusoidal wavelet used by Ilves et al. (2020).

### 2.6.1 Systematic Review

To gain an overview of the stimulation parameters used in the field, and to compute current densities allowing a better cross-study comparison, we conducted a systematic review of the fNMES literature using surface electrodes in humans, published up to November 2022. We also coded the goal of each study using rough categories – allowing us to investigate which aspects of cognition and/or emotion were studied the most/least. The Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guided the conduct of this systematic review (Page et al., 2021).

### 2.6.2 Search Strategy

We searched two databases the Web of Science and Scopus for the terms ( ( TITLE-ABS-KEY ( functional AND electrical AND stimulation ) OR TITLE-ABS-KEY ( neuromuscular AND electrical AND stimulation ) OR TITLE-ABS-KEY ( nmes ) OR TITLE-ABS-KEY ( electrical AND muscle AND stimulation ) OR TITLE-ABS-KEY ( electrical AND nerve AND stimulation ) ) AND TITLE-ABS-KEY ( face

) OR TITLE-ABS-KEY ( facial ) ), which resulted in a total of 2,109 manuscripts (see Figure 8). This number was reduced to 885 after filtering, removal of duplicates, and manuscripts with no abstract.

### 2.6.3 Eligibility criteria

The systematic review employed a two-round screening process conducted by three coders (authors TE and SK, plus a trained research assistant). Initially, the coders reviewed the abstract of each manuscript, adhering to specific criteria for rejection. Manuscripts were rejected if they: 1) did not involve human subjects, 2) did not involve surface electrical stimulation on the face (excluding the neck and scalp), or 3) only presented results from cadavers or fully anaesthetised patients. Manuscripts that were deemed uncertain in relevance were included for further evaluation in the second round of screening.

Out of the initial 885 articles, 190 were assessed for eligibility by all three coders, resulting in a substantial level of inter-rater agreement (calculated in R, average Cohen's Kappa = .65). Any discrepancies were resolved through discussion. Among the initial 885 manuscript abstracts, 301 were considered relevant, but only 254 were accessible. The second screening phase was carried out on these 254 articles, with 64 of them being triple coded. This round also resulted in substantial inter-rater agreement (Cohen's Kappa = .71). We then added two additional articles that were known to the authors, bringing the total number of articles to 136.

### 2.6.4 Data extraction

Next, information related to fNMES parameters was extracted from these 136 articles and divided between the three coders. A number of decisions were taken for manuscript coding: 1) we restricted the study goal categories to “Facial Paralysis/Weakness Treatment”, “Cosmetic”, “Pain relief/induction”, “Emotion/Mood modulation”, “Bruxism relief”, “Blink

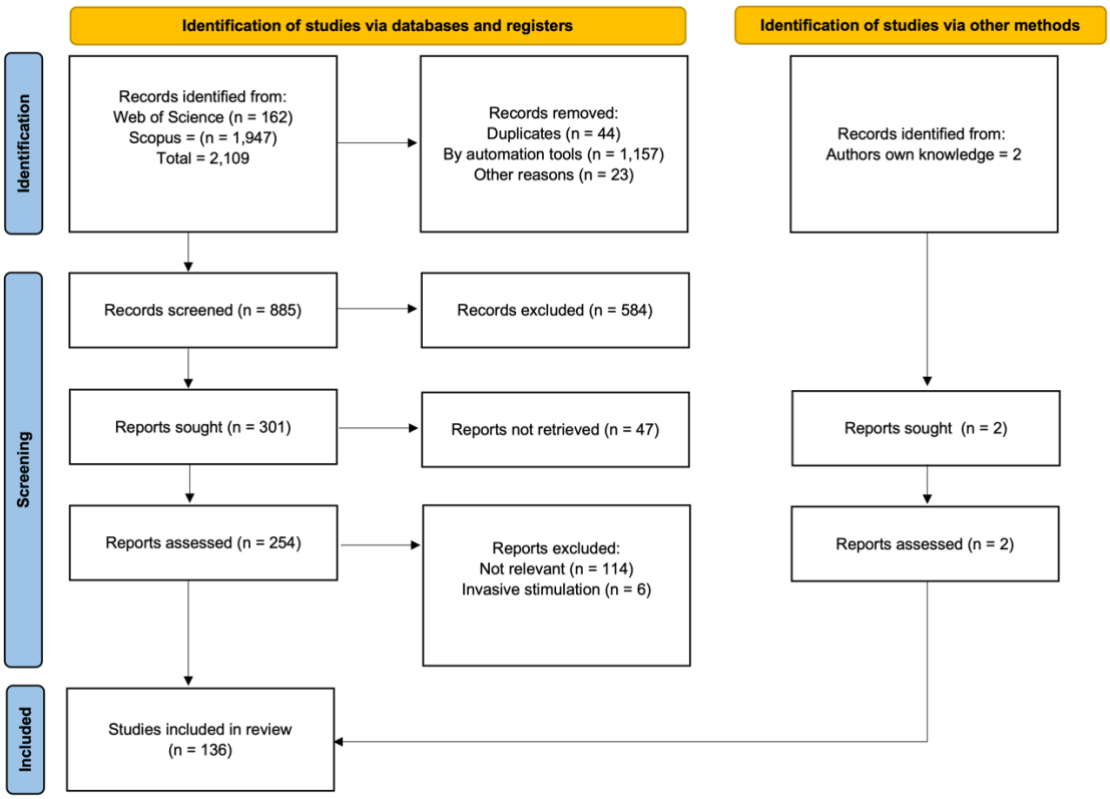
Reflex", and "Other"; 2) if several electrode sizes were used, we noted the smallest one; 3) if electrode size was not provided, we tried to recover it from other sources, e.g., Ilves et al. (2019) and Safi et al. (2017) show photos allowing to estimate the approximate electrode size, while other manuscripts provided the brand name of the electrodes, allowing us to verify the exact size with an online search; 4) when the waveform was not specified, e.g., it was only described as "symmetrical" (e.g., Safi et al. 2018), nothing was entered in the table, unless we were able to verify what waveform the stimulating device delivered (e.g., Ferreira et al. 2017 used Neurodyn Sapphire, which according to its user manual uses a square wave); 5) in case of polyphasic waveforms (Rantanen et al. 2018; Ilves et al., 2020), we provided the frequency of the pulse train, and not of the pulses inside of polyphasic "packages"; 6) if several amplitudes were used, we noted the largest one; 7) due to large variety in stimulation sites, some specifying muscles and other nerves, we used a broad classification system of upper, middle, and lower face (Nguyen & Duong, 2023).

To ensure accurate information extraction across all categories in the table, we had all three coders extract data from the same set of 35 articles. Disagreements in categorising the experimenter's goal accounted for 34.29% of cases while identifying the stimulation device yielded a 5.71% disagreement rate. The discrepancy for electrode surface area reached 11.43%, and the average disagreement for all stimulation parameters (including pulse width, shape, and duration) was 25.36%. In the case of the stimulation site, where various muscles were listed, we employed a comprehensive classification system grouping them into upper, middle, and lower facial regions as per Nguyen and Duong (2023). All disagreements were settled by verifying descriptions in the articles, and through discussion among the coders. The full table was also verified by the first author. Once completed, Table 1 was loaded into R, where we computed the duty cycle, Irms/cm$^2$ based on the formulas provided below (section

Formulas). Unfortunately, due to most manuscripts failing to report one or several of the stimulation parameters, we were only able to compute the current density in eight cases.

**Figure 8**

*PRISMA flow diagram depicting the information at the different phases of the systematic review*




*Note*. The parameter table and R code to compute current density are available on OSF (bit.ly/3faUYkP).

## 2.6.5 Findings

We first report an overview of the review's findings based on study goals and muscles targeted, before summarising what was the focus of the review, i.e., the extraction of stimulation parameters and the computation – when possible – of current densities.

We found that most studies (33 out of 136, i.e., 24.26%) had used fNMES for pain relief; 22 studies (16.17%) used it to recover muscular function after facial paralysis; 18

studies used it to invoke a blink reflex (13.24%), five studies (3.67%) used it for Bruxism recovery, three studies (2.20%) to induce modulation of mood and/or emotion (Goto et al., 2018; Kapadia et al., 2019; Zariffa et al., 2014), and three studies (2.20%) to ameliorate facial appearance (Kavanagh et al., 2012b). The majority of studies (51, 37.5%) had various goals, e.g., they investigated the effects of variations in fNMES parameters on physiology and subjective reports (Ilves et al., 2020; Rantanen et al., 2018), and were thus classified as "Other".

Various muscles were stimulated, such as the frontalis, orbicularis oculi, orbicularis oris, zygomaticus major, depressor angulii oris, and masseter muscles. Overall, most studies (36, 26.47%) stimulated a combination of the upper, middle, and lower face, followed by 31 studies (23.13%) that stimulated the upper face (mainly eye region and forehead), 22 studies (16.17%) that stimulated the middle face (focusing mainly on the cheek area), and finally 18 studies (13.28%) that stimulated the lower face (mostly around the chin and lower mandibular branch of the trigeminal nerve). The most popular choice of pulse type was biphasic (25, 18.38%), followed by the monophasic pulse (19, 13.97%), although the majority of studies did not report the pulse type used. Electrode surfaces varied greatly from 0.03 to 78.5 $cm^2$ with no common size observed. The preferred biphasic pulse width was between 10 and 100 us (11 studies, 8.08%), and the second most frequent biphasic pulse-width was between 101 and 200 us (10 studies, 7.35%). Cycle frequencies varied from 0.1 to 10000 Hz, but most studies employed a frequency between 10 and 100 Hz.

A major goal of this review was to compute the maximum current density utilised by each study, as this provides a unit of stimulation intensity that is comparable across studies. However, only 8 out of 136 studies (5.88%) provided the information necessary to compute current density. In contrast, 90 studies (66.17%) did not provide electrode surface in $cm^2$ (nor could it be recovered otherwise, e.g., by estimating based on figures), and 91 studies (66.91%)

did not provide the stimulation amplitude in mA (only stating that stimulation was at motor threshold). The inconsistency and variability with which the NMES parameters are typically reported is a known problem, which has been pointed out before (Maffiuletti, 2010). Scholars are therefore urgently invited to always provide as much information as possible about their fNMES methods (Pfeiffer et al., 2016), especially about muscle or muscle group targeted; type, size (in $cm^2$) and placement of electrodes; stimulation amplitude in mA; pulse type; waveform; pulse width and (if it applies) biphasic pulse width; frequency of the stimulation train (unless single pulses were provided); and duration of stimulation train in seconds. Moreover, with the help of the Shiny app we provide, authors can compute and provide the maximum current density of their fNMES, which serves both as a measure of effect size allowing cross-study comparison, as well as a verification of participant safety in terms of international thresholds (see Table 1 or the table following bitly.ws/UJNU).

## Table 1

*Summary of Findings: Information on Formation and Stimulation Parameters Extracted from 136 Systematic Review Papers*

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Abdelatief (2020) | Facial Paralysis/ Weakness Treatment | Medserve. Ltd, Prostim / ET3000, S/N:0314 | Middle Face | Monophasic | Square | Muscle Contraction | | | 100 | | 30 | 48 | | |
| Abraham (2016) | Other | | Middle Face | | | | | | 3 | | | | | |
| Alakram (2010) | Facial Paralysis/ Weakness Treatment | EV-803 Digital SD TENS | Upper and Middle Face | | | Muscle Contraction | 10 | 10 | 10 | | 600 | | | |
| Alyassiri (2019) | Facial Paralysis/ Weakness Treatment | | | | | | | | | | | | | |
| Baad-Hansen (2006) | Pain relief/induction | | Lower Face | | | Pain Threshold | 300 | 300 | 333 | 1 | 0.01 | | | |
| Baad-Hansen (2006) | Blink reflex | | Lower Face | | | Pain Threshold | 300 | 300 | 333 | 1.18 | 0.01 | | | |
| Baduni (2017) | Other | | Middle Face | | | | | | 80 | | 720 | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Baijens (2008) | Pain relief/induction | VitalStim ¬Æ Therapy | Upper and Middle Face | | | Muscle Contraction | 700 | 700 | 80 | 17.5 | | | | |
| Benoliel (2011) | Other | | Middle Face | Monophasic | | Sensory Threshold | | | 200 | | | 0.5 | | |
| Bergenheim (1991) | Pain relief/induction | ISSAL 1412 | | | | Pain Threshold | | | | 25 | | | | |
| Bischoff (1993) | Pain relief/induction | | | | | | | | | | | | | |
| Boelhouwer (1982) | Blink reflex | | Upper Face | Monophasic | Square | | 100 | 100 | 0.1 | | | | | |
| Boiardi (1975) | Other | Multistim DISA | Upper Face | | Square | | 50000 | 50000 | 1 | | | | | |
| Borodic (1991) | Other | | Upper Face | | | Muscle Contraction | 100 | 100 | 1 | | | 0.03 | | |
| Bour (2000) | Blink reflex | | Upper Face | | | Muscle Contraction | | | | 20 | | | | |
| Cacho (2022) | Pain relief/induction | Enraf Nonius S82 | Upper and Middle Face | | | | | | 220 | | 180 | 9.6 | | |
| Casanova-Molla (2011) | | | Middle Face | | | Muscle Contraction | | | | | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Chia (1997) | Blink reflex | | Upper Face | | | | | | | | | | | |
| Choi (2016) | Facial Paralysis/ Weakness Treatment | Vitalstim | | Biphasic | | Muscle Contraction | 350 | 700 | 80 | 14 | 1800 | | | |
| Conte (2010) | Other | | | | Square | | 200 | | | | 3600 | | | |
| Conti (2014) | Pain relief/induction | GrindCare, Medotech A/S | Upper Face | | | | | | | | | | | |
| Cui (2021) | Facial Paralysis/ Weakness Treatment | NT6021, Dundex | Upper and Middle Face | Biphasic | Square | Sensory Threshold | 100 | 200 | 20 | 20 | 600 | 3.8 | 0.4 | 0.33 |
| Currier (1963) | Cosmetic | | Upper, Middle, and Lower Face | | | | 500000 | | | | | | | |
| da Silva (2022) | Cosmetic | TONEDERM, Fortis model M40 | Middle Face | | | | | | | | 5 | | | |
| De Giorgi (2017) | Pain relief/induction | NeuroTrac¬Æ TENS (Verity Medical Ltd., Farley | | Biphasic | | | 50 | | 50 | | 3600 | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Lane, Braishfield, Hampshire, UK) | | | | | | | | | | | | |
| de Sire (2022) | Facial Paralysis/ Weakness Treatment | Imperium 400 | Upper, Middle, and Lower Face | | | | | | | | 900 | | | |
| de Tommaso (2001) | Blink reflex | | Upper Face | | | | 100 | | | 60 | | | | |
| Didier (2019) | Pain relief/induction | Myomonitor | | | | | 500 | | 0.66 | | 2700 | | | |
| El-Ebiary (1971) | Facial Paralysis/ Weakness Treatment | | Upper Face | | Square | | 100 | | 2 | | | | | |
| Eliav (2003) | Other | | Upper, Middle, and Lower Face | | | | | | 200 | | | 0.5 | | |
| Esteban & Prieto (1999) | Blink reflex | | Upper Face | | | | | | | 65 | | | | |
| Farrotonato (2022) | Other | | Upper and Middle Face | | | | | | | | 2700 | | | |
| Ferreira (2017) | Pain relief/induction | Neurodyn Sapphire Compact | Upper and Middle Face | | | | 100 | | 100 | | 1500 | 7 | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Line, by Ibramed¬ Æ | | | | | | | | | | | | |
| Ferreira (2004) | Other | | | | | | | | | | | | | |
| Findler and Feisod (1982) | Other | Nicolet CA-1000 - Constant Current | Lower Face | | | Sensory Threshold | | | 30 | 20 | 0.02 | 0.03 | | |
| Fisch (1980) | Other | | | Biphasic | | Sensory Threshold | | | | | 0.02 | 0.07 | | |
| Fukumoto (2001) | Other | Trio-300, Ito Physio-Therapy and Rehabilitation Constant current / constant voltage modes | Upper and Middle Face | | | | 60 | 60 | 100 | | 1800 | | | |
| Gandiglio & Fra (1967) | Other | MS3R MEDELEC apparatus | Middle Face | Biphasic | Square | Sensory Threshold | | | | | 0.1 | | | |
| Goto (2018) | Emotion/ Mood modulation | Custom | Middle Face | | | | | | | | 7.07 | | | |
| Geissler & McPhee (1986) | Pain relief/induction | The TENS Pulsar (TENS | Middle Face | | | Pain Threshold | | | 20 | | 1800 | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pulsar, Spembly Ltd, Newbury Road, Andover, Hants., UK) | | | | | | | | | | | | |
| Gittins (1999) | Other | Model 120Z; ITO, Tokyo, Japan Constant current / constant voltage modes | Upper Face | | | | 200 | 200 | 200 | | 1 | 2.54 | | |
| Gunduz (2016) | Other | | Upper and Lower Face | monophasic | | Muscle Contraction | | | | 20 | | | | |
| Haginomori (2008) | Other | | Lower Face | Biphasic | Square | Muscle Contraction | 200 | 200 | 1 | | | 0.6 | | |
| Hansson (1986) | Pain relief/induction | | | | | Pain Threshold | | | 100 | | 2700 | 17.5 | | |
| Hansson (1984) | Pain relief/induction | Cefar SIII | Upper, Middle, and Lower Face | monophasic | Square | Pain Threshold | 200 | 200 | 100 | | 0.08 | 6 | | |
| Hansson & Ekblom (1983) | Pain relief/induction | Cefar SIII | Upper, Middle, and Lower Face | monophasic | Square | Pain Threshold | 200 | 200 | 2 | | 1800 | 6 | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Hyvärinen (2008) | Other | (Prizm Medical Inc., Duluth, GA) | Middle and Lower Face | monophasic | | Sensory Threshold | 100 | 100 | 20 | | | 2.5 | | |
| Ilves (2019) | Other | custom | Upper and Middle Face | Biphasic | Square | Muscle Contraction | 400 | 800 | 250 | 10 | 0.08 | 1.5 | 20 | 2.98 |
| Ilves (2020) | Other | custom | Upper Face | Biphasic; (polyphasic) | Square; (Sine wavelet) | Muscle Contraction | 400 | 800 | 250 | 48 | 1 | 1.5 | 20 | 14.31 |
| Jadidi (2011) | Other | | Lower Face | | Square | Muscle Contraction | | | 220 | | | 0.5 | | |
| Kapadia (2019) | Emotion/ Mood modulation | Complex Motion | Middle Face | Biphasic | | Muscle Contraction | 75 | 150 | 60 | 15 | 15 | | | |
| Kavanagh (2012b) | Cosmetic | Slenderotone | Middle Face | | | | 100 | 100 | 70 | 35 | | | | |
| Kim (2000) | Other | Neurometer CPT by Neurotron Inc. constant current | Middle and Lower Face | | | Sensory Threshold | | | 250 | 20 | 300 | 0.5 | | |
| Kim & Choi (2016) | Other | Kwangwoo Medix, Inc., Seoul, Korea, version 3 | Lower Face | Monophasic | Square | | | | | 1.4 | | 3.14 | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Kim (2009) | Other | EMGFES 3000, Cybermedic | Middle Face | Biphasic | Square | | 50 | 50 | 60 | 40 | 2 | 3.14 | 0.6 | 0.99 |
| Kurimoto (2019) | Other | Mayo¬© Corporation | Upper Face | Biphasic | Square | | | | 20 | 1 | 1800 | | | |
| Liao (2007) | Blink reflex | | Upper and Lower Face | | | Sensory Threshold | | | | | | | | |
| Livermore (1993) | Other | Digitimer DS7, UK constant current | Middle and Lower Face | | Square | Sensory Threshold | | | | | 0.02 | | | |
| Lugo (2018) | Other | | Middle Face | | Square | | | | | | | | | |
| Maillou & Cadden (2008) | Other | | Lower Face | | | Muscle Contraction | | | | 4.5 | | | | |
| Maisonobe (1998) | Other | | Upper Face | | Square | Muscle Contraction | | | 0.16 | | | | | |
| Makela (2020) | Other | | Upper Face | | | Pain Threshold | | | 250 | 24 | 1 | 1.5 | | |
| Makela (2021) | Facial Paralysis/ Weakness Treatment | custom | Upper Face | Biphasic | Square | | 400 | 800 | 250 | 24 | 1 | 1.5 | 20 | 7.16 |
| Manca (2001) | Blink reflex | | Upper Face | | | | | | | | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Marcelli (2013) | Blink reflex | Digitimer DS7A; Digitimer, Hertfordshire, UK constant current | Upper Face | Biphasic | | Muscle Contraction | | | 200 | 3.5 | 2 | | | |
| Marchand (1991) | Other | two-channel Medtronic adjustable stimulator (TENS 7720). | Middle Face | monophasic | Square | Pain Threshold | 125 | 125 | 100 | | | | | |
| Marotta (2020) | Pain relief/induction | imperium 400; Brera Technologies | Upper, Middle, and Lower Face | Biphasic | Square | | | 700 | 80 | | 1800 | 4 | | |
| Mastryukova (2020) | Other | | Middle and Lower Face | | | | | | | | | 24 | | |
| Matsuo (2013) | Other | | Upper Face | Monophasic | | | 200 | | | 15 | 0.2 | | | |
| Maul (2019) | Pain relief/induction | | Upper Face | | | | | | | | 900 | | | |
| May & Hawkins (1972) | Facial Paralysis/ Weakness Treatment | Hilger Nerve Stimulator | | | | Muscle Contraction | | | | 5 | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| May et al. (1976) | Facial Paralysis/ Weakness Treatment | Hilger Nerve Stimulator | | | | Muscle Contraction | | | | 5 | | | | |
| Mercante (2020) | Blink Reflex | Winner stimulator (Fisioline biomedical instrumentation, Verduno, CN, IT) | Middle Face | Biphasic | Square | Pain Threshold | | 50 | 120 | 18 | 30 | | | |
| Merlo (2020) | Pain relief/induction | Ibramed Neurodyn II | Upper and Middle Face | Biphasic | Square | Muscle Contraction | | 300 | 10 | | | 12.25 | | |
| Montero (2007) | Blink Reflex | | Middle Face | | | Muscle Contraction | | | | | | | | |
| Mummolo et al. (2020) | Pain relief/induction | QuadraTENS, BioResearch Associates Inc. | Middle Face | Biphasic | | | 300 | 300 | 600 | | 1800 | 12.16 | | |
| Muñoz (2003) | Blink Reflex | | Upper, Middle, and Lower Face | | | | | | | | | | | |
| Murphy (1990) | Pain relief/induction | Dynex II | Upper, Middle, and Lower Face | Biphasic | | Sensory Threshold and Motor Contraction | | 110 | | | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Nakashima & Takahashi (1991) | Pain relief/induction | | Lower Face | | | Sensory Threshold | | 500 | | | | | | |
| Natori (2015) | Other | Stimuplex NHS12 | Upper Face | | | Muscle Contraction | | | 2 | 4 | | | | |
| Nowak (2005) | Pain relief/induction | | | | | | | | | | | | | |
| Núñez (2006) | Pain relief/induction | | | | | | | | | | | | | |
| O'Neil (1981) | Pain relief/induction | Cefar SIII | Upper, Middle, and Lower Face | | | Sensory Threshold | | | 100 | | 600 | | | |
| Öge (1993) | Facial Paralysis/ Weakness Treatment | | | | Square | | 100 | 100 | | 100 | 0.1 | | | |
| Orhan (2011) | Pain relief/induction | | | | | Muscle Contraction | | | | | | | | |
| Palmeri (2000) | Blink Reflex | | | | | | | | | | | | | |
| Paracampo (2016) | Other | DS7A, Digitimer | Middle Face | Monophasic | Square | | 200 | 200 | 6 | 0.41 | | | | |
| Pavesi (2000) | Other | Dantec 13L20; | Upper, Middle, | Monophasic | Square | | 200 | | | | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Dantec Medical, Copenhagen, Denmark | and Lower Face | | | | | | | | | | | |
| Pilurzi (2013) | Other | DS7, Digitimer | Upper and Lower Face | Monophasic | Square | | 200 | | 25 | | | | | |
| Pilurzi (2020) | Other | DS7, Digitimer | Lower Face | Monophasic | Square | | 200 | | 25 | | 0.0002 | | | |
| Priya (2017) | Pain relief/induction | | | | | | | | | | | | | |
| Puls (2020) | Facial Paralysis/ Weakness Treatment | Paresestim (Krauth + Timmermann, Hamburg, Germany), PierenStimParese (Schwa-Medico, Ehringshausen, Germany), or Stimulette r2x (Dr. Schufried, Vien, Austria) | Middle and Lower Face | Biphasic | Triangle | Muscle Contraction | | 500 | | 20 | 600 | 24 | | |
| Raphael (2013) | Bruxism relief | Grindcare device | Upper Face | Biphasic | | Sensory Threshold | | | 204 | | 450 | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Raslan (2020) | Pain relief/induction | Microstim, Krauth & Timmermann GmbH, Hamburg, Germany | Middle Face | Monophasic | Square | Muscle Contraction | | | | | | 0.63 | | |
| Rimpiläinen (1994) | Other | Nihon Kohden Neuropack Four device | Upper and Middle Face | | | | | 200 | | 30 | | | | |
| Rode (2012) | Pain relief/induction | | | | | | | | | | | | | |
| Rösler (1995) | Pain relief/induction | | | | | | | | | | | | | |
| Rossi & Scarpini (1992) | Other | | Upper Face | | | | 500 | | | | 20 | | | |
| Rossi (1979) | Blink Reflex | | Upper Face | | Square | Muscle Contraction | 200 | 200 | | | | | | |
| Roth & Thrash (1986) | Pain relief/induction | Alpha Stim Model 2000 | Middle Face | Biphasic | | | | | 5 | 500 | 1200 | | | |
| Adour (1996) | Other | Hilger model 2-R Facial | Upper and Lower Face | | | | | | | 50 | | 0.28 | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Safi (2022) | Other | Nerve Stimulator Ampcares ES | Lower Face | Biphasic | | | | 50 | 30 | | 5000 | 2.5 | | |
| Safi (2017) | Facial Paralysis/ Weakness Treatment | AMPCARE ES; Restorative Medical Inc., Brandenburg, Kentucky, USA | Lower Face | Biphasic | Square | Sensory Threshold | 50 | 100 | 30 | 78.4 | 5 | 4.9 | 0.3 | 0.88 |
| Safi (2018) | Facial Paralysis/ Weakness Treatment | AMPCARE ES; Restorative Medical Inc., Brandenburg, Kentucky, USA | | | | Sensory Threshold | 50 | | 30 | | 5 | 4.9 | | |
| Schmidt (2016) | Pain relief/induction | Digitimer DS7 constant current stimulator | Upper Face | Monophasic | | Pain Threshold | 500 | | 33 | 15 | 2.5 | 0.2 | 3.3 | 13.62 |
| Schmolesky (1996) | Blink reflex | Devices Isolated Stimulator (type 2533) coupled in series with a Grass CCU-1A | Upper Face | Monophasic | Square | Muscle Contraction | 100 | | | 16 | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | constant current unit | | | | | | | | | | | | |
| Schoenen (1994) | Other | | Lower Face | | | | 200 | | 0.1 | 25 | | | | |
| Seifi (2017) | Pain relief/induction | TENSTem dental device (Schwamedico BV; The Netherlands) | Middle Face | | | | | | 50 | 15 | 1800 | | | |
| Seki (1990) | Other | | Middle Face | | Square | Muscle Contraction | 100 | | | | | | | |
| Serrao (2015) | Pain relief/induction | Digitimer DS7A | Upper, Middle, and Lower Face | | | Pain Threshold | 1000 | | 167 | 67.2 | 0.018 | 0.8 | 33.4 | 48.55 |
| Serrao (2003) | Other | | Upper Face | | Square | Pain Threshold | 500 | | | | | | | |
| Shimada (2019) | Bruxism relief | | | | | | | | | | | | | |
| Singh & Singh (2016) | Facial Paralysis/ Weakness Treatment | | | | | Muscle Contraction | 10 | | 10 | | 600 | | | |
| Sommerauer (2021) | Facial Paralysis/ Weakness Treatment | Paresestim device; Krauth+Timmerman | | | | Muscle Contraction | 100000 | | | 10 | | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | n GmbH, Hamburg, Germany | | | | | | | | | | | | |
| Sundaram (1999) | Other | | Lower Face | | | Sensory Threshold | 200 | | 2 | | | | | |
| Suzuki (2004) | Other | | Lower Face | | Square | Sensory Threshold | 50 | | 1 | 5 | | | | |
| Tada (2015) | Bruxism relief | constant-current stimulator (Neuropack Four mini: Nihon Kohden, Japan) | Middle Face | | Square | | 1000 | | 2 | | | 0.3 | | |
| Tal & Sharav (2005) | Bruxism relief | constant current stimulator (Iso-Flex AMPI) | Lower Face | | | Pain Threshold | 450 | | 1000 | | 0.02 | | | |
| Tankéré (2000) | Blink reflex | constant current stimulator | Upper Face | | Square | Muscle Contraction | 100 | | 0.16 | 30 | | | | |
| Targan (2000) | Facial Paralysis/ Weakness Treatment | NT-2; BMR NeuroTech Inc, Bunbeg, Ireland | Upper, Middle, and Lower Face | Monophasic | | Sensory Threshold | 86 | | 1.4 | | 6 | 0.78 | | |
| Tian (2020) | Facial Paralysis/ Weakness Treatment | | Lower Face | Biphasic | Square | | | 700 | 80 | 25 | 1800 | | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Tian (2019) | Facial Paralysis/ Weakness Treatment | Custom Built Device | Upper Face | | | | | | | 10.6 | | 3.14 | | |
| Topçu (2018) | Facial Paralysis/ Weakness Treatment | RehaStim-1, Hasomed GmbH | | | | | 60 | | 30 | | 40 | 0.63 | | |
| Topka & Hallett (1992) | Other | | Upper and Lower Face | | | | 300 | | | | | | | |
| Treacy (1999) | Bruxism relief | | Middle Face | | | Muscle Contraction | | | 4 | | | | | |
| Tuncay (2015) | Facial Paralysis/ Weakness Treatment | Dytron 438 device (Enraf, Germany) | Upper, Middle, and Lower Face | Monophasic | | | 100000 | | 2.5 | | | 3 | | |
| Valls-Sole (1994) | Blink reflex | | Upper Face | | | | | | | | | | | |
| Wang (1999) | Other | constant current | Lower Face | | Square | | 100 | | | | | 2.8 | | |
| Westerhof & Bos (1983) | Other | Bio-Medical Research (BMR) P8 unit | | | | | 250 | | 120 | | 1800 | 78.5 | | |
| Wilson & Ronan (2010) | Facial Paralysis/ | Empi 300 PV NMES unit | Middle and Lower Face | Biphasic | | Muscle Contraction | 200 | | 50 | | | 7.9 | | |

| Author | Goal | Stimulator | Stimulation site | Pulse type | Waveform | intended intensity | Phase pulse Width (usec) | Biphasic pulse Width (usec) | Cycle frequency (Hz) | Max Amp (mA) | Pulse train duration (sec) | Elec surface (cm2) | Duty Cycle (% On) | Max current Density [mA/cm2] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Weakness Treatment | (Empi, St. Paul, MN) | | | | | | | | | | | | |
| Yamamoto & Nishimura (1987) | Other | Nihon Koden, Type SEM-2301 | Upper, Middle, and Lower Face | | Square | Muscle Contraction | 1000 | | | | | | | |
| Yavlal (2020) | Blink reflex | | Upper Face | | | | 200 | | | | | | | |
| Yıldız (2004) | Other | | Lower Face | | | | | | 5 | | | | | |
| Zariffa (2014) | Emotion/ Mood modulation | Compex Motion stimulators (Compex SA, Vaud, Switzerland) | Upper and Middle Face | Biphasic | | Muscle Contraction | 150 | | 60 | 9 | | 3.12 | | |
| Zayan (2020) | Pain relief/induction | TENS device (RS Medical, Vancouver) | Upper Face | | | Sub-Pain Threshold | | | 100 | | | 19.6 | | |
| Zhang (2020) | Pain relief/induction | TENS unit (J5 Myo-monitor; Myotronics-noromed, INC., Seattle, USA) | | | Square | Sub-Pain Threshold | 500 | | 0.67 | | 2700 | | | |

## 2.7 Recommended fNMES parameters

Based on the literature (see Table 1), our own experience (Baker et al., 2023; Elsenaar, 2010; Elsenaar & Scha, 2002), and the characteristics of most commodity NMES devices, we recommend the use of the following parameters to reliably and safely induce facial muscle contractions with fNMES, and minimizing the risk of inducing discomfort in participants: disposable Ag/AgCI electrodes with an approximate surface area of 3 $cm^2$ (e.g., 1.6 x 1.9 cm Ambu blue sensor electrodes bit.ly/3yVRr05), a pulsed biphasic current with square waveform, a frequency of 50 - 70 Hz, pulse width of 10 to 100 us, and a current that is large enough to induce visible contractions but not as high to induce discomfort or pain. Importantly, changes in one or several of these parameters (in isolation as well as in combination) can have dramatic effects on the efficacy, comfort, and safety of fNMES. For example, the same current will have greater effects when increasing pulse width and/or stimulation frequency. Therefore, caution should be used when setting up a new experiment, and the greatest care must be taken to verify that safety thresholds are not exceeded (see section ‘2.5 Safety recommendations for fNMES’). However, at times it can be challenging to obtain localised muscle contractions, where the electrical current remains confined to the targeted muscles without spreading to adjacent ones. This can be assessed through visual inspection or by asking participants to self-report their sensations and pinpoint whether they feel the muscular response exclusively in the desired area. Nonetheless, in certain instances, achieving such precision in muscle contractions may prove difficult due to variations in nerve branching and the presence of subcutaneous fat in the participant's face (Maffiuletti, 2010). Experimenters should therefore oversample and expect that some participants cannot be tested, or if tested will produce low-quality data.

## 2.8 Testing the FFH with fNMES

As shown in Table 1, the majority of studies have used fNMES as a method of acute or chronic pain relief – the underlying neurological mechanism was suggested by the gate control theory (Melzack & Wall, 1965). Five studies have investigated the use of fNMES to recover muscular function after Ball's palsy, or other forms of facial paresis (Cui et al., 2021; Makela et al., 2020). The goal of some studies was to further explore the physiological and subjective effects of varying fNMES parameters, such as the waveform (Ilves et al., 2020; Rantanen et al., 2018). Surprisingly, only three studies have used fNMES to modulate mood and/or emotion (Goto et al., 2018; Kapadia et al., 2019; Zariffa et al., 2014), and thus investigate aspects of the facial feedback hypothesis, despite the great potential that this technique has to help investigate aspects central to psychological mechanisms and theories, such as embodied cognition and sensorimotor simulation (Halberstadt et al., 2009; Niedenthal, 2007; Wood, et al., 2016b). In the following section, we briefly review the facial feedback hypothesis and outline why fNMES may be useful to study it.

The facial feedback hypothesis (FFH) posits that the engagement of facial muscles conveys proprioceptive information to the brain, where it can have (at least) two types of effects (Coles et al., 2022; Coles et al., 2019b; Hatfield et al., 1993). First, the feedback from facial muscles can initiate or modulate emotional states; for example, you may feel happier when posing a smile and sadder when frowning (Adelmann & Zajonc, 1989; Coles et al., 2022, 2023). Second, facial feedback can alter the processing of affective stimuli and can contribute to the accurate and efficient processing of someone else's emotional facial expressions, as well as neural correlates (McIntosh, 1996; Niedenthal, 2007; Sel et al., 2015). Consequently, other people's faces appear happier when you are smiling yourself, and the impact of this facial feedback effect gets stronger when the observed face is one of neutral or emotionally ambiguous expressions (Beffara et al., 2012). Although fNMES can be utilised to

test both aspects of the FFH, we believe that its greatest contribution might be to the investigation of this second aspect of the FFH.

Support for the FFH in relation to the processing of emotional face stimuli comes, for example, from studies showing that facial mimicry is emotion specific (Wingenbach et al., 2020), and spontaneous smile mimicry predicts judgments of smile authenticity (Korb et al., 2014), as well as from studies that blocked or interfered with spontaneous facial responses, by restricting or over-engaging certain facial muscles, e.g., by instructing participants to hold a pen between their lips to inhibit smiling (Neal & Chartrand, 2011; Strack et al., 1988, but see Hess & Fischer, 2022; and Wagenmakers et al., 2016). Past studies aiming to block or interfere with facial feedback were however limited in their ability to precisely control which muscles are activated/inhibited, and at what point in time. These limitations can be overcome using fNMES. Therefore, we suggest that fNMES is a new and powerful means to clarify the role of facial feedback in emotion processing.

To date, only three studies have used fNMES to investigate the first effect of the FFH, namely, whether facial feedback can induce and/or modulate emotional states. The study by Goto et al. (2018) constitutes preliminary work that did not include any quantitative measures (similarly also for Yen-Chin et al., 2017). The other two are of notice. Zariffa et al. (2014) applied fNMES to the zygomaticus major and orbicularis oculi muscles, while participants simultaneously produced voluntary smiles and performed a visual n-back test. In contrast to the authors' hypotheses, fNMES did not improve mood, although participants in the NMES group did report feeling more determined, daring, and concentrated, compared to a control group that underwent the same procedure but did not receive fNMES. A later study by the same group (Kapadia et al., 2019) explored the use of fNMES as a method to improve symptoms of depression. fNMES was applied in depressed patients to the zygomaticus major and orbicularis oculi muscles three times per week, for a minimum of 10 and a maximum of

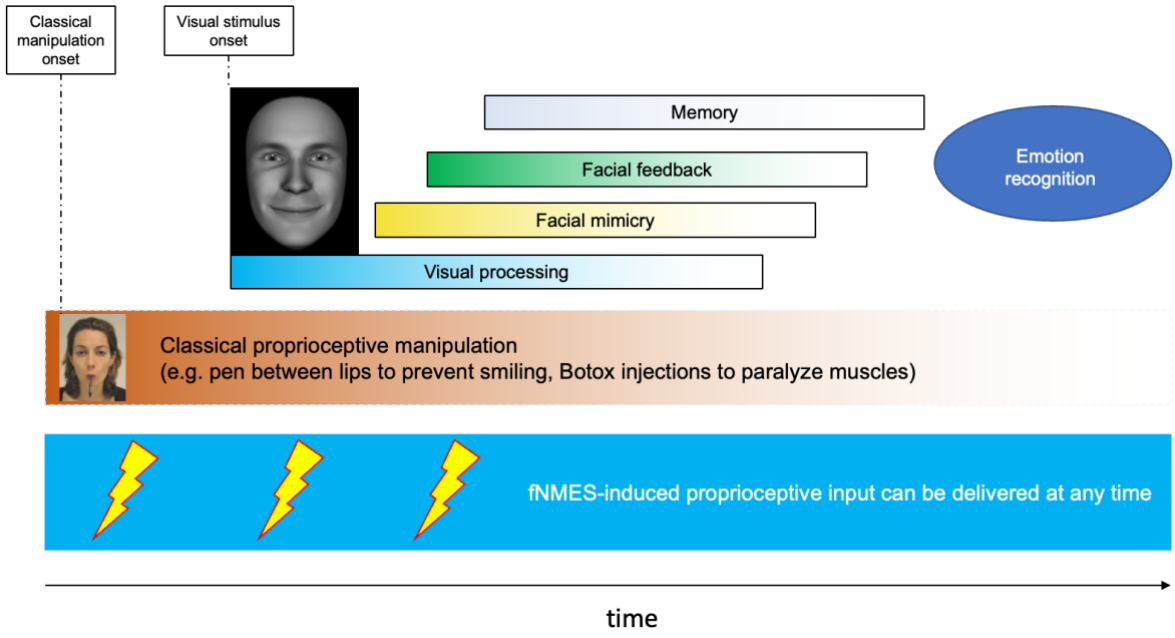
40 sessions. The stimulation was delivered in alternating 15–second long periods of stimulation and rest, while participants posed a voluntary Duchenne smile and viewed comedy videos. After 10 or more fNMES sessions, participants reported reduced symptoms of depression – assessed with the Depression Inventory of Depressive Symptomatology and the Hamilton Rating Scale for Depression – as well as improvements in sleeping patterns. These results are promising but should be considered preliminary evidence, due to the small sample size of 10 patients, the absence of a control group, and the lack of fNMES effects on self-reported mood. Importantly, no study to date has employed fNMES to investigate the second effect stipulated by the FFH, i.e., that facial feedback can alter the processing of affective stimuli, such as other people's emotional facial expressions.

In summary, research testing the FFH with fNMES is in its infancy and has so far tested (with mixed success, likely due to the small sample sizes) only one aspect, namely if facial feedback modulates emotional experience. The question of whether fNMES modulates perception and recognition of others' emotions has, to the best of our knowledge, never been investigated. This is unfortunate, as fNMES promises to provide excellent opportunities to test important aspects of the FFH, such as the chronological relevance of visual and proprioceptive events during embodied emotion recognition. Indeed, if it is the case that theories of embodied cognition assume that spontaneous facial mimicry contributes to emotion recognition, it is also true that they expect it to follow the onset of a visual stimulus (the encounter with an emotional face). However, experimental manipulations of proprioceptive facial input used in research to date (e.g., holding a pen between the lips) suffer from the limitation that the proprioceptive modulation *precedes* the visual presentation of facial expressions, and is typically kept in place for many trials (when it comes to studies on people who received Botox injections, the change in facial input even precedes testing by many weeks). Instead, an adequate test of the role of proprioceptive input for emotion

recognition requires precise control of its onset with respect to the onset of a visual stimulus. fNMES seems better suited for this goal, as it can activate facial muscles in a controlled manner and at different time intervals (e.g., before, during, or shortly after stimulus presentation, see Figure 9). Further, fNMES allows researchers to have greater control – compared to instructing participants to pose an expression or hold a pen in their mouth – over the duration and intensity of the facial muscle activation. One caveat is that we do not know yet exactly what duration and amplitude of stimulation are required to produce reliable facial feedback effects on perception and mood – a point that should be addressed by systematically varying these and other fNMES parameters.

**Figure 9**

*Illustration of Classical Proprioceptive Manipulations with fNMES*



*Notes.* Classical proprioceptive manipulations, e.g., preventing smiling by holding a pen between the lips, or inducing a smile by holding a pen between the teeth, are in place before the onset of the visual stimulus. This is not fully in line with theories of embodied cognition, which conceive facial mimicry and its accompanying change in facial feedback as a reaction to the visual stimulus. fNMES, on the other hand, allows us to provide physiologically sound proprioceptive inputs that can be targeted both in time (before, during, and after the visual stimulus) and space (congruent or incongruent muscles).

## 2.9 Conclusion

fNMES is a valuable and exciting (pun intended) tool for psychophysiology and other related fields, allowing for precise control over which muscles are activated and at what intensity and duration. This bears enormous potential for investigating questions of interest to psychologists, such as aspects of the FFH, and multisensory integration. The purpose of this paper was to bring attention to this emerging technique and to provide researchers with an overview of considerations for using it in their research. We have provided step-by-step recommendations based on our experience and a systematic review of the literature. We also provide a free companion app that can be used to verify the waveform and safety of a large number of stimulation parameters. It is our hope that these recommendations and tools will contribute to introducing fNMES to a wider audience of psychologists. Although many questions remain, we are convinced that the future looks bright for fNMES in the psychophysiological laboratory.

## 2.10 Summary

Chapter 2 provided an in-depth examination of fNMES and its potential applications in psychology, neuroscience, and clinical settings. It began with a historical perspective, highlighting the pioneering work of Duchenne de Boulogne in the 19th century and its recognition by Charles Darwin. The chapter then discussed the evolution of fNMES in

various domains, including pain relief, recovery from facial paralysis, cosmetic applications, and artistic performance.

A key focus of the chapter was the lack of adoption of fNMES in contemporary psychology research, despite its significant potential. The variability in fNMES parameters used in studies was addressed, and the importance of standardising these parameters for comfort, safety, and effective comparison across studies was emphasised. A comprehensive guide was provided for the use of fNMES, including detailed recommendations for safe and reliable delivery, reporting parameters for cross-study comparison, and a free online tool for visualising fNMES parameters and verifying their safety.

The chapter also discussed the role of fNMES in investigating the FFH, which posits that facial muscle feedback can influence emotional experiences and perceptions. It highlighted the advantages of fNMES over traditional methods (as outlined in Chapter 1) used in FFH research, such as its precision in activating specific facial muscles at exact timings.

Furthermore, the chapter presented a systematic review of the fNMES literature, examining the stimulation parameters used and their goals. Most studies focused on pain relief and facial paralysis recovery, with few studies exploring emotion induction and/or modulation. The review revealed a lack of consistency in reporting fNMES parameters, underscoring the need for standardised reporting for effective cross-study comparisons.

In conclusion, specific fNMES parameters were recommended based on the literature and research experience, emphasising the need for careful calibration to ensure participant comfort and safety. Finally, the use of fNMES in FFH research was encouraged, especially for understanding the role of proprioceptive feedback in emotion processing.

# 3 Volunteers' concerns about facial neuromuscular electrical stimulation

Themis Nikolas Efthimiou[1], Paul H. P. Hanel[1], Sebastian Korb[1,2]

[1]Department of Psychology, University of Essex, Colchester, United Kingdom

[2]Department of Cognition, Emotion, and Methods in Psychology, University of Vienna, Austria

Authors note:

Correspondence concerning this article should be addressed to Themis N. Efthimiou, Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ. Email: t.efthimiou@essex.ac.uk

## 3.1 Abstract

Facial neuromuscular electrical stimulation (NMES) is the application of an electrical current to the skin to induce muscle contractions and has enormous potential for basic research and clinical intervention in psychology and neuroscience. Because the technique remains largely unknown, and the prospect of receiving electricity to the face can be daunting, willingness to receive facial NMES is likely to be low and gender differences might exist for concern for the sensation of pain and skin burns. We investigated these questions in a pre-registered online study of 182 healthy participants. The likelihood of taking part (LOTP) in a hypothetical facial NMES study was measured with a 7-point Likert scale both before and after presenting a detailed vignette about facial NMES including its risks. Results showed that LOTP was generally high and that participants remained more likely to participate than not, despite a decrease in LOTP after the detailed vignette. LOTP was significantly predicted by participants' previous knowledge about electrical stimulation and their tendency not to worry about the sensations of pain, and it was inversely related to concerns for burns and loss of muscle control. Fear of pain was also inversely related to LOTP, but its effect was mediated by the other concerns. We conclude that willingness to receive facial NMES is generally high across individuals in the studied age range (18-45) and that it is particularly important to reassure participants about facial NMES safety regarding burns and loss of muscle control. The findings are relevant for scholars considering using facial NMES in the laboratory.

Keywords: facial neuromuscular electrical stimulation; user concerns; risks; burns; pain

## 3.2 Introduction

Neuromuscular electrical stimulation (NMES) is a non-invasive technique that activates body muscles by delivering an electrical current through surface electrodes placed on the skin. While NMES is commonly used on the muscles of the trunk and limbs, its application to facial muscles has been relatively rare. This is unfortunate, as facial NMES holds enormous potential for investigating perceptive phenomena such as multisensory integration involving proprioception (Lunghi et al., 2017; Salomon et al., 2013) and psychological theories of embodied cognition (Niedenthal, 2007; Wood, et al., 2016b). Additionally, it may have clinical applications, such as improving mood in depressed patients (Kapadia et al., 2019). Due to the considerable novelty of this technique in psychological laboratories, there is a need to understand the most effective ways to advertise studies involving facial NMES. We have conducted a pre-registered survey to estimate people's willingness to receive facial NMES and to explore how this willingness might vary depending on the amount of information provided about the risks of NMES, as well as differences in participants' demographics and personality traits.

NMES produces muscle contractions by exploiting the human body's natural electrical characteristics (i.e., its' conductivity and resistance) and manipulates them in a controlled way to induce motor action potentials. Stimulation intensity is typically applied at one of three thresholds: 1) the sensory threshold, at which people feel light tingling sensations; 2) the motor threshold, at which weak (visible) muscle contractions are produced; and 3) the functional threshold, at which a maximal muscle contraction is observed (Smith et al., 2003; Insausti-Delgado et al., 2020). NMES is mainly applied to the limb or trunk muscles and is popular for sports rehabilitation (Alon et al., 2007), and for restoring the function of paralysed muscles (Peckham & Knutson, 2005). It is also used for brain research, as it allows for the

investigation of both motor and sensory nerves (George et al., 2000; Corbet et al., 2018; Carson & Buick, 2019).

NMES is considered safe relative to other electrical stimulation techniques commonly used in psychological research, such as transcranial Alternating and Direct Current Stimulation. The risk of inducing injuries with NMES is low, provided that stimulation parameters are carefully selected (Doucet et al., 2012), the device complies with the International Electrotechnical Commission guidelines (BS IEC 60479-1:2018, 2019), and administrators follow safety guidelines (Kono et al., 2018). Apart from facial application, there has been only one reported case of burns due to deviation from the established protocol (Rodriguez et al., 2012). The most common side effects of NMES are pain and discomfort, usually caused by inadequate electrode placement and high impedance between the skin and electrode. In one study, 15% of participants receiving limb NMES reported 'prickling' sensations (Abu-Khaber et al., 2013). Additionally, pain or discomfort led one in 68 (Iwatsu et al., 2015) and one in 9 (Vivodtzev et al., 2012) participants to withdraw from NMES studies. Another concern is skin irritation (redness under the surface electrode), which is typically short-lived, fading after 20-30 minutes (Kavanagh et al., 2012b). Skin irritation can result from excessive 'Joule heating', i.e., the build-up of heat due to current resistance in the skin (Balmaseda et al., 1987; Walls et al., 2018).

To date, NMES has rarely been used on the face for scientific purposes, particularly in healthy participants. Some studies have applied NMES to the face in clinical populations, for example, to treat facial paralysis (Fargher & Coulson, 2017; Mäkelä et al., 2019; Marotta et al., 2020), symptoms of depression (Kapadia et al., 2019), and to assist individuals with dysphagia in swallowing food (Q. Zhang & Wu, 2021). Additionally, three studies have used facial NMES to explore afferent feedback to the central nervous system (Ginatempo et al., 2018; Pilurzi et al., 2013, 2020). Two other studies have investigated whether NMES-induced

activation of specific facial muscles, such as the zygomaticus major involved in smiling, can alter the mood of healthy participants, yielding mixed results (Yen-Chin et al., 2017; Zariffa et al., 2014). In summary, the investigation of facial NMES effects in healthy participants is still in its early stages.

There are two important challenges to the use of facial NMES research in psychology. One is the influence of participants' anticipated concerns (e.g., of being in pain) on the phenomenon of interest, for example, their emotional experience (Zariffa et al., 2014). In line with this, the literature on pain expectation (Schrooten et al., 2012) finds that the anticipation of pain impacts the subjective experience and neural processing of painful stimulation (for review see, Atlas & Wager, 2012). When interviewing patients before they received an electrical stimulation garment for rehabilitation purposes, Moineau et al. (Moineau et al., 2021) reported that participants were concerned about suffering burns and painful shocks but were nevertheless willing to use the garment for the benefits it offered. Consequently, if concerns are not adequately addressed participants' experience with facial NMES may be modulated by their anticipated concerns, thereby confounding the results of the research.

A second obstacle is difficulty in recruiting and retaining participants, as they are likely to be concerned about potential side effects. Despite being a safe procedure when limits are followed and precautions are taken, the fact that NMES applies an electric current to the face contributes to making it appear dangerous and/or painful to the eyes of naïve volunteers. Volunteers may be deterred by the potential risks considering the negative consequences of damage to the body (Rumsey & Harcourt, 2004). This concern is greater for facial NMES, because of the importance, the face has for nonverbal communication, and because it quickly reveals an individual's sex, age, and attractiveness (Peters et al., 2007; Calder, 2011). Further, if skin irritation takes place on the limbs or trunk it can easily be concealed from view. In contrast, any burns or marks caused by NMES on the face are considerably more noticeable

and can negatively affect psychological well-being (Brown et al., 2008) and social interactions, as individuals with facial injury are perceived negatively and judged as less trustworthy and competent (Rankin & Borah, 2003). Nonetheless, the precise concerns that healthy individuals have about receiving NMES – particularly in the face – remain unknown.

How much these concerns about, and the willingness to receive, facial NMES vary based on demographic (e.g., gender, education, and age) and individual difference variables (e.g., personality, concerns), remains unknown to date. These factors seem relevant, as they have also been found to influence risky behaviour in general (Figner & Weber, 2011), and facial NMES might be considered risky by naïve individuals. For example, there is a clear gender disparity in risk-taking in choices of safety and health, with women being more risk-opposed than men (Harrant & Vaillant, 2008; Harris & Jenkins, 2006). Additionally, as stated, one of the risks of NMES is that it may create skin irritation, which can impact body image. Fear of facial skin irritation and burns is likely to be greater in women since they are generally more concerned with their body image than men (El Ansari et al., 2014; Mellor et al., 2010). There also exists a distinction between men and women within their pain threshold and tolerance in experimental tasks (Alabas et al., 2012; Samulowitz et al., 2018), which is modulated based on gender role beliefs (Robinson et al., 2003; for review see Racine et al., 2012). Gender and gender beliefs can also impact thresholds for expected pain tolerance during the anticipation of a fictitious electrical stimulation to the finger. For example, Pool et al. (2007) found a substantial difference in reported pain tolerance between men and women who strongly identify with their gender role, compared to those who weakly identify with their gender role. Therefore, there may be gender differences in the overall willingness to participate in facial NMES research, as well as in the prevalence of specific concerns.

Additionally, gender-independent personality characteristics might also determine participants' likelihood to take part in research involving facial NMES. Older populations

tend to be more risk-averse than younger groups and may be less interested in participating in this type of research (Albert & Duffy, 2012). Similarly, participants may be more reluctant to receive facial NMES when they have particularly high or low levels of interoceptive awareness, which is known to play a role in the experience of pain (Di Lernia et al., 2016; Ramírez-Maestre et al., 2004). How people think of and perceive facial NMES could also differ by their motivation to approach or avoid emotion-inducing situations, as measured by the need for affect scale (Maio & Esses, 2001). Indeed, research has shown that the need for affect is positively associated with risky behaviours, such as sensation-seeking and drug consumption (Coelho et al., 2018). Similarly, personality characteristics can also influence motivation to engage in new and risky activities (Cooper et al., 2000). Two traits of the five-factor model, neuroticism, and openness, seem particularly relevant. Individuals high in neuroticism also have high levels of anxiety and report greater negative affect in their daily lives (Barlow et al., 2014). They might therefore be less inclined to participate in an NMES study, as they are more attentive to its risks and consequences (Kroencke et al., 2020). Alternatively, neurotic individuals may be more inclined to participate in activities perceived as risky, due to their impulsivity and motivation to regulate their negative affect (M. L. Cooper et al., 2000). In contrast, individuals high in openness seek out new experiences that are abstract and intellectual (DeYoung, 2013, 2015), and may therefore be more inclined to participate in psychological research using facial NMES.

In summary, we conducted an online survey, to better understand healthy people's concerns about receiving facial NMES, both before and after receiving detailed information about the potential risks involved, and how these concerns differ by gender and personality characteristics. We made the following a priori hypotheses (pre-registered at https://osf.io/uf2ed/). H1: Participants' concerns about skin burns, pain, and involuntary muscle movement are significant predictors of their willingness to take part in a hypothetical

facial electrical stimulation study. Specifically, the higher the concern the less willing the subject is to take part. H2: Participants' gender interacts with their concern about being burned, being in pain, and involuntary muscle movement. Specifically, concerns with pain and skin burns are, respectively, higher in men and women. This hypothesis was made on the assumption that female participants are more concerned about their physical appearance than men, especially in the face, and based on the popular belief that women tolerate pain better than men. Moreover, we carried out exploratory analyses, e.g., to investigate if the need for affect is positively associated with the likelihood of taking part in a facial NMES study.

## 3.3 Method

A cross-sectional design was used, and the survey was completed online. All materials, pre-registered hypotheses, analysis scripts, and data are freely available (https://osf.io/uf2ed/).

### 3.3.1 Participants

A total of 233 people living in the UK, between the ages of 18 and 45, were recruited from the online platforms SONA (https://www.sona-systems.com; $n$ = 68) and Prolific (https://www.prolific.com; $n$ = 165). Participants were compensated financially or received course credits. We selected participants from those two pools to increase ecological validity: Researchers interested in recruiting participants for lab studies are likely to recruit from one of these pools. The research was approved by the ethics committee of the University of Essex (ETH2021-0744).

### 3.3.2 Sample size justification

Due to the novelty of the research effect sizes from previous work were unavailable. The sample size was estimated based on Schönbrodt and Perugini's (2013) suggestion that a

correlation with Rho = .2 and width = .15 stabilises with 197 participants. Therefore, we aimed to obtain data from slightly more than 200 participants, as some data loss was expected.

## 3.3.3 Measures

### 3.3.3.1 Likelihood of taking part

The main dependent variable was participants' likelihood of taking part (LOTP) in a hypothetical facial NMES study. LOTP was measured at two time points: at the beginning of the survey, after the hypothetical facial NMES research had been described with minimal information (LOTP1, see Appendix B), and later in the survey, after a comprehensive description of facial NMES and the associated risks had been provided (LOTP2 see Appendix C). At LOTP1 and LOTP2 participants answered the question 'How likely are you to take part in a study involving facial neuromuscular electrical stimulation?' using a 7-point scale, with the anchors 1 (*Extremely unlikely*), 4 (*Neither likely nor unlikely*), and 7 (*Extremely likely*). To ensure participants carefully considered their response, LOTP was measured one more time immediately after LOTP2. This LOTP3 rating (not pre-registered) used slightly different wording: 'How much do you intend to take part in a facial NMES study if offered the possibility'. The 7-point Likert scale of LOTP3 had the anchors 1 (*I would never want to participate*), 4 (*I am undecided about participating*), and 7 (*I want to participate*). The two ratings of the likelihood of taking part after reading the detailed NMES descriptor (LOTP2 and LOTP3) produced nearly identical values (respectively, $M$ = 4.84 and 4.88, $SD$ = 1.77 and 1.75; $\alpha$ = .96) and were consequently averaged (henceforth called LOTP2). This was true in all but 19 participants, whose LOTP2 and LOTP3 values differed by more than two points, and who were therefore excluded from analyses (which however did not change the pattern of results, see Appendix F).

Moreover, participants rated how much they agree with the statement that they feel concerned about i) being burned, ii) being in pain, and iii) involuntary muscle movement, on a 7-point Likert scale with anchors 1 (*Strongly* disagree) to 7 (*Strongly agree*). These potential risks were included in the comprehensive description of facial NMES provided towards the end of the experiment (just before LOTP2 and LOTP3).

Additionally, we recorded through self-report participants' gender, age, education, prior experience with electrical stimulation, theoretical and practical knowledge of electrical stimulation (0 *beginner* to 100 *expert)*, and scores on five questionnaires.

#### 3.3.3.2 Questionnaires

We measured approach and avoidance of emotions, using the Need for Affect Questionnaire (NAQ) (Appel et al., 2012), which measures motivation to approach emotion-inducing situations (e.g., "I feel the need to experience strong emotions", 5-items, $\alpha = .85$) and avoidance of emotion-inducing situations (e.g., "If I reflect on my past, I see that I tend to be more afraid of feeling emotions", 5-items, $\alpha = .78$). Risk-taking was measured using the Domain-Specific Risk-Taking Scale (DOSPERT; Blais & Weber, 2006) specifically its subscale for health/safety (e.g., "Riding a motorcycle without a helmet", 6-items, $\alpha = .55$). To assess emotional distress or worry with sensations of pain or discomfort, we used the Not-Worrying subscale from the Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2018), which includes five items ($\alpha = .80$) such as: "I can stay calm and not worry when I have feelings of discomfort or pain". The MAIA uses a 6-point Likert scale (*never*) 0 – 5 (*always*), but due to a programming error, our version used 5-points but kept the same anchors (*never*) 1 – 5 (*always*). We reverse scored the MAIA subscale to make it more intuitive: high scores on the subscale reflect greater concern for or worry about sensations of pain or discomfort. Concerns with body image were measured using 20 items of the Body Image Concern Index (BICI; Littleton et al., 2005), which includes statements of the

type "I try to camouflage certain flaws in my appearance". Neuroticism (e.g., "I have frequent mood swings", α = .71) and Intellect/imagination (e.g., "I have a vivid imagination", α = .79) were assessed using the 4-item subscales taken from the mini–International Personality Item Pool (mini-IPIP; Donnellan et al., 2006).

### 3.3.4 Procedure

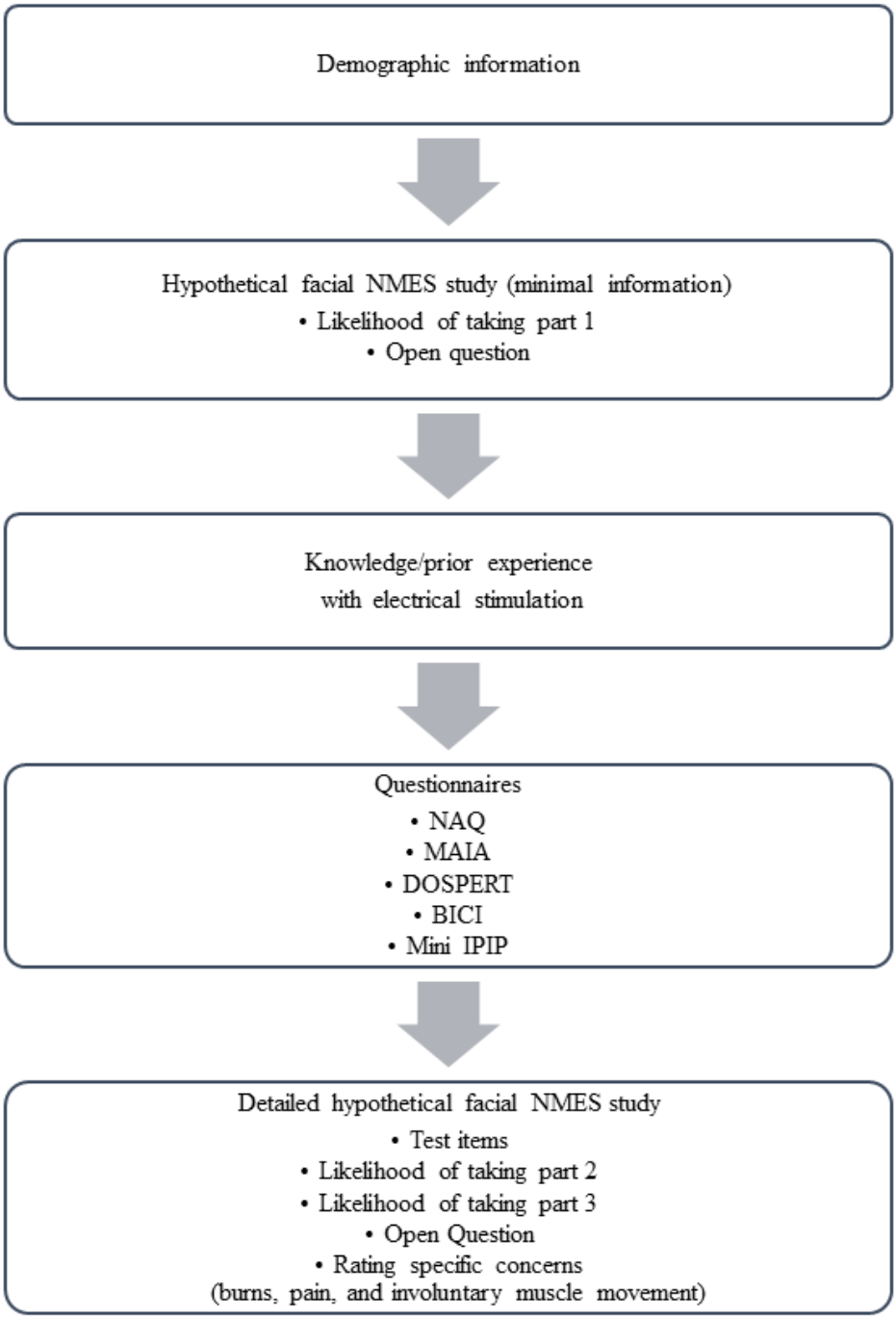
The study was administered online using Qualtrics software (Provo, UT). Participants were told that we were interested in their opinions and beliefs regarding facial NMES and that they would complete questionnaires concerning risk, personality, body awareness, and body image.

The order of measures is shown in Figure 10 (Appendix G The complete Qualtrics survey). After providing consent and demographic information, participants read a written description of a hypothetical scenario, in which NMES would be delivered to their faces as part of a study in a psychological laboratory (Appendix B). Notably, the scenario described facial NMES as "a safe and non-painful technique" and provided little other information. Participants were asked to indicate on a 7-point Likert scale how likely they were to take part in the said hypothetical study (LOTP1) and subsequently participants could provide their concerns by responding to an open-ended question about taking part in the study. Thereafter, participants were asked about their knowledge of and experience with receiving electrical stimulation, and they then completed the five questionnaires. Subsequently, the hypothetical study was described in greater detail, highlighting the safety risks associated with facial NMES, such as burns, pain, and involuntary muscle movement, hereby called loss of muscle control. Some content questions were included, to ascertain that the descriptor had been read and understood. Participants were then asked again how likely they were to take part in the hypothetical study using two nearly identical questions (LOTP2 and LOTP3). Further, they were asked what concerns they might have – both using an open question and three separate

Likert scales for ratings of the specific concerns of i) pain, ii) burns, and iii) loss of muscle control.

**Figure 10**

*Flow diagram presenting the order of the survey administered to all participants*



## 3.4 Analyses

Data and analysis scripts are available online (https://osf.io/uf2ed/). The data were analysed following our pre-registered plan, after excluding participants who had given incorrect responses to two of the three content questions and test items, who had completed the survey in more than 15 minutes, or whose LOTP changed by two or more points in the two back-to-back items LOTP2 and LOTP3. Responses to LOTP1 and LOTP2 were analysed using separate stepwise multiple linear regressions using the *lm* function in R (R Core Team, 2020). For the regression analysis, the continuous independent variables were cantered. Both models contained the initial predictors of age, gender, level of education, knowledge of electrical stimulation (theoretical & practical), prior experience with electrical stimulation, as well as the five questionnaires. To reduce its terms, each model was run iteratively, progressively dropping terms with the largest *p* and smallest *t* value (backward elimination procedure). Then three moderated regressions were conducted to examine whether gender interacted with the specific concerns (burns, pain, and loss of muscle control). Finally, responses to open questions were assigned to one of ten themes, and summary statistics were computed. Additional exploratory analyses were also conducted. A third regression was conducted on the difference between LOTP1 and 2 to explore if any terms predicted a change in LOTP (LOTP2 minus LOTP1, larger values indicate a decrease in LOTP). Two one-sample t-tests examined whether LOTP1 and LOTP2 were above the neutral point of the scale (4: *neither likely nor unlikely*). In addition, three t-tests were used to compare men and women's self-reported concerns for burns, pain, and Loss of muscle control. Finally, a mediation analysis was conducted on responses to LOTP2 using the package Psych (Revelle, 2017).

## 3.5 Results

The final analysis was conducted on a group of 182 participants between the ages 18 – 45 ($M_{age}$ = 27.84, SD = 7.75), which is comprised of 90 men ($M_{age}$ = 28.63, *SD* = 7.52) and 92 women ($M_{age}$ = 27.07, *SD* = 7.93). Thirty-two people were excluded from analyses for failing one or more attention checks (filler questions included to determine data quality). An additional 19 participants were rejected, owing to the large change (two or more points out of seven) in their responses between two back-to-back items with slightly different wordings, measuring their likelihood of taking part (excluding those participants who did not change the pattern of results, see analyses with 201 participants in (Appendix F).

Overall, participants reported having low levels of theoretical and practical knowledge of electrical stimulation (see Table 2 and Table 3). In the following, we first describe the pre-registered analyses, central to our hypotheses (data and analysis script can be found online: https://osf.io/uf2ed/), followed by exploratory analyses).

**Table 2**

*Summary of participants' prior experience with NMES*

| Experience with NMES | Count | % |
|---|---|---|
| No | 128 | 25.30 |
| Unsure | 8 | 70.30 |
| Yes | 46 | 4.40 |
| Sum | 182 | 100 |
| Reason | | |
| Medical | 19 | 41.30 |
| Research | 2 | 4.30 |
| Other | 25 | 54.30 |

### 3.5.1 Pre-registered Analyses:

To examine the relations between all independent and dependent variables, a correlation matrix with Spearman correlations was produced (see Table 3). This showed that concern for pain was significantly inversely related to LOTP1 and that all three types of concerns (pain, burns, and loss of control) were significantly negatively correlated with LOTP2. Also notable, greater LOTP2 was found for participants who reported greater theoretical knowledge about electric stimulation, and who scored higher on the worrying subscale of the MAIA questionnaire.

To test our first hypothesis that concern for NMES-induced pain, burns, and loss of muscle control negatively predict the likelihood of taking part –, and to explore the contribution of individual differences as specified in the pre-registered exploratory analyses, two separate multiple regression analyses were conducted for LOTP1 and LOTP2.

**Table 3**

*Descriptive statistics and correlations for the likelihood of taking part before (LOTP1) and after (LOTP2) reading a detailed description of NMES and the study variables*

| Variables | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. LOTP1 | 5.17 | 1.59 | 1.00*** | | | | | | | | | | | | | |
| 2. LOTP2 | 4.87 | 1.73 | .56*** | 1.00*** | | | | | | | | | | | | |
| 3. Theoretical know. | 20.05 | 20.25 | .24 | .28* | 1.00*** | | | | | | | | | | | |
| 4. Practical know. | 11.21 | 17.19 | .15 | .21 | .59*** | 1.00*** | | | | | | | | | | |
| 5. NAQ-Approach | 1.01 | .93 | -.02 | -.03 | .02 | .07 | 1.00*** | | | | | | | | | |
| 6. NAQ-Avoidance | -.42 | 1.34 | -.05 | .06 | -.15 | -.14 | -.30** | 1.00*** | | | | | | | | |
| 7. MAIA | 3.00 | .75 | -.21 | -.39*** | -.23 | -.27* | .16 | .15 | 1.00*** | | | | | | | |
| 8. DOSPERT | 18.83 | 6.26 | .01 | .18 | .02 | .01 | -.14 | .11 | -.17 | 1.00*** | | | | | | |
| 9. BICI | 45.29 | 15.85 | -.04 | .05 | -.06 | -.07 | .04 | .42*** | .16 | .24 | 1.00*** | | | | | |
| 10. Neuroticism | 11.66 | 3.45 | -.10 | -.09 | -.19 | -.14 | .18 | .46*** | .43*** | -.06 | .47*** | 1.00*** | | | | |
| 11. Openness | 14.70 | 3.43 | .08 | .15 | .19 | .06 | .09 | -.02 | -.12 | .07 | .01 | .03 | 1.00*** | | | |
| 12. Burns | 4.09 | 1.97 | -.19 | -.39*** | -.11 | -.14 | .05 | .09 | .27* | -.03 | .13 | .10 | -.14 | 1.00*** | | |
| 13. Pain | 4.14 | 1.87 | -.29** | -.37*** | -.16 | -.14 | .15 | .01 | .44*** | -.04 | .22 | .15 | -.19 | .58*** | 1.00*** | |
| 14. Loss of muscle control | 4.02 | 1.92 | -.30** | -.52*** | -.21 | -.24 | .16 | .11 | .45*** | -.12 | .13 | .27* | -.09 | .53*** | .51*** | 1.00*** |

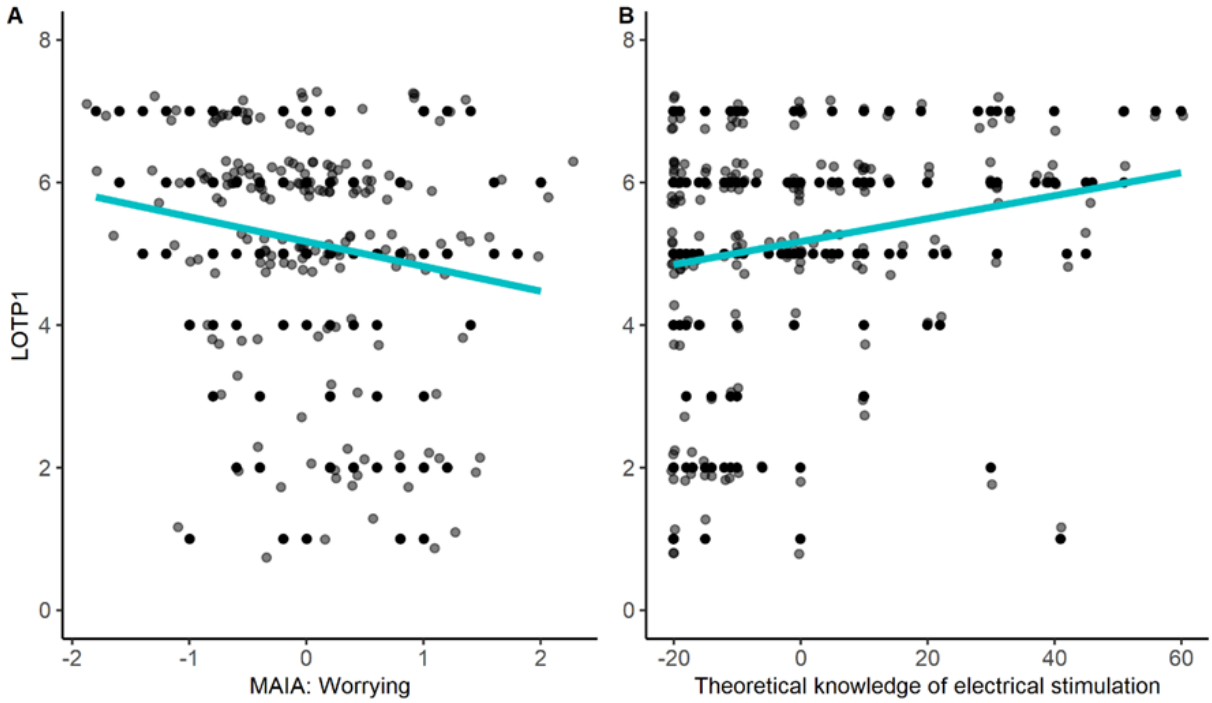
*Notes*. $n$ = 182 for all correlations. Spearman correlation rho values. Statistical significance (corrected for multiple inferences with Holm's method) is indicated by asterisks: * $p < .05$, ** $p < .01$, ***$p < .001$. NAQ, need for affect questionnaire; MAIA, multidimensional assessment of interoceptive awareness; DOSPERT, domain-specific risk-taking scale; BICI, body image concern index; loss of muscle control.

### 3.5.2 LOTP1 – minimal knowledge of NMES

The multicollinearity of the initial model was in the acceptable range, with all variance inflation factors below 10. The model was reduced until only two significant terms remained (Figure 11): the level of prior theoretical knowledge of electrical stimulation (β = .02, $p$ = .006), and MAIA's worrying subscale (β = -.35, $p$ = .027). This reduced model explains a significant and small proportion of variance, $R^2$ = .09, $F(2, 179) = 8.32$, $p < .001$; *adj.* $R^2$ = .07.

**Figure 11**

*Scatterplots of significant terms predicting LOTP1*



*Notes.* Participants' LOTP1 increased significantly the less they worried about physical pain and discomfort, as measured with the (reversed) MAIA worrying subscale (A), and the more they knew about electrical stimulation (B). Model fit is shown by the blue line, and black dots show individual data points (jittered in both dimensions to increase visibility).

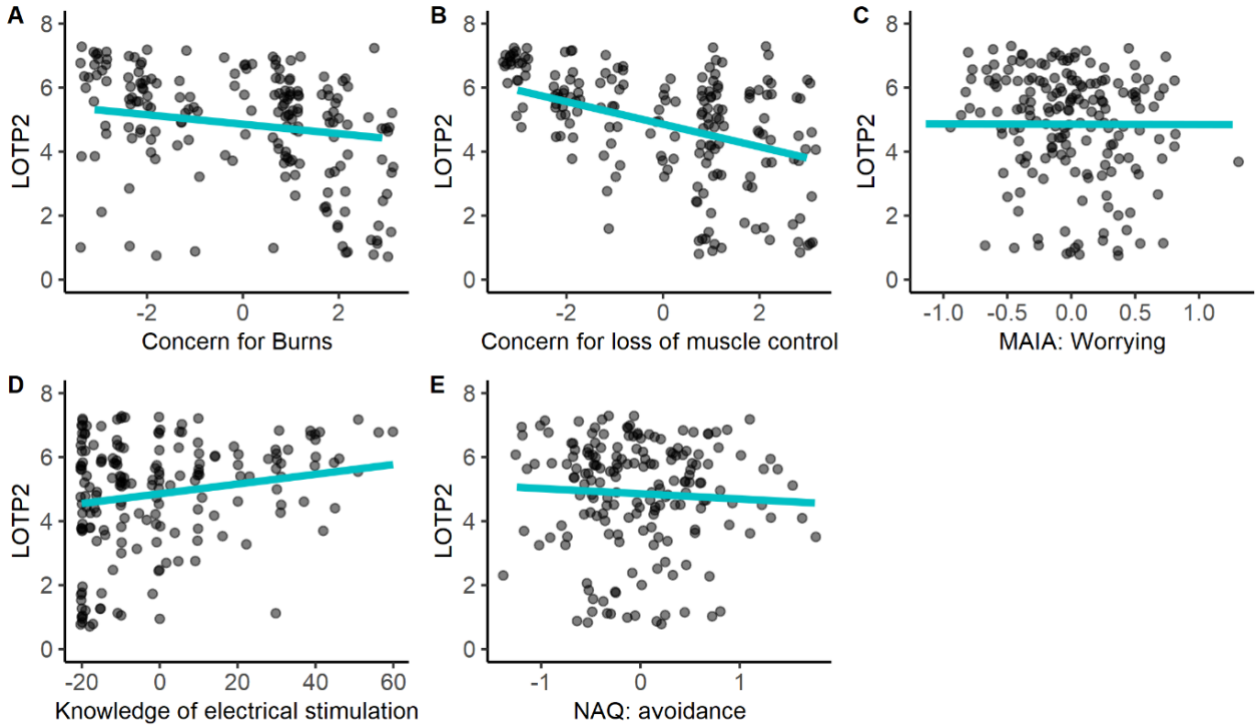
### 3.5.3 LOTP2 – detailed knowledge of NMES

The initial model for LOTP2 included the same terms as for the initial model fitted on LOTP1, with the addition of scores for the three concerns, for example, burns, pain, and loss of muscle control. Multicollinearity was in the acceptable range, with all variance inflation factors below 10.

The reduced model explains a significant and substantial proportion of variance, $R^2$ = .37, $F(5, 176) = 20.33$, $p < .001$, adj. $R^2 = .35$. The final model included three significant negative terms: concern for burns (β = -.14, p = .022; Figure 12A), concern for loss of muscle control (β = -.30, p < .001; Figure 12B), and the MAIA's worrying subscale (β = -.40, p = .011; Figure 12C). In addition, there were two significant positive terms: theoretical knowledge of electrical stimulation (β = .01, p = .006; Figure 12D) and surprisingly the NAQ avoidance subscale (β = .21, $p$ = .009; Figure 12E).

**Figure 12**

*Scatterplots of significant terms predicting LOTP2*




*Notes.* The likelihood of taking part in the NMES experiment significantly decreased the participants' concern for burns (A) and loss of muscle control (B). Moreover, it increased significantly the less participants worried about physical pain and discomfort (C), the more they knew about electrical stimulation (D), and the higher their score on the NAQ avoidance (E). Model fits are shown by the green line, and individual data points by black dots (jittered to increase visibility).

To test our second hypothesis – of a significant interaction between the participants' gender and their concerns about being burned, being in pain, and losing muscle control – we ran three moderated regression analyses, one per concern, with the dependent variable being LOTP2 and the predictor gender and the concern. Only the model (full model descriptions in Appendix D and E) for loss of muscle control produced a main effect ($\beta$ = -.49, $p$ = .011), no other main effects were found (all $ps$ > .059). Further, contrary to predictions, no significant interaction with gender was found in any of the models (all $ps$ > .313).

To further capture participants' thoughts about NMES, the open questions were reviewed and coded according to their content. A total of 10 categories emerged (see Table 4). Approximately 25% of participants reported having no concern or non-NMES related concerns, such as about the compensation or practicalities of travelling to a laboratory.

**Table 4**

*The number of participants indicating concerns in open questions, as well as their average (SD) LOTP, before and after reading a detailed description of facial NMES and its risk*

| | Before | | | After | | |
|---|---|---|---|---|---|---|
| Categories of concern | *n* | LOTP1(*M*) | LOTP1(*SD*) | *n* | LOTP2(*M*) | LOTP2(*SD*) |
| No or non-NMES related concerns | 49 | 5.55 | 1.50 | 63 | 5.28 | 1.69 |
| Skin burns and irritation | 4 | 5.75 | 2.40 | 31 | 4.68 | 1.65 |
| Pain and discomfort | 39 | 4.92 | 1.99 | 30 | 5.17 | 1.47 |
| Pain and burns/irritation | 4 | 5.50 | 1.11 | 11 | 3.27 | 1.74 |
| Involuntary muscle movement and appearing odd | 7 | 5.57 | .95 | 9 | 4.56 | 2.26 |
| Immediate or long-term damage to the face/nerve | 40 | 5.45 | 1.30 | 12 | 4.92 | 1.14 |
| Lack of information and unfamiliarity with the sensation or technique | 25 | 4.36 | 1.80 | 8 | 4.81 | 1.81 |
| Interaction with a pre-existing health condition | 0 | 0 | 0 | 3 | 2.83 | 1.61 |
| Concerned but no specific reason | 11 | 4.73 | 1.86 | 11 | 4.41 | 1.81 |
| Faulty machine or lack of trust in administrator | 3 | 4.67 | 3.33 | 4 | 5.00 | 2.12 |

## 3.5.4 Exploratory Analyses:

As can be seen in Table 4, the average LOTP decreased after the detailed NMES description was presented. This reduction in LOTP was noted in 96 participants, whilst LOTP increased in 41 participants, and did not change in 45 participants. At LOTP1, 78.6% of the sample were 'slightly likely' or more to take part, and 21.4% were 'unlikely' or 'unsure'. At

LOTP2, 70.3% were 'slightly likely' or more to take part, and 29.7 were 'unlikely' or 'unsure'. Therefore, we explored this decrease in LOTP, and whether it differed by gender, by fitting a linear model to predict LOTP, with the time of LOTP (1 and 2) were measured and gender (male and female) as predictors. The model explains a significant and very small proportion of variance, $R^2$ = .02, $F(3, 360) = 2.32$, $p$ = .075, *adj.* $R^2$ = .01, but there were no significant main or interaction effects (all *ps* > .058). However, within the model the term gender was marginally significant (β = -.33, $p$ = .058), with overall LOTP being lower in female participants ($M$ = 4.85, $SD$ = 1.47) compared to males ($M$ = 5.18, $SD$ = 1.45).

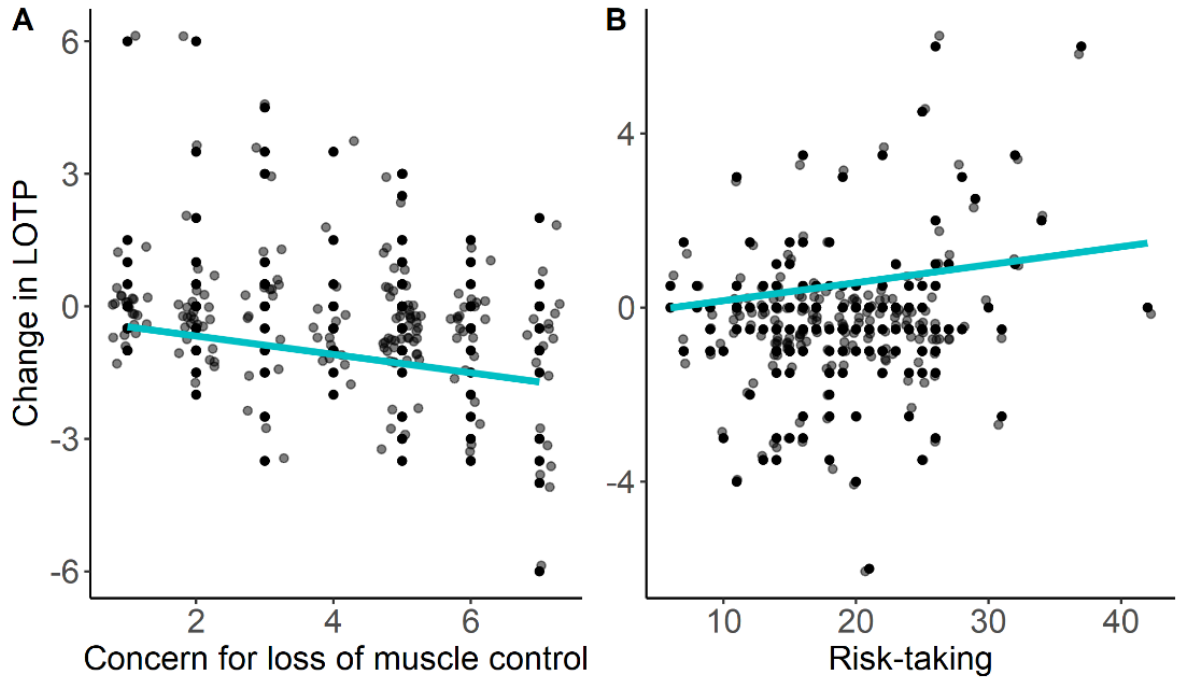
To test whether LOTP1 and LOTP2 substantially differed from the neutral scale mid-point, we carried out two one-sampled t-tests testing the difference between the two LOTPs and μ = 4 (corresponding to the midpoint on the 7-point rating scale, labelled '*neither likely nor unlikely*'). The t-test for LOTP1 ($M$ = 5.17) resulted in a statistically significant, medium-to-large effect size (difference = 1.17, 95% CI [4.94, 5.40], $t(181) = 9.95$, $p$ < .001; $d$ = .74, 95% CI [.57, .90]). The t-test for LOTP2 ($M$ = 4.86) resulted in a significant medium-sized effect (difference = .86, 95% CI [4.60, 5.11], $t(181) = 6.70$, $p$ < .001; $d$ = .50, 95% CI [.34, .65]). Thus, in both cases participants were significantly more likely to take part than not to.

Next, we ran another model to explore further which variables explain the observed slight decrease in LOTP. To achieve this, we computed the change in LOTP (LOTP2 minus LOTP1) and fitted a multiple regression analysis with all terms previously used for the analysis of LOTP2. The model was reduced using the backward-elimination method until only significant terms remained: risk-taking (β = .25, $p$ = .021) and concern for loss of muscle control (β = -.21, $p$ < .001). The model explains a significant and moderate proportion of variance, $R^2$ = .10, $F(2, 179) = 10.37$, $p$ < .001, *adj.* $R^2$ = .09. Participants' willingness to participate in the fictitious facial NMES study decreased after they received more detailed information about the associated risks, and this decrease was larger (more negative values) the

greater the concern for losing control of facial muscles (Figure 13A), and it was smaller (more positive values) the higher the risk-taking score (Figure 13B).

**Figure 13**

*Scatterplots of significant terms predicting a change in LOTP after the detailed vignette was presented*




*Notes*. The reduction in LOTP was (A) negatively predicted by concern for the loss of muscle control, and (B) positively predicted by risk-taking. Model fits are shown by the blue line.

Next, we tested if our sample shows a significant difference in risk-taking by gender, as reported in the literature (Harris & Jenkins, 2006). A two-sample t-test on the health & safety subscale of the DOSPERT found a non-significant marginal difference between male and female participants, $t(180) = 1.89$, $p = .065$. As expected, female participants had lower risk-taking scores ($M = 17.97$, $SD = 1.87$) than male participants ($M = 19.71$, $SD = 1.77$).

As participants' gender did not predict LOTP1 or LOTP2 and did not interact with specific concerns, we explored whether ratings for concerns differed between men and

women. Using two-sample t-tests, we found greater concern in female than male participants across all three types of concerns (Table 5).

**Table 5**

*Mean differences in self-reported concern for pain, burns, and loss of muscle control between male and female participants*

| Concern | *t* | *p* | $M_{diff}$ 95% CI | Cohens *d* | $M_{male}$ | $M_{female}$ |
|---|---|---|---|---|---|---|
| Pain | 3.20 | .002 | [.33, 1.40] | .48 | 3.70 | 4.57 |
| Burns | 3.61 | <.001 | [.46, 1.58] | .54 | 3.58 | 4.60 |
| Loss of muscle control | 3.37 | <.001 | [.39, 1.48] | .50 | 3.54 | 4.48 |

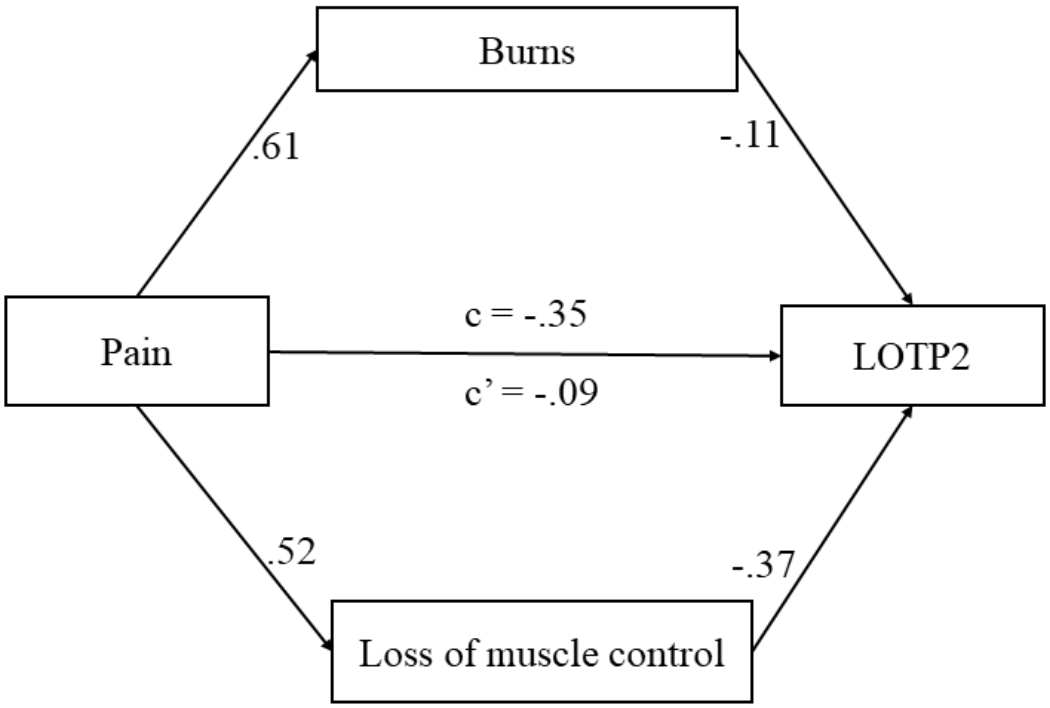
*Note.* All two-sample t-tests had 180 degrees of freedom.

Furthermore, we conducted a mediation analysis to explore the relationship between the three concerns and their impact on LOTP2 (Figure 14). The effect of concern for pain on LOTP2 was fully mediated via the concern for burns and loss of muscle control.

The regression coefficient between concern for burns and LOTP2 and the regression coefficient between concern for loss of muscle control and LOTP2 were both significant. The total effect(c) of pain on LOTP2 is -.35, $SE$ = .06, $t(180) = 5.40$ with $p$ = <.001. The direct effect (c') of concern for pain on LOTP2 removing the concern for burns and loss of muscle control is -.09, $SE$ = .07, $t(178) = 1.17$ with $p < .001$. The mean bootstrapped indirect effect of pain on LOTP2 through the concern for burns and loss of muscle control is -.26 with $SE$ = .05, 95% CI [-.36, -.16], $R = .55$, $R^2 = .30$, $F(3, 178) = 25.08$, $p < .001$.

**Figure 14**

*Mediation Analysis*




*Notes.* Regression coefficients for the relationship between the participant's concern for Pain and LOTP2 as mediated by concern for burns and loss of muscle control.

A final analysis compared this study's sample characteristics on the four questionnaires to the samples from previous research, using two-sample tests. The current sample's mini IPIP score (including the subscales Neuroticism and Intellect/Imagination) was compared to a confirmatory analysis of the mini IPIP (2010). For NAQ (Appel et al., 2012), DOSPERT (Blais & Weber, 2006), and BICI (Littleton et al., 2005) we compared our sample to the original samples used in the development of those questionnaires. Compared to the literature, our participants were found to score significantly lower (see Table 6) in risk-taking (measured with the health and safety subscale of DOSPERT), intellect/imagination (subscale of IPIP), and dysmorphic concern (BICI).

**Table 6**

*Mean differences between our sample and those reported in prior research across four questionnaires utilised in this study*

| Questionnaire | Subscale | *t* | *df* | *d* | *p* | $M_{prior}$ | $SD_{prior}$ | $M_{current}$ | $SD_{current}$ |
|---|---|---|---|---|---|---|---|---|---|
| IPIP | Neuroticism | .52 | 1662 | .04 | .303 | 11.81 | 3.72 | 11.66 | 3.49 |
| | Intellect/Imagination | 4.49 | 1662 | .35 | <.001 | 15.81 | 3.11 | 14.70 | 3.44 |
| NAQ | Avoidance | 1.04 | 416 | .10 | .149 | -.55 | 1.20 | -.42 | 1.34 |
| | Approach | .10 | 416 | .01 | .458 | 1.02 | 1.00 | 1.01 | .93 |
| DOSPERT | Health/Safety | 2.51 | 352 | .27 | .006 | 20.63 | 7.43 | 18.83 | 6.26 |
| BICI | | 3.25 | 364 | .34 | .001 | 50.40 | 14.20 | 45.29 | 15.85 |

*Notes.* The column M and SD prior contain mean and standard deviation reported in the prior literature this studies sample is being compared to, which in turn is reported as M and SD current. We did not include the MAIA worrying subscale, as we scored it differently to the literature.

## 3.6 Discussion

The present pre-registered cross-sectional study investigated the concerns of individuals about facial NMES, and their likelihood of taking part (LOTP) in a hypothetical study that uses facial NMES. Moreover, it explored whether LOTP changes depending on the level of information provided about facial NMES and its risks (comparing LOTP across two-time points) and whether LOTP differed depending on demographics and individual differences.

The results are in line with our first hypothesis (H1), which stated that LOTP is lower among participants who are more concerned about the risks described to them, that is the risks of burns, pain, and loss of muscle control. Indeed, we found that all three concerns were significantly negatively correlated with LOTP1 and LOTP2 (Table 3). This finding is unsurprising and consistent with theories of decision-making, which propose that the

risks/costs of an action are weighed against its benefits (Tversky & Kahneman, 1992; Slovic et al., 2005). However, only concerns for burns and loss of muscle control emerged as significant predictors of LOTP2, such that greater concern resulted in a lower likelihood of taking part. As indicated by a mediation analysis, concern for pain was mediated by the other concerns (Figure 14). Thus, while pain is a real concern, burns and loss of muscle control appear to be more important for participants' decision-making process. Therefore, when recruiting participants for an experiment using facial NMES, and upon arrival to the lab, researchers should prioritise addressing potential concerns about burns and loss of muscle control. For example, to address concerns of loss of muscle control, it could be emphasised that participants can remove the electrodes at any time (or hit a "stop" button) if they feel they are losing control over their facial muscles.

It is also noteworthy that in the first open question (prior to the mention of facial NMES related risks), participants reported being concerned for the three concerns we later highlighted, with pain being the most commonly evoked. Nevertheless, the number of times participants mentioned feeling concerned about skin burns and markings increased between the beginning and the end of the experiment, that is after receiving more detailed information about NMES. Surprisingly, nerve damage or facial paralysis was the second most common risk participants believed to be associated with facial NMES, and our data suggest that this concern can be reduced by providing a more detailed description of facial NMES (its prevalence dropped from 40 to 12, see Table 4). We suggest that to reduce their negative effect, volunteers' self-reported concerns should be acknowledged by researchers and that they should be directly addressed during recruitment and upon arrival to the lab.

Additional unregistered analyses were carried out to explore the influence of informing participants about the risks associated with facial NMES on their overall LOTP. We found that providing detailed information about facial NMES and the possible risks

slightly reduced LOTP, indicating that participants were less likely to take part at time point two ($M$ = 4.86, $SD$ = 1.73) compared to time point one ($M$ = 5.17, $SD$ = 1.59) – yet this difference was not statistically significant, and participants remained more likely to take part than not to.

Finally, we looked at which variables explain a change in LOTP after a detailed description of NMES was given (LOTP2 minus LOTP1). The concern for the loss of muscle control predicted a decrease in LOTP, thus it should be one of the main concerns addressed by research interested in using facial NMES. This finding is consequential for research interested in applying NMES above the sensory threshold and may be reduced by applying low-intensity NMES to the limb before the face, to familiarise participants with the sensation and technique. Lastly, we find that high-risk takers' LOTP increased after the detailed NMES description. These results are relevant to psychological research as the risks of participating in a facial NMES study must be stated to acquire informed consent. Therefore, researchers should address the specific concerns, possibly by explaining how burns occur and what safety measures have been put in place to minimise them.

To test our second hypothesis, (H2), we examined whether concerns about burns, pain, and loss of muscle control interacted with gender in predicting LOTP. Overall, men and women are equally likely to take part in facial NMES studies. Interestingly, we have found that women and men differed in their concerns (see Table 5). Men were less worried by all three risks compared to women, contrary to our hypothesis that men will be more concerned with pain. Crucially, this did not influence LOTP. Speculatively, this may be due to gender norms, with male participants trying to appear more stoic and less concerned about pain (Pool et al., 2007; Samulowitz et al., 2018). The finding of lower concern for pain in male participants is also in line with reports of greater tolerance for both actual and expected pain

in male participants, especially in those conforming to traditional gender roles (Alabas et al., 2012; Pool et al., 2007; Samulowitz et al., 2018).

Another possibility is that the greater concern for pain, burns, and loss of muscle control in females than male participants stems from differences in risk-taking between men and women in the domain of health and safety (Byrnes et al., 1999). Indeed, although the difference was only marginally significant ($p$ = .065), we did find lower risk-taking scores in female than male participants. It should also be noted that our sample consists of overall low-risk takers, with both genders reporting to be on average '*unlikely*' to engage in risky activities. This general risk aversiveness could be due to the study being carried out during the covid19 pandemic (January 2021), although only one participant mentioned concerns relating to covid19 when answering the open questions. In summary, LOTP did not differ significantly by demographic characteristics, which suggests that these factors can be (mostly) disregarded when designing recruitment materials or information sheets for facial NMES research.

To further explore the effect of demographic and individual differences on LOTP, we conducted exploratory analyses including the questionnaires. For both LOTP1 and LOTP2, the 'worrying subscale' of the MAIA was found to be a significant negative predictor (Figure 11A and 3D). Specifically, the more participants tended to be worried or experience emotional distress with sensations of pain or discomfort, the less likely they were to take part in the hypothetical facial NMES study. It might be possible to reduce participants' worries about pain and discomfort by making them more mindful (Mehling et al., 2012). However, it does not seem practical to always include a mindfulness intervention in a laboratory study on facial NMES. Therefore, researchers should instead assess potential participants' a priori propensity for suffering pain, as participants who are less concerned with uncomfortable physical sensations may better tolerate the effects of facial NMES.

Another significant predictor of LOTP, both at times one and two, was found to be self-reported theoretical knowledge of electrical stimulation (Figure 11B and 12D). Interestingly, this result seems at odds with our other findings that LOTP decreases when participants are given more detailed information about facial NMES. Although the information given to the participants was mainly related to risks, future research should aim to examine in more detail how the initial description of facial NMES influences volunteers' willingness to participate in the study, depending on their prior knowledge about electrical stimulation.

Surprisingly, the tendency to avoid emotions and emotion-inducing situations, measured with NAQ's avoidance subscale, predicted greater LOTP2 (Figure 12E). The finding was unexpected and seems counterintuitive. However, it is unlikely to originate from an anomaly in our sample, as NAQ avoidance scores were similar to those reported in previous research (Appel et al., 2012) (see Table 6, and were positively correlated with neuroticism ($r = .46$, $p < .001$, see Table 2) – as expected based on the literature (Maio & Esses, 2001). Speculatively, the positive link between NAQ avoidance and LOTP2 is due to the facial NMES descriptor. Prior research suggests that individuals with a high NAQ-approach are more attentive and immersed in emotional narratives (Appel & Richter, 2010). For these subjects, facial NMES may not have appeared as an emotion-inducing event.

The description provided in the current study mimics the typical process of recruiting participants for laboratory-based studies, by presenting an advert describing the study's aims, as well as details about compensation and risks involved. Our findings demonstrate that the type and level of information presented influences participants' decision to take part in a laboratory study involving facial NMES. Providing more information about the potential risks linked to facial NMES tends to reduce participants' likelihood of taking part. Importantly, however, the majority of participants remained willing to take part in the hypothetical study

even after reading such information. The current study cannot inform us about how much the information provided influences participants' inclination to withdraw from such a study once they already accepted to take part. To answer that question, the variables influencing the likelihood to take part, and the likelihood not to withdraw prematurely, need to be explored in a laboratory setting. In an actual laboratory experiment, participants can typically ask questions and interact otherwise with the experimenter(s). Therefore, it is of paramount importance that experimenters establish a relationship of trust with participants. Overall, for psychological research using facial NMES, it is important to gain insight into the concerns that participants might have. This aspect seems particularly relevant when examining the effects of proprioceptive feedback on mood (Zariffa et al., 2014), as participants' concerns may induce negative affect, which in turn could confound the experimental results.

There are several limitations to be considered. First, as there is limited research in this area, the sample size is based on general rules of thumb relating to statistical power, rather than on a proper power analysis based on existing effect sizes. Therefore, the power of our statistical analyses remains unclear. Second, we did not exclude participants who may be unable to partake in research using facial NMES, such as individuals with pacemakers, the responses may be largely influenced by their pre-existing conditions over pain, burns, and loss of muscle control. However, as only three participants reported concern for facial NMES interacting with a pre-existing condition, this would have not skewed the results. Third, the outcome measure used for our statistical analysis, "likelihood of taking part" (LOTP), is a novel measure that has yet to be validated. However, prior research has used similar single-item questions to capture participants' self-perception (Atchley et al., 2011; Pool et al., 2007). Third, participants' responses at LOTP2 may have been influenced by the first vignette. Future, research should use a between-subject design to eliminate this difference. Lastly, participants responded to a hypothetical scenario, and it is unclear how well the results will

generalise to real-world scenarios. It should be noted, however, that participants' pain reports to a hypothetical scenario involving electrical stimulation had previously been found to resemble their actual behaviour in the lab (Pool et al., 2007).

In summary, healthy participants aged 18-45 are generally likely to take part in facial NMES research, and this remains true even after highlighting to them the risks associated with facial NNES. Furthermore, the most important concerns standing in the way of participation in such research relate to skin burns and involuntary muscle movement (loss of muscle control). Fear of pain is also a major concern but seems mediated by the other two points. Finally, the choice to participate in a laboratory study involving the administration of facial NMES does not seem to differ by gender, age, and education level; instead, it depends on people's prior knowledge about electrical stimulation, and their propensity to worry about sensations of pain or discomfort.

## 3.7 Summary

Chapter 3 delved into understanding individuals' willingness to participate in fNMES research, focusing on their concerns and the side effects of fNMES. Through an online survey with 182 healthy UK residents aged 18-45, the study measured their likelihood of participating (LOTP) in fNMES studies. Participants rated their LOTP initially with minimal information and then after receiving a detailed description of the potential risks involved with facial NMES.

The study revealed that generally, participants were quite willing to engage in fNMES studies. However, there was a noticeable, albeit slight, decrease in LOTP after they were informed about the risks. Despite this decrease, the overall inclination to participate remained positive. Several factors significantly influenced the willingness to participate. Participants' previous knowledge about electrical stimulation and their tendency not to worry about sensations of pain positively affected their LOTP. Conversely, concerns regarding burns and

loss of muscle control negatively impacted their willingness. Interestingly, while both men and women showed a high willingness to participate, women exhibited greater concerns about pain, burns, and loss of muscle control.

The provision of detailed information about fNMES risks was found to slightly reduce the participants' willingness to participate, indicating a shift towards reluctance when more aware of potential risks. The study highlighted that the main deterrents affecting participation willingness were primarily the fear of burns and loss of muscle control, with fear of pain also playing a significant role, albeit mediated by the other concerns. Personality traits and risk perception were also found to influence participants' concerns about fNMES risks.

In conclusion, the chapter suggested that while there was a general willingness to participate in facial NMES research, addressing potential safety concerns, especially regarding burns and loss of muscle control, was crucial for effective participant recruitment. It also emphasized the importance of tailoring safety information and reassurance to individual concerns, which may vary based on demographic and personality differences. The findings underlined the need for researchers to be mindful of these factors when designing and conducting fNMES studies.

# 4 Smiling and frowning induced by facial neuromuscular electrical stimulation (fNMES) modulate felt emotion and physiology

Themis Nikolas Efthimiou[1*], Joshua Baker[1], Alasdair Clarke[1], Arthur Elsenaar[2], Marc Mehu[3], Sebastian Korb[1,4*]

[1]Department of Psychology, University of Essex, Colchester, United Kingdom

[2]ArtScience Interfaculty, Royal Academy of Art, Royal Conservatory, The Hague, Netherlands

[3] Department of Psychology, Webster Vienna Private University, Vienna, Austria

[4] Department of Cognition, Emotion, and Methods in Psychology, University of Vienna, Austria

Themis N. Efthimiou https://orcid.org/0000-0002-8458-5493

Joshua Baker https://orcid.org/0000-0001-8133-7622

Arthur Elsenaar, ArtScience Interfaculty, Royal Academy of Art

Marc Mehu https://orcid.org/0000-0001-5164-3573

Sebastian Korb https://orcid.org/0000-0002-3517-3783

This work was funded by a Stand-Alone Grant by the Austrian Science Fund (FWF; https://www.fwf.ac. at/en/; Grant number: P 32637-B), the funders had no role in the study. The authors declare no conflict of interest. All materials including, data, analysis scripts, and pre-registration are available on the Open Science Framework: http://bitly.ws/SxEq. All authors contributed to the study's conceptualisation. TE led the formal analysis, investigation, and visualisations, and the original draft preparation. TE, MM, and JB contributed to the

software. JB, SK, MM, and AE were involved in Writing – Review & Editing. The methodology was jointly developed by TE, SK, and JB. Funding acquisition was successfully secured by SK, AE, and MM. Additionally, SK led the supervision and project administration.

Correspondence concerning this article should be addressed to Themis N. Efthimiou, Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ.

Contact: t.efthimiou@essex.ac.uk

## 4.1 Abstract

According to the Facial Feedback Hypothesis (FFH), feedback from facial muscles can initiate and modulate a person's emotional state. However, this assumption is debated, and existing research has arguably suffered from a lack of control over which facial muscles are activated, when, to what degree, and for how long. To overcome these limitations, we carried out a pre-registered experiment recruiting 58 participants in 2023 in which we applied facial neuromuscular electrical stimulation (fNMES) to the Zygomaticus Major (ZM) and Depressor Anguli Oris (DAO) muscles for 5–seconds at 100% and 50% of the participants individual motor threshold (MT). After each trial, participants reported their emotions' valence and arousal. Heart rate and electrodermal activity were recorded throughout. Results showed that muscle activation through fNMES, even when controlling for fNMES-induced discomfort, modulated participants' emotional state as expected, with more positive emotions reported after stronger stimulation of the ZM than the DAO muscle. The addition of expression-congruent emotional images increased the effect. Moreover, fNMES intensity predicted arousal ratings and skin conductance responses. The finding that changes in felt emotion can be induced through brief, controlled activation of specific facial muscles is in line with the FFH and offers exciting opportunities for translational intervention.

Keywords**:** fNMES, facial muscles, emotion, facial feedback, electrical stimulation

## 4.2 Introduction

In his 1989 Grammy award-winning song 'Don't Worry, Be Happy', Bobby McFerrin sang about the importance of not letting oneself down in the face of life's misfortunes. Importantly, the song's lines 'when you worry your face will frown, and that will bring everybody down' also expressed the intuition that our emotional facial expressions can affect our feelings, as well as those of the people around us. For more than a century and a half, scholars from psychology and related fields have indeed first hypothesised and then documented the important link between feelings and bodily expressions of emotion. Charles Darwin (Darwin, 1872) wrote that "*the free expression by outward signs of an emotion intensifies it. On the other hand, the repression as far as this is possible, of all outward signs softens our emotions*." Similarly, William James wrote in 1884 "*Refuse to express a passion, and it dies*." (James, 1884).

In the 20th century, these ideas contributed to the emergence of theories of embodied cognition, which argue that we partially recreate emotions observed in others through the activation of sensorimotor and emotional brain regions and a cascade of changes in peripheral physiology (Niedenthal, 2007; Wood, et al., 2016b). Most related research has however focused on the face, rather than the rest of the body, as the face constitutes one of the richest means of emotional expression, made possible by the activation patterns of 40 facial muscles, whose fine motor control requires powerful proprioceptive feedback mechanisms (Cobo, Abbate, et al., 2017; Cobo et al., 2019). In line with this, the Facial Feedback Hypothesis (FFH) posits that because the state of facial muscle activation and relaxation is continuously fed back to the brain, the human face does not just express emotions, but can also be a powerful tool for shaping how the emotion expresser feels (Laird, 1974; Strack et al., 1988). For example, when one smiles, engaging the *Zygomaticus Major* (ZM) and at times also the *Orbicularis Oculi* (OO) muscle (Ekman & Davidson, 1990), one can initiate and/or strengthen

the felt emotion of happiness (Coles et al., 2022). Conversely, if facial muscle activation is inhibited, participants report a weakened experience of the corresponding emotion (Davis et al., 2009).

Researchers have attempted several methods of the manipulation of facial muscle activity and investigated facial feedback effects. For example, facial muscles can be activated by asking participants to voluntarily pose a facial expression (Laird, 1974), and muscles linked to smiling can be activated or inhibited by holding a pen between the teeth or lips, respectively (Marmolejo-Ramos et al., 2020; Sel et al., 2015; Strack et al., 1988). A major advantage of this pen-in-mouth technique is that it does not require explicit references to emotions or emotional expressions. Botox injections, typically applied to the brow and eye area for cosmetic reasons, result in partial muscle paralysis (Davis et al., 2010), and other means such as tapes (Carpenter & Niedenthal, 2019), and hardening gels (Neal & Chartrand, 2011; Wood, et al., 2016a) can be used to modulate not only facial muscle activity but also face sensations. This line of research has generally confirmed the role of facial feedback in the modulation of felt emotion (Coles et al., 2019b).

The understanding of facial feedback effects has important practical implications for a variety of fields, including psychology and medicine. For example, administering Botox to the glabellar region encompassing the *Corrugator Supercilii* (CS) muscle suppresses frowning and can improve mood in people suffering from mood disorders, such as depression (Finzi & Rosenthal, 2014, 2016; Kruger & Wollmer, 2015; but see Coles et al., 2019a). Moreover, efforts have been made to address the symptoms of hypomimia and impaired emotion recognition in Parkinson's disease (Argaud et al., 2018) by targeting the impaired facial feedback loop, without conclusive results so far (Kuehne et al., 2023).

Facial feedback effects can also modulate brain activity and peripheral physiology. The amygdala, a brain region intricately linked with the initiation of emotional reactions

(Sergerie et al., 2008), demonstrates diminished activation in response to angry facial expressions after the inhibition of the CS muscle, which is part of an expression of anger (Hennenlotter et al., 2009; M. J. Kim et al., 2014). Further, changes in autonomic nervous system activity — quantifiable through parameters like heart rate (HR), electrodermal activity (EDA), skin temperature and pupil dilation (Kreibig, 2010; Shehu et al., 2023; Sun et al., 2013) — are also modulated by emotional state and facial feedback. For example, heart rate (HR) increases during both negative and positive emotional states induced by stimuli (for review see Kreibig, 2010). Similar effects on emotional state can also be induced by posing expressions. For example, when actors voluntarily posed prototypical expressions of several emotion categories, such as anger, fear, and sadness, it resulted in a faster HR response than expressions of happiness, surprise, and disgust (Ekman et al., 1983). Smiling has also been associated with stress reduction, as individuals who smile, even unknowingly, exhibit lower HR during stress recovery and experience a milder decrease in positive affect compared to those displaying other expressions (Ansfield, 2007; Kraft & Pressman, 2012). EDA, on the other hand, decreases for negative and increases for positive emotional states (Kreibig, 2010). Soussignan (2002) reported different skin conductance responses for “Duchenne” smiles (recruiting both the ZM and OO muscles) vs. non-Duchenne smiles (including only the ZM muscle). The Duchenne smile group demonstrated increased EDA and HR when exposed to positive video clips, suggesting an increase in arousal. For instance, disruption of the facial feedback loop can diminish physiological responses. For instance, Parkinson’s patients, who have reduced facial mimicry and impaired emotion recognition (Argaud et al., 2018; Kuehne et al., 2023), also show lower EDA to negative and high arousing images (Balconi et al., 2016).

Despite numerous experiments demonstrating that changes in facial muscle activation modulate affective processes, the FFH has remained controversial. For example, changes in

humour perception induced by the pen-in-mouth technique introduced by Strack et al. (1988) failed to replicate in a multi-laboratory study (Wagenmakers et al., 2016; but, see Noah et al., 2018). Nevertheless, a subsequent meta-analysis of 134 studies has confirmed the facial feedback effect, showing that it is a small effect and variable in size across studies (Coles et al., 2019b). Some facial feedback manipulation techniques might thus be more effective than others, as suggested by an international collaboration across 19 countries, which revealed that voluntary posing a smile makes one feel happier, while the pen-in-mouth technique has little to no effect (Coles et al., 2022). Importantly, these effects are not explained just by participants' beliefs, as a recent study showed that participants showed facial feedback effects even when they were unaware of the study's aims (Coles et al., 2023). One potential reason why the effects of the pen-in-mouth technique do not always replicate is that it results in weaker smiles compared to voluntary facial expressions, as shown by electromyographic activity (EMG, Cross et al., 2019).

It becomes clear then that the precise mechanism by which facial muscles are activated or inhibited is important to consider when embarking on this type of research. Unfortunately, the facial manipulations available to date suffer from certain limitations. For example, voluntary posing of facial expressions is effortful, and not all participants can adequately engage the necessary muscles (Coles et al., 2022). Botox injections, on the other hand, are an invasive procedure whose effects last for several months, making them less than ideal for controlled laboratory settings, where researchers are typically interested in the immediate effects of generating or blocking an expression. A promising alternative may however be the controlled exogenous activation of facial muscles through electric impulses.

Facial neuromuscular electrical stimulation (fNMES) consists of delivering electrical currents to facial muscles using surface electrodes, allowing researchers to activate specific facial muscles non-invasively and with high temporal precision. fNMES has already shown

promise as a treatment for depression (Demchenko et al., 2023; Kapadia et al., 2019), and we have recently emphasised its potential for testing aspects of the FFH (Efthimiou et al., 2023c). For a recent review of the literature on human surface fNMES, and recommendations on how to implement it in the psychology laboratory and combine it with EEG (see Baker et al., 2023; Efthimiou et al., 2023a, and Efthimiou et al., 2023c).

To date, only a handful of studies have employed fNMES within the framework of the FFH. A proof-of-concept study applied fNMES to the ZM and OO muscles in 8 individuals, who reported that the stimulation helped them to smile (Yen-Chin et al., 2017). Zariffa et al. (Zariffa et al., 2014) used fNMES to investigate changes in positive and negative affect. Participants in a control group ($n$ = 12) and an intervention group ($n$ = 12) alternated 30–seconds of voluntary smiling with periods of 60–seconds of rest, for a total duration of 25 minutes. In addition, the intervention group received fNMES to bilateral ZM and OO muscles. Both groups completed unrelated cognitive tasks, which was claimed to ensure that participants remained unaware of the study's goal. The 60-item version of the Positive and Negative Affect Schedule (PANAS-X expanded form; Watson & Clark, 1994) was measured before and after the 25 minutes of tasks. No statistically significant difference between groups was found for the hypothesised outcomes, namely self-rated happiness, joviality, and overall positive affect. However, the authors reported findings on some PANAS-X items: participants in the intervention group were less scared and reported more determination and daring. The authors suggested that these effects may be explained by the induction of the wrong type of facial feedback, as stimulation of the OO muscle results in the tightening of the eyelids, and this muscle activation is not only part of smiling but also of expressions of determination. Further OO has been suggested as an emotional intensity indicator, independent of valence (Messinger et al., 2001)

In another study by the same group (Kapadia et al., 2019), 10 individuals with major depressive syndrome received 25-minute sessions of fNMES to the ZM and OO muscles for periods of 15–seconds, interleaved with rest. This treatment was repeated three times a week for a minimum of 10 weeks. The authors reported an improvement in depression symptoms, with reduced scores on the Inventory of Depressive Symptomatology and the Hamilton Rating Scale for Depression. Conversely, there was no change in positive affect, but a decrease in negative affect (both were measured with the PANAS-X at the beginning and end of each session), which the authors interpreted as an improvement in mood.

In a more recent study, Warren (2021) investigated the application of weak and often imperceptible electrical stimulation to the ZM muscle for 10–seconds, while participants ($n$ = 56) viewed emotional visual stimuli. The pattern of fNMES delivery was structured to alternate predictably across trials, with the fNMES being turned on and off in succession; it was administered in every other trial. The author reported that participants felt more positive when viewing positive, but not neutral images, in trials with concurrent fNMES. This study provides evidence that weak facial feedback effects can modulate image-elicited emotions.

In summary, very few studies have employed fNMES as a tool to modulate emotional state (Kapadia et al., 2019; Warren, 2021; Zariffa et al., 2014). The results of these studies seem promising but should be considered preliminary, given their small sample sizes, and their delivery of fNMES in conjunction with voluntary posed smiling. Further, the studies mentioned earlier did not measure emotional states immediately after fNMES delivery but instead did so after a longer delay (at the end of a 25-minute session). This seems relevant given that some scholars have suggested that facial feedback effects are brief, and dissipate after about four minutes (Söderkvist et al., 2017; experiment 1).

To address gaps in the literature and delve deeper into the potential of fNMES as a tool for investigating facial feedback effects, our pre-registered study (http://bitly.ws/SxEq)

aims to accomplish several objectives. Firstly, we wanted to explore whether fNMES is capable of both initiating, in the absence of a visual stimulus, and modulating emotional states, in the presence of a visual stimulus (Coles et al., 2019b). Further, we wanted to examine if fNMES-induced expressions alone are enough to produce facial feedback effects, as previous work in this area has employed fNMES in conjunction with posed expressions (Kapadia et al., 2019; Zariffa et al., 2014), thereby obfuscating the distinct impact of fNMES. By isolating the effects of fNMES, in the absence of voluntary expression, our study aims to provide a better understanding of its role in instigating and shaping emotional experiences.

Moreover, the current body of work on the relationship between fNMES-induced facial expressions and emotional states (Kapadia et al., 2019; Warren, 2021; Zariffa et al., 2014) is limited to one type of facial expression: the smile. It thus remains unknown if fNMES-induced activation of facial muscles associated with negative facial expressions can induce or amplify negative emotional states. For example, it remains to be investigated if activating the DAO muscle, active when expressing sadness (Ekman, 2007; Ekman et al., 2002), results in increased feelings of sadness and/or decreased feelings of happiness.

Finally, we investigate the effects of fNMES intensity on facial feedback. Previous research has shown that facial feedback effects can be induced by both weak intensities of fNMES (described as imperceptible stimulations) (Warren, 2021) and more robust intensities that elicit muscle contractions (Kapadia et al., 2019; Zariffa et al., 2014). By varying the intensity of fNMES, we aim to determine how different amounts of proprioceptive facial feedback differentially affect emotional states. This will help us better understand the interplay between stimulation strength and affective responses.

To this end, our study employs fNMES to discern alterations in participants' subjective emotional experiences as gauged by self-report measures and peripheral physiology. Facial muscles associated with happiness (ZM) and sadness (DAO) were

stimulated for 5-seconds with three levels of fNMES intensity: i) 100% of each individual's motor threshold (MT), corresponding to the minimum intensity to reliably see weak muscle activation, ii) 50% of MT, which induces cutaneous tingling but no observable movement, and iii) 0% of motor threshold, or 'off', as no stimulation was delivered. The two muscles and three intensities were combined into a single continuous variable with five levels (DAO 100%, DAO 50%, off, ZM 50%, and ZM 100%), henceforth called fNMES. To strengthen the fNMES effect positive, negative, or neutral images were shown in some trials.

We predicted (http://bitly.ws/SxEq): (H1) that varying fNMES (see above) will result in progressively more positive valence ratings, indicating an overall positive emotional state. Moreover, (H2) we anticipated that the effect observed in H1 (greater valence with increasing levels of fNMES) would be more pronounced when participants view emotion-congruent images compared to neutral images, or when no image is present. We expected a higher HR (H3) and skin conductance response (SCR, H4) at higher fNMES intensities, reflecting a startle response. Moreover, because different muscles were targeted in each block, and the repeated activation of the same muscle over the duration of a block could modulate mood, we expected the ZM block to result in greater heart rate (HR, H5) and higher skin conductance level (SCL, H6), relative to the block with DAO muscle stimulation.

## 4.3 Methods

### 4.3.1 Transparency and Openness

We have provided a full account of our sample size determination, justifications for data exclusion, and comprehensive descriptions of all measures used within our research. The materials supporting our research, analysis script, and pre-registration are openly accessible through the Open Science Framework and can be located at (http://bitly.ws/SxEq).

### 4.3.2 Research Design

The study used a within-subject design. Participants received fNMES to the ZM and DAO muscles in the same session, but in separate blocks – each block consisted of 36 trials and lasted 20-30 minutes. The muscle order was counterbalanced across participants.

### 4.3.3 Participants

To determine the appropriate sample size, an a priori power analysis was conducted based on data from Coles et al. (2023) as our designs are similar. Our study differs in how we manipulated facial expressions and which expressions were generated. Specifically, Coles et al. (2023) asked participants to voluntarily pose happy and angry faces, while we used fNMES to induce expressions of both happiness and sadness. Due to these methodological differences, we reduced our anticipated effect size to $\beta = 0.10$. To facilitate cross-study comparison, the rating of self-reported happiness from Coles et al. (2023) was transformed into a 100-point scale, and facial expressions were converted into numeric variables. These transformed data were standardised and analysed using the lme4 package (Bates et al., 2015) in R (formula: rating ~ fNMES + (1 | participants)). Subsequently, a power analysis was conducted using the MixedPower package (Kumle et al., 2021) enabling us to simulate a linear mixed effects model (LMM) that accounted for trial and sample size variations. Based on 1000 simulations with four trials per condition, a sample size of 45 was estimated to provide 92% power for the detection of a main effect of fNMES when no image was present.

Data collection was carried out in 2023, we oversampled expecting some data loss. Out of the 60 participants tested, one was excluded due to experimenter error, and another because no reliable ZM activation could be generated. For the analysis of physiological data, another 10 participants were excluded due to low-quality data (see cleaning section in data preparation). Final sample sizes were thus 58 for ratings (female = 38; $M_{age}$ = 24.57, $SD_{age}$ =

5.54) and 48 for physiology (female = 31; $M_{age}$ = 23.85, $SD_{age}$ = 5.01). The study was approved by the local ethics committee (ETH1920-0847) and all participants provided informed consent.

### 4.3.4 Equipment and NMES parameters

The delivery of fNMES was achieved using two DS5 constant-current electrical stimulators (Digitimer, Welwyn, UK) and in-house digital-to-analogue converters. Stimulation was administered using a 70 Hz train of biphasic square pulses with a width of 100 μs and a pulse delay of 14 ms. We used disposable Ag/AgCI electrodes measuring 16 × 19 mm (Ambu BlueSensor BRS, surface area = 3.04 $cm^2$). The maximum stimulation intensity used was 35 mA, which corresponds to 0.96 Root Mean Square (RMS) mA/$cm^2$ and is well below the advised safety threshold of RMS 2 mA/$cm^2$ and follows the safety guidelines outlined in EN 60601-2-10:2000 (see Efthimiou et al., 2023c).

For measures of skin conductance, two disposable 24 mm Ag/AgCl pre-gelled electrodes (Kendall™ H124SG model) were placed around the middle and index finger of the non-dominant hand, whilst a disposable electrode placed on the wrist of the same hand served as a system ground. For measures of HR, a photoplethysmogram (PPG) sensor attached to a strap was placed around the index finger of the non-dominant hand. Both EDA and HR data were amplified using an ANT eego sports amplifier and were recorded throughout the entire testing session at 512 Hz.

### 4.3.5 Procedure

Before the laboratory session, participants completed a Qualtrics survey assessing Alexithymia levels using the Toronto Alexithymia Scale (TAS-20, Taylor et al., 2010). Additionally, participants reported any prior experience with electrical stimulation applied to the body or face. Concern regarding receiving facial NMES was rated on two visual analogue

scales (VAS), with participants indicating their agreement to the statements *'I am excited about receiving facial NMES'* and *'I am worried about receiving facial NMES*' using a scale from '*0 – Strongly disagree'* to '*100 – Strongly Agree'*.

Upon arriving at the laboratory participants were given a detailed description of fNMES (see Appendix H), specifying its prior use in facial paralysis research, and emphasising the safety of the technique. To avoid drawing immediate attention to the concepts of emotion and mood, a cover story was used: Participants were informed that the experiment investigated the comfort of various fNMES intensities. Participants were seated in a sound-attenuated booth positioned 60 cm from the centre of a 24.5-inch screen (Alienware aw2521h) with a resolution of 1920 × 1080 pixels, and a refresh rate of 360 Hz. To be able to verify correct muscle activation patterns, we recorded participants' faces using a Logitech webcam, sampling at 15 frames per second.

For each muscle on each side of the face, a calibration phase of approximately 15 minutes was carried out to identify the muscle motor point and ensure that facial movement could be induced without causing discomfort. The experimenter cleaned the participants' skin using alcohol wipes (70% isopropyl alcohol). Four electrodes were placed on the participant's face (two on each side) over the muscle of interest, following EMG guidelines (Fridlund & Cacioppo, 1986). fNMES was administered for 500 ms, starting at 5 mA and gradually increasing in increments of 5 mA until there was noticeable muscle movement (100% of MT). During the stimulation period participant's face was visually inspected for noticeable muscle contractions according to the respective muscle function. For example, when stimulating the ZM, the lip corner moves up and towards the ears, whereas stimulation of the DAO makes the lip corner move down towards the chin. If the muscle contractions were not satisfactory, or participants reported high levels of discomfort, electrode positions were changed slightly – this process was repeated until the administrator considered the contractions to be adequate.

Once a comfortable and optimal electrode placement and intensity were found, fNMES was delivered for 5–seconds three times to introduce the subjects to the parameters defined in the experiment.

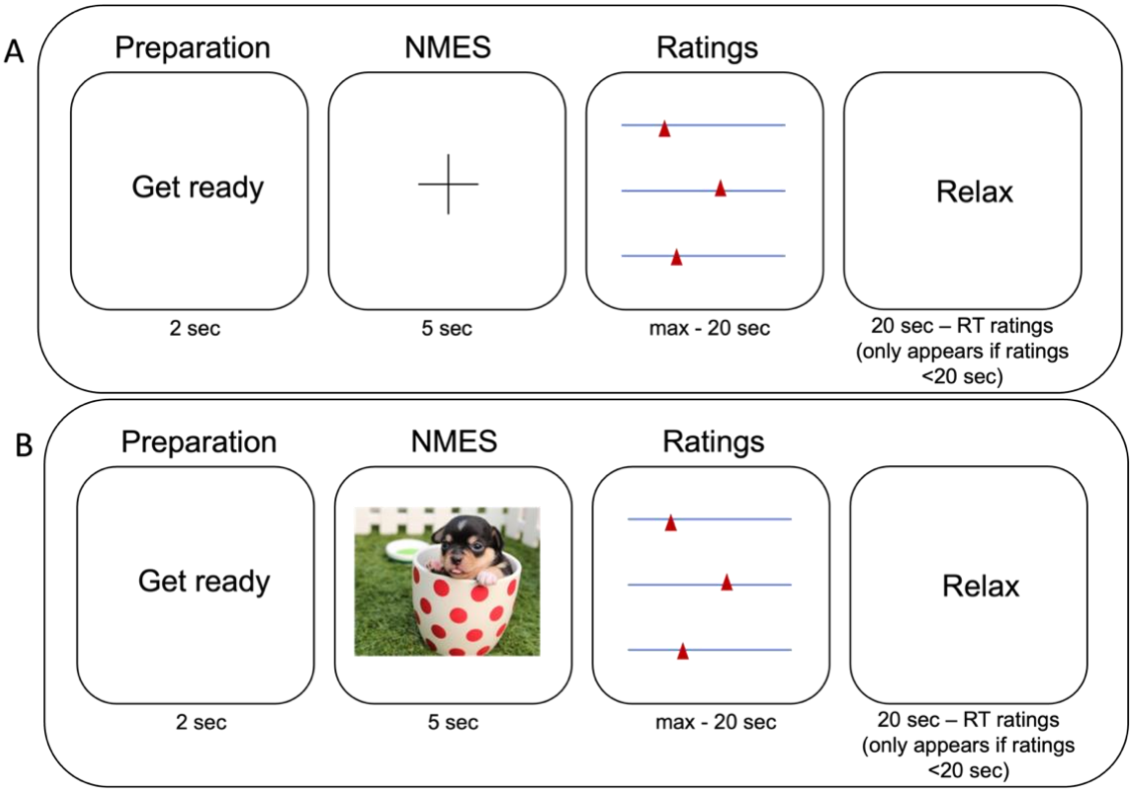
The experiment was programmed in PsychoPy v2021.1.4 (Peirce et al., 2019). To obtain a baseline of EDA and HR activity, participants began by sitting still and watching a video of a moving ball for 3 minutes. Participants were then asked to report their mood on a 100-point VAS with the anchors '0 - *Low mood (sad/angry)*' and 100 - *High mood (happy/cheerful)*' and to complete the Positive and Negative Affect Schedule (PANAS, Watson et al., 1988) to get a measure of their emotional state.

Thereafter the first block of fNMES began, comprising 36 trials presented in a pseudorandom order (avoiding back-to-back repetitions of the same fNMES intensity). In the first 12 trials, participants received 5–seconds of fNMES at 0, 50, or 100% of MT while viewing a fixation cross at the centre of the screen ('no image' condition). In the remaining 24 trials, a neutral or stimulation-congruent image was shown in conjunction with fNMES. Images were selected from the Open Affective Standardised Image Set (OASIS, Kurdi et al., 2017, see Appendix I for the list of images selected). Both blocks included neutral and no image conditions. However, the ZM block only had positive images, while the DAO block only had negative images. After each trial, participants were shown three 100-point VAS through which they reported the valence and arousal of their emotions, as well as the amount of fNMES-induced discomfort. Valence was measured with the item: '*Rate how you feel right now*' and had anchors '*0 – negative/low'* and *'100 – positive/high*'. Arousal was measured with the item: '*Rate the intensity of your feelings*', with anchors '0 – *not at all intense'* and '100 – *extremely intense'*. fNMES-induced discomfort was measured by asking: '*How uncomfortable did you find the stimulation?*', and anchors were '0 – *not at all uncomfortable'* and *'*100 – *extremely uncomfortable'* (see Figure 15). At the end of each block, participants

were asked '*Please rate to what extent the stimulation felt like you were: smiling/frowning*', for which they used two 100-point VAS with anchors '0 – *Not at all*' and '100 – *Very much*'.

**Figure 15**

*Example of two trials*



*Note.* During a single trial, participants were given a two-second warning before receiving fNMES at varying intensities, at either 0% (off), 50%, or 100% of MT. The experiment consisted of two blocks of 36 trials. Panel A illustrates the first 12 trials presenting a fixation cross. Panel B illustrates the subsequent 24 trials in which one image from the OASIS database was shown. At the end of each trial, participants rated the valence and arousal of their felt emotion, as well as felt discomfort. Participants had up to 20–seconds to answer these questions, and the trial ended when all three questions had been completed, or after the 20–seconds elapsed, whichever occurred first. Once questions were answered, a rest period was provided, which lasted for the remainder of 20–seconds minus the time taken to respond. If a participant used the entire 20–seconds to respond, there was no additional rest period, and the next trial commenced immediately.

### 4.3.6 Data preparation and analyses

Behavioural data processing and statistical analyses were performed using R (R Core Team, 2020). Self-reported valence, arousal, discomfort, positive and negative affect, and alexithymia were z-score transformed. Further, fNMES was organised based on muscle and fNMES intensity[4], resulting in the order: DAO 100%, DAO 50%, off, ZM 50%, ZM 100% and converted into numerical values ranging from -2 to 2. The visual stimuli were also categorised into three groups: no image, neutral, and congruent. Congruent stimuli are those in which the participant's facial expression matches the emotional content of the visual stimulus. For example, a negative image is considered congruent in trials with fNMES applied to the DAO.

In total, 2.98% of all trials were excluded from the analysis for the following reasons. First, we excluded trials in which participants failed to rate arousal and discomfort within the provided 20–seconds (0.17% of all trials). Second, we noticed that in some cases participants reported high levels of discomfort related to fNMES in situations where fNMES was not administered (off condition), suggesting a random or erroneous response. We, therefore,

[4]We also provide results for the analysis keeping muscle and fNMES intensity separate (Appendix K).

decided to exclude any trials in the fNMES-off condition where the reported discomfort exceeded twice the standard deviation above the mean (that is, discomfort ≥ 35; 82 trials, 2% of all trials). Finally, we rejected trials with valence, arousal, or discomfort ratings ± 3.29 SD (33 trials, 0.81% of all trials) as they were considered outliers[5].

Linear mixed-effects models (LMMs) were conducted using the lme4 package (Bates et al., 2015), and p-values for fixed effects in LMMs were computed using the lmerTest package (Kuznetsova et al., 2017). To analyse main and interaction effects, the emmeans package (Lenth, 2023) was utilised, from which we report estimated marginal means. Model comparisons were conducted using the ANOVA function. To evaluate model performance and test its accuracy, we used the performance package (Lüdecke et al., 2021) to extract conditional $R^2$ and marginal $R^2$ values. The confint function was employed to extract 95% confidence intervals.

To verify that fNMES resulted in the intended muscle activation, the video recordings of each participant were segmented into seven-second clips (-1s to 6s post-fNMES onset), and facial muscle activity was coded based on the Facial Action Coding System (FACS; Friesen & Ekman, 1978) using the OpenFace toolkit (Baltrusaitis et al., 2018). The software provides a confidence rating (0 – 1) for each frame, which indicates the tracker's confidence in the detection of activity in an action unit (AU). These confidence ratings were averaged across all frames for a single trial, and we rejected trials in which confidence was < 95%. The data were baseline corrected by subtracting the average of the preceding -500 ms from each subsequent time point. We extracted activation levels for AU12 (ZM) and AU15 (DAO) as our primary index of smiling and frowning, respectively. Further, we extracted activation of two related but non-target AUs, specifically AU6, which corresponds to the OO muscle and is engaged

[5]Inclusion of these trials does not change the pattern of results.

during a Duchenne smile (Ekman & Davidson, 1990), and AU4, which is a measure of CS activity resulting in the lowering of the brow. This was done to confirm that fNMES did not recruit other surrounding muscles. Further, AU4 was to ensure participants were not grimacing in discomfort (Pressman et al., 2021).

Physiological data were processed using MATLAB and the EEGLAB toolbox (Delorme & Makeig, 2004). Skin conductance was analysed in two ways. For block-level (tonic) responses (skin conductance level, SCL), data were detrended (removal of the mean across all samples) and then subjected to a 10 Hz low-pass filter. Mean activity in the baseline periods (2-minute video that preceded each stimulation block) was calculated and subtracted from the respective mean activity during each stimulation block (i.e., DAO and ZM separately), resulting in baseline-corrected tonic activity during the application of successive stimulations to DAO and ZM. For event-related activations (i.e., phasic skin conductance response, SCR), a 0.1 Hz high pass filter was applied before data were segmented into 21-second epochs (1 second before the onset of the stimulation, and 20–seconds following the stimulation). Epochs were baseline-corrected by removing the mean activity of pre-stimulation activations. The amplitude of SCR was quantified for each trial by taking the mean of the samples between 2 s and 10 s after the onset of stimulation. The first 2 s of data were discarded because the changes in the data were too fast to be a SCR (Ohira & Hirao, 2015). The next 8 s were used based on a visual inspection of the data.

For HR measures, the findpeaks function in MATLAB was used, with the minimum peak distance parameter set to 300. We confirmed this through a visual inspection of a 1-minute period, confirming the correct number of peaks were counted. This demonstrated that this was sufficient to extract the number of peaks in the PPG signal. For the block-level analysis, similarly to the SCL analysis, HR (bpm) was calculated in each baseline period and subtracted from the HR observed during each stimulation block. This resulted in a HR-change

measure for each block, which allowed us to examine whether HR increased or decreased during each block, relative to the baseline. HR was also derived in the event-related analysis, whereby the number of peaks in the PPG signal was derived in each trial.

## 4.4 Results

Participants reported a moderate level of excitement ($M$ = 63.02, $SD$ = 25.38) and a low level of worry ($M$ = 23.64, $SD$ = 25.56) at the prospect of receiving fNMES. Only five participants reported prior experience with some form of electrical stimulation, two were for medical and three for research purposes. Results from the TAS questionnaire showed that 34 participants had no alexithymia (TAS score ≤ 50), 11 had possible alexithymia (TAS score 52-60), and in 11 alexithymia was present (TAS score ≥ 61)[6]. TAS scores were missing for two participants. In the DAO block, participants reported feeling that fNMES induced more frowning ($M$ = 77.04, $SD$ = 25.35) than smiling ($M$ = 16.91, $SD$ = 26.05). Conversely, in the ZM block, participants felt that fNMES made them smile ($M$ = 70.21, $SD$ = 26.97) more than frown ($M$ = 21.33, $SD$ = 24.16).

We performed a linear regression to examine the predictive relationship between the amount of current needed to induce motor contractions and the variables of facial side ($R^2$ = .03, $F(3, 228) = 2.02$). A main effect of muscle emerged indicating that the DAO muscle required a higher current to contract than the ZM (β = 33.36, 95% CI[1.97, 64.75], $t(228)$ = 2.09, $p$ = .037). No statistical difference in current between each side of the face emerged (β = 2.50, 95% CI[-28.89, 33.89], $t(228) = 0.16$, $p$ = .875). Finally, no interaction between muscle and side emerged (β = -13.79, 95% CI [-58.19, 30.60], $t(228) = -0.61$, $p$ = .541). The currents

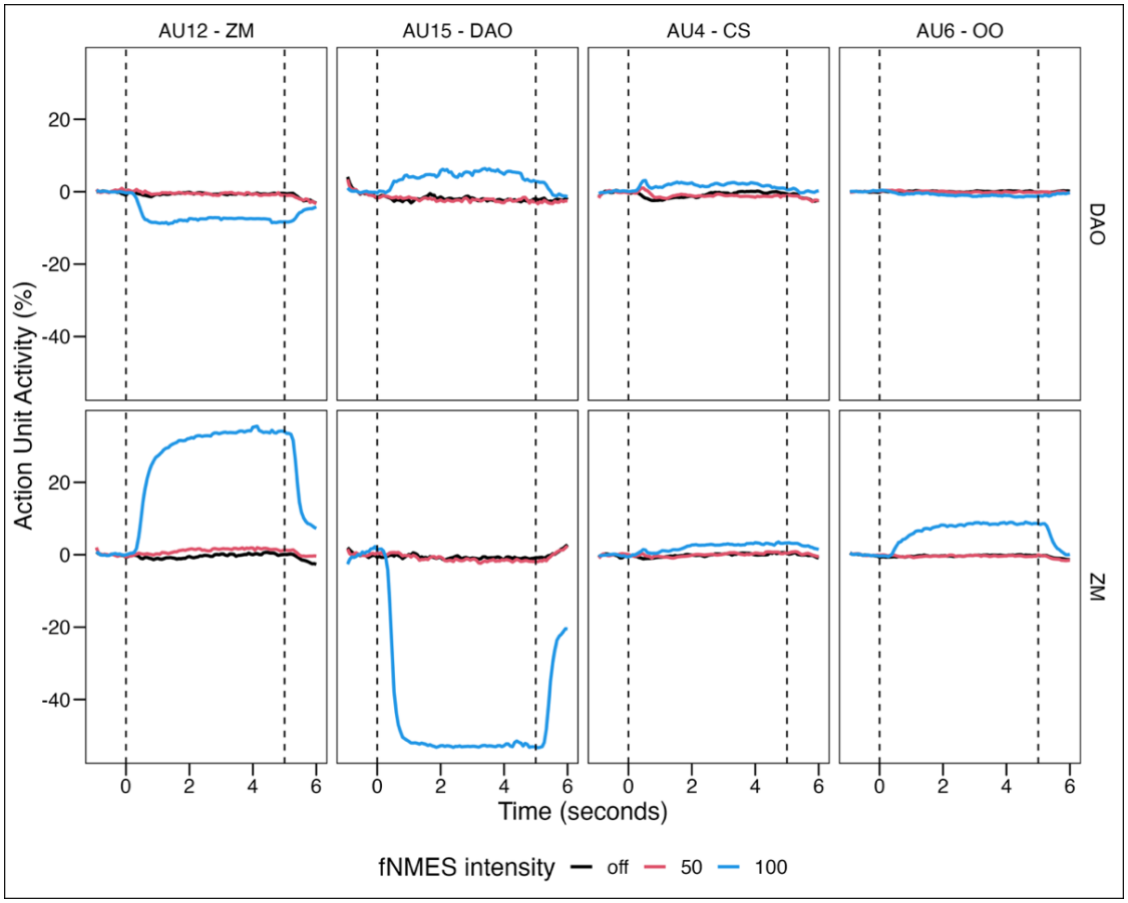
[6]The pattern of results did not change when excluding the high-alexithymia participants.

for each side of the face were averaged, the mean fNMES intensity applied was 22.96 mA (*SD* = 4.25, range: 15.38 – 38.75) for the DAO and 24.29 mA (*SD* = 3.98, range: 15.25 – 35).

Activation and relaxation patterns across four AUs (4, 6, 12, 15) were extracted from video recordings using automatic FACS coding. This allowed us to observe (Figure 16) DAO activation (AU15) and ZM relaxation (AU12), when fNMES was delivered at 100% of MT to the DAO muscle. The opposite pattern of DAO relaxation and ZM activation, as well as some OO activation (AU6), was found when the ZM muscle was targeted with fNMES. The activity of the CS muscle (AU4) was low and similar across fNMES targets. Importantly, no substantial changes across all four AUs occurred when fNMES was delivered at 50% of MT, or when fNMES was off. To summarise, the intended target muscles DAO and ZM were reliably activated with fNMES at 100% MT, while they stayed at baseline level when lower intensity fNMES or no fNMES at all were applied.

**Figure 16**

*Average activity of four AUs*




*Note.* AUs correspond to the activity of the ZM, DAO, CS, and OO muscles) during fNMES application to the DAO muscle (top row), and the ZM muscle (bottom row). This graph displays the adjusted values of four action units (AUs) after baseline correction. The baseline mean has been subtracted from each AU. The period is over 7–seconds, including the 5–seconds of fNMES (between vertical dotted lines). The coloured lines show the intensity of the stimulation: 100%, 50%, and 0% (off) of MT. Only trials with confidence > .95 were included in the grand average.

## 4.4.1 Ratings

Our primary model to analyse self-reported valence included the predictors fNMES (continuous), image (categorical with levels congruent, neutral, no image), and the covariates positive affect (measured with the PANAS at the beginning of the experiment), and discomfort (measured after each trial and averaged per participant), which were selected

based on model fit comparisons (see Appendix J for details). The model (formula: valence ~ fNMES + fNMES:image + positive affect + discomfort) produced substantial explanatory power (conditional $R^2$ = .68, marginal $R^2$ = .28). Planned comparisons were conducted using contrast treatments, for image congruent trials.

In line with H1, we found a significant main effect of fNMES on self-reported emotional valence (ß = 0.44, *SE* = 0.03, 95% CI [0.39, 0.50], *t*(976.35) = 15.76, *p* < .001), suggesting, as expected, a linear increase in valence from DAO 100% of MT with the highest valence at ZM 100% of MT.

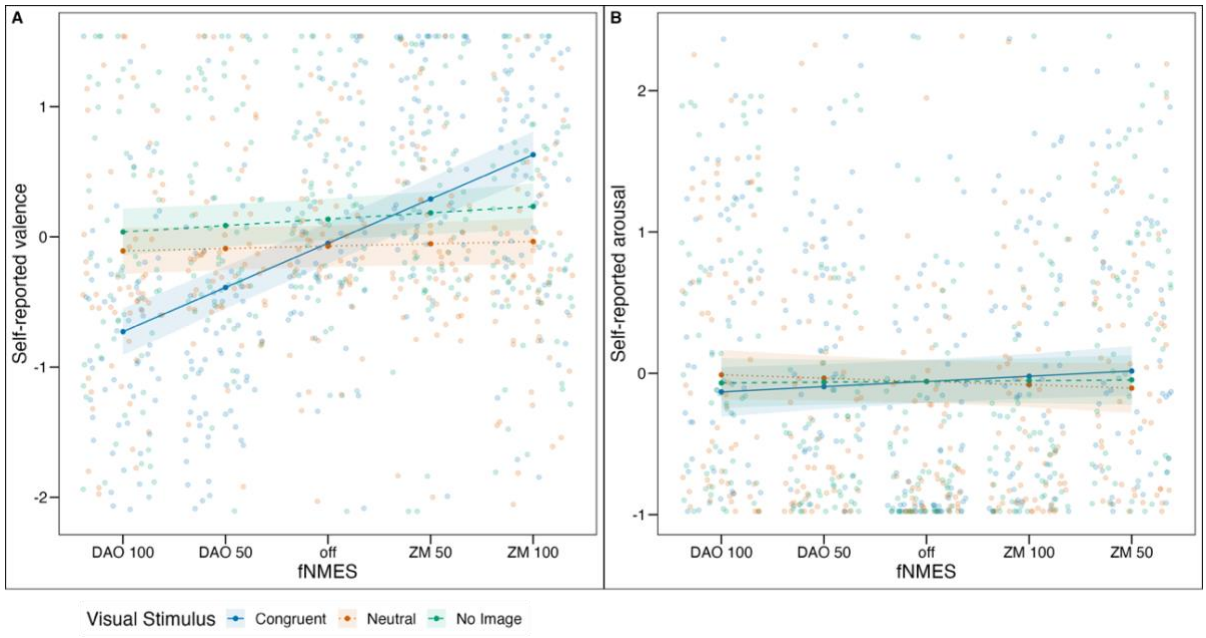
Second, in line with H2, an fNMES by image interaction emerged. The size of the fNMES effect on valence of felt emotion was greater (steeper slope) in the congruent image compared to both the neutral image ($ß_{diff}$ = 0.42, SE = 0.04, *t*(976) = 10.55, *p* < .001) and the no image ($ß_{diff}$ = 0.37, SE = 0.04, *t*(976) = 9.56, *p* < .001) conditions, but the neutral and no image conditions did not differ ($ß_{diff}$ = -0.04, *SE* = 0.04, *t*(976) = 1.08, *p* < .577). This suggests (see Figure 17A) that fNMES resulted in the expected changes in emotional valence, both when provided without images (green line) and to an even bigger extent when combined with an emotionally congruent image (blue line).

This was also confirmed by comparing slopes against zero. The slope for the congruent image condition was significantly greater than zero (ß = 0.44, *SE* = 0.03, *t*(976) = 15.76, *p* < .001), and so was the one for the no image condition (ß = 0.06, *SE* = 0.03, *t*(976) = 0.86, *p* = .023). The neutral image condition, however, did not significantly differ from zero (ß = 0.02, *SE* = 0.03, *t*(976) = 2.28, *p* = .390). This suggests that activating facial muscles did result in the expected changes in felt emotion, although the effects were much stronger when congruent emotional images were shown at the same time. Finally, both covariates had a statistically significant effect. Valence was higher for participants who started the session with higher levels of positive affect (ß = 0.31, *SE* = 0.08, 95% CI [0.16, 0.46], *t*(56) = 4.01, *p*

< .001), and lower for participants who reported high levels of discomfort (ß = -0.24, SE = 0.02, 95% CI [-0.28, -0.20], $t(1001) = 12.10$, $p < .001$).

**Figure 17**

*Effects of fNMES condition and visual stimulus on valence (A) and arousal (B)*




*Note.* Individual data shown as lighter points jittered for clarity. The darker points represent the marginal means for each fNMES level; shaded ribbons indicate the standard error.

To analyse self-reported arousal, we included the same predictors as above and obtained a good fit (conditional $R^2 = .62$, marginal $R^2 = .20$). Only the covariates had significant effects. We found that participants who reported higher levels of positive affect in the PANAS also reported higher values of arousal (ß = 0.23, *SE* = 0.08, 95% CI [0.08, 0.39], $t(56) = 3.01$, $p = .004$). Additionally, self-reported discomfort significantly contributed to higher arousal (ß = 0.36, *SE* = 0.02, 95% CI [0.32, 0.40], $t(976) = 17.18$, $p < .001$). No other main or interaction effects were observed (all ßs < 0.08 and *ps* > .060).

Finally, we conducted additional pre-registered analyses that compared self-reported valence and arousal between the fNMES conditions DAO 100, off, and ZM 100, treating them as categorical variables. The same covariates as in the previous models were used. For

valence, significant main effects of positive affect ($F(1, 56) = 15.89$, $p < .001$) and discomfort ($F(1, 668) = 57.84$, $p < .001$) were found. An interaction between fNMES and image also emerged ($F(8, 627) = 18.48$, $p < .001$). Overall, differences in valence between fNMES conditions only emerged for the conditions where an image was presented (see Table 7), although the DAO 100 – ZM 100 contrast was at significance threshold ($p = .05$). Not surprisingly, statistical significance of the "pure" fNMES effect (no image condition) was thus reduced when treating fNMES as a categorical predictor, which takes more degrees of freedom, compared to treating it as continuous predictor. For arousal, we found significant main effects of positive affect ($F(1, 55) = 8.22$, $p = .006$) and discomfort ($F(1, 670) = 50.00$, $p < .001$), and interaction between fNMES and image ($F(8, 626) = 7.49$, $p < .001$), suggesting arousal was higher in conditions where fNMES was at 100% of MT (see Table 7).

**Table 7**

*Bonferroni corrected post hoc comparisons of self-reported valence and arousal by fNMES conditions and image*

| Outcome | Image | Contrast | $M_{diff}$ | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|---|---|
| Valence | Congruent | DAO 100 – off | -0.40 | 0.10 | 638 | 4.17 | < .001 |
| | | DAO 100 – ZM 100 | -1.01 | 0.09 | 624 | 10.71 | < .001 |
| | | off – ZM 100 | -0.62 | 0.09 | 634 | 6.74 | < .001 |
| | Neutral | DAO 100 – off | 0.05 | 0.09 | 634 | 0.58 | 1 |
| | | DAO 100 – ZM 100 | -0.08 | 0.09 | 623 | 0.80 | 1 |
| | | off – ZM 100 | -0.13 | 0.09 | 636 | 1.36 | .519 |
| | No image | DAO 100 – off | -0.10 | 0.09 | 635 | 1.05 | .888 |
| | | DAO 100 – ZM 100 | -0.23 | 0.09 | 623 | 2.40 | .050 |
| | | off – ZM 100 | -0.13 | 0.09 | 636 | 1.38 | .504 |
| Arousal | Congruent | DAO 100 – off | 0.36 | 0.10 | 638 | 3.60 | .001 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | DAO 100 – ZM 100 | -0.09 | 0.10 | 624 | 0.94 | 1 |
| | off – ZM 100 | -0.45 | 0.10 | 635 | 4.74 | <.001 |
| Neutral | DAO 100 – off | 0.23 | 0.10 | 635 | 2.41 | .049 |
| | DAO 100 – ZM 100 | 0.08 | 0.10 | 623 | 0.77 | 1 |
| | off – ZM 100 | -0.16 | 0.10 | 637 | 1.59 | .335 |
| No image | DAO 100 – off | 0.49 | 0.10 | 636 | 5.06 | < .001 |
| | DAO 100 – ZM 100 | -0.01 | 0.10 | 623 | 0.14 | 1 |
| | off – ZM 100 | -0.50 | 0.10 | 637 | 5.13 | < .001 |

### 4.4.2 Physiological results

Models to investigate trial-wise differences in HR and SCR included the muscle stimulated (ZM and DAO), the intensity of the stimulation (off, 50%, and 100% of the MT), and the image shown (no image, neutral, congruent emotion). For SCR, we found (see Figure 18) a main effect of muscle ($F(1, 776) = 7.18$, $p = .008$), with a larger SCR when the ZM ($M = -1.33$, $SE = 0.24$) compared to DAO muscle was targeted ($M = -1.86$, $SE = 0.24$). A significant main effect of fNMES was also found ($F(2, 776) = 55.21$, $p < .001$). Planned contrasts showed a larger SCR for the 100% MT condition ($M = -3.00$, $SE = 0.26$) compared to 50% MT ($M = -1.25$, $SE = 0.26$; $t(869) = 7.05$, $p < .001$) and off ($M = -0.54$, $SE = 0.26$; $t(870) = 10.32$, $p < .001$). No other main or interaction effects emerged (all $Fs < 2.25$ and all $ps > .081$).

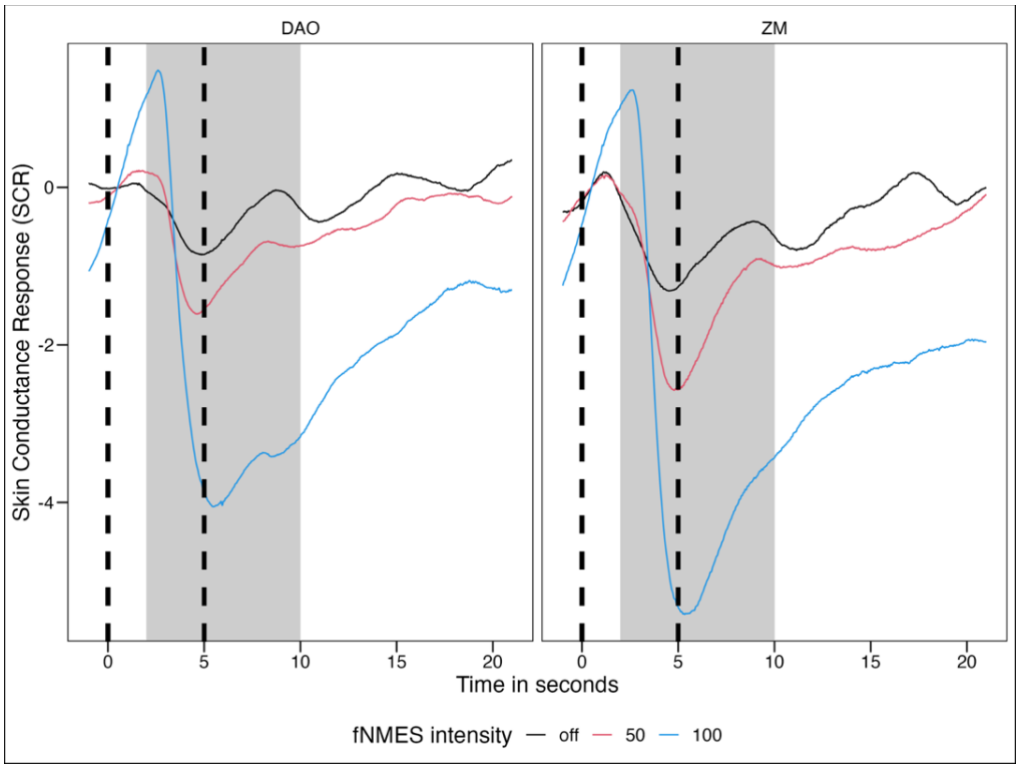
For HR only, fNMES intensity emerged as statistically significant ($F(2, 775) = 4.57$, $p = .011$). Specifically, HR was faster in the fNMES off ($M = 74.79$, $SE = 1.27$) compared to the fNMES 100% of MT condition ($M = 73.99$, $SE = 1.27$; $t(775) = 2.99$, $p = .003$). No other main or interaction effects emerged (all $Fs < 2.09$ and all $ps > .111$).

To test H5 and H6, we fitted separate LMMs to compare differences in HR (conditional $R^2 = .49$, marginal $R^2 = .00$) and SCL (conditional $R^2 = .24$, marginal $R^2 = 0.00$)

between muscles (formula: HR/SCL ~ Muscle). There were no statistically significant differences between the ZM and DAO blocks in either HR (ß = -0.27, *SE* = 0.57, *t*(47) = 0.47, 95% CI [-0.43 0.70], *p* = .640) or SCL (ß = 3.68, *SE* = 56.63, 95% CI [-1.40, 0.86], *t*(47) = .07, *p* = .950), suggesting that tonic SCL and HR were unaffected by the muscle being stimulated.

**Figure 18**

*Changes in SCR over time for each target muscle and fNMES intensity*




*Note.* SCR by muscle and fNMES condition. fNMES was delivered from 0 to 5–seconds, as indicated by dashed lines. The shaded area highlights the region of interest averaged for statistical analysis (2 to 8–seconds).

## 4.4.3 Exploratory Analyses

Additional exploratory analyses were carried out without directional predictions. Sum contrasts were used, and outputs were reported using type 3 ANOVAs.

First, we conducted a paired t-test and found that mood did not differ across blocks ($\underline{M_{diff}}$ = 0.21, 95% CI [-0.05, 0.47], *t*(57) = 1.63, *p* = .108). Second, we investigated possible

changes in levels of discomfort between fNMES conditions with an LMM including the categorical predictors of fNMES intensity (off, 50 and 100% of MT) and muscle (DAO, ZM), and mood at the start of each block as a covariate. A statistically significant main effect of fNMES intensity ($F(2) = 530.99$, $p < .001$) was followed up with Bonferroni corrected post-hoc comparisons using the emmeans function. fNMES at 100% of MT ($M = 0.76$, $SE = 0.07$) produced higher levels of discomfort compared to 50% ($M = -0.24$, $SE = 0.07$; $t(974) = 23.48$, $p < .001$), and off ($M = -0.58$, $SE = 0.07$; $t(974) = 31.30$, $p < .001$). Additionally, 50% of MT resulted in greater discomfort than off ($t(974) = -7.92$, $p < .001$). Further, the main effect of muscle was statistically significant ($F(1) = 8.62$ $p = .003$), with self-reported discomfort being greater when stimulation was applied to the DAO ($M = 0.03$, $SE = 0.06$) compared to the ZM ($M = -0.07$, $SE = 0.06$). This effect was however driven by muscle differences at the 50% intensity only, as shown by an intensity by muscle interaction ($F(2) = 5.90$, $p = .003$; see Table 8).

**Table 8**

*Post hoc comparisons of self-reported discomfort by muscle and fNMES intensity*

| fNMES intensity | Contrast | $M_{diff}$ | *SE* | *df* | *t* | *p* |
|---|---|---|---|---|---|---|
| off | DAO – ZM | 0.01 | 0.06 | 982 | 0.16 | .870 |
| 50 | DAO – ZM | 0.28 | 0.06 | 982 | 4.51 | < .001 |
| 100 | DAO – ZM | 0.03 | 0.06 | 982 | 5.27 | .598 |

Finally, we used an LMM (formula: valence ~ muscle + discomfort) to investigate block effects on valence ratings, irrespective of fNMES intensity. We found (conditional $R^2 = .74$, marginal $R^2 = .16$) higher valence in the ZM compared to the DAO block (ß = 0.27, $SE = 0.05$, 95% CI [0.18, 0.36], $t(293) = 5.76$, $p < .001$), suggesting an overall shift in participants' mood during each block. Further, there was a main effect of discomfort (ß = -0.55, $SE = 0.09$,

95% CI [-0.71, -0.39], $t(342) = 6.58$, $p < .001$), reflecting lower valence for higher discomfort. In summary, valence was larger in the ZM block when controlling for fNMES-induced discomfort, which suggests that 20–30 minutes of ZM activation can improve mood. However, one should keep in mind that these fNMES effects are confounded with the (larger) image effects.

## 4.5 Discussion

Common intuition, supported by a substantial body of scientific literature, suggests a bidirectional link between facial expressions and feelings, indicating that simulating an emotional facial expression (e.g., through voluntary posing or the pen-in-mouth technique) can initiate and/or modulate the corresponding feelings (Coles et al., 2019b; Wood, et al., 2016b). However, some of the more famous findings have not been replicated (Wagenmakers et al., 2016), and it remains debated exactly what role facial feedback effects have in generating and modulating affective responses. With the goal of using a more controlled alternative to common facial feedback manipulations (e.g., expression posing, pen-in-mouth, Botox), this study set out to examine whether fNMES-induced expressions of smiling and frowning could trigger self-reported positive and negative emotional states, respectively. Additionally, we sought to investigate if these induced expressions could modify ongoing emotional states elicited by emotional visual stimuli. Furthermore, we explored whether the intensity of fNMES influenced the strength of facial feedback effects. Lastly, we examined if changes in emotional states corresponded to changes in the physiological measures of HR, SCL, and SCR.

Our main hypothesis (H1) was confirmed, as the main effect of fNMES on valence ratings was found in the expected direction. Participants' self-reported emotional valence was modulated by the combination of target muscle and stimulation intensity, with the highest and

lowest ratings respectively occurring for ZM and DAO stimulation at 100% of MT, and the other fNMES conditions resulting in intermediate levels of valence. Importantly, this effect persisted even after accounting for initial positive mood and fNMES-related discomfort.

In line with H2, the fNMES effect was further modulated by the concurrent presentation of neutral or stimulation-congruent images (positive for the ZM block, negative for the DAO block), as indicated by a significant fNMES by image interaction. The effect of fNMES on valence ratings was indeed much stronger when images in congruent emotions were shown at the same time (Figure 17A). Importantly, however, the pure fNMES effect remained significant in the condition without image presentation. Together, these results indicate that fNMES can elicit emotional states independently of concurrent visual stimuli, consistent with prior research demonstrating that posing emotional facial expressions can initiate a corresponding emotional experience (Coles et al., 2023). Nonetheless, it is worth noting that this effect was relatively small, in line with recent meta-analyses on facial feedback effects (Coles et al., 2019).

Interestingly, we did not observe facial feedback effects when participants were exposed to neutral images, which is consistent with Warren's (2021) findings. This seems nevertheless peculiar, as neutral images should not generate any emotions, and thus one would expect similar results as the conditions in which no image was presented. The research in this domain presents a mixed picture: some studies propose that facial feedback effects can initiate emotional states in the presence of neutral stimuli (Adelmann & Zajonc, 1989; McIntosh, 1996; Mori & Mori, 2009). Others, however, have been unable to replicate this effect and have even suggested that the lack of consistency may stem from the presentation of neutral and emotional stimuli in the same block (Dimberg & Söderkvist, 2011), a point that also applies to our study.

No differences in HR or SCL were found between the two experimental blocks. Nevertheless, in a trial-wise analysis, we observed two differences. First, larger SCR was found for fNMES delivered at 100% of MT, compared to the 50%, and off conditions. This is likely due to high-intensity fNMES somewhat startling and surprising participants as indicated by the short-duration positivity (Alaoui-Ismaïli et al., 1997; Collet et al., 1997) and the increased HR in the 100% of MT condition (Ekman et al., 1983). Interestingly, we also observed differences in SCR by muscle, with a larger negative response in the ZM compared to the DAO muscle across all conditions. One interpretation is that this reflects relief as the participants were attempting to anticipate the fNMES condition (Kreibig, 2010). However, the difference between muscles may better be explained by facial feedback effects that is the act of smiling throughout the trials resulted in an increase in happiness enhancing the difference consistent with the FFH (Kreibig, 2010; Soussignan, 2002). This is particularly noteworthy since the image condition did not significantly influence changes in SCR. We did not find an interaction between muscle and fNMES intensity on peripheral physiology. These results diverge from prior research on induced smiles, which have reported reductions in the HR (Ekman et al., 1983). A possible explanation for the mixed bag of physiological results found here is that the effects of faint fNMES-induced muscle activation on physiology may be very small and require larger sample sizes (our study was instead powered for the main effect of fNMES on valence ratings).

Several limitations should be noted. First, we only stimulated one muscle for each expression, while genuine smiles typically involve the OO in addition to the ZM, and sadness expressions also involve several additional muscles, such as the CS. Consequently, the expressions we induced may not have fully captured genuine emotional expressions. In relation to that, some research has found that facial feedback effects are smaller when the

smile predominantly involves the ZM but lacks activation of the OO (Soussignan, 2002; Kraft & Pressman, 2012).

Second, fNMES-induced discomfort affected participants' experience and resulted in lower ratings of emotional valence. Although we did control for discomfort by including it as a covariate, it would have been ideal to eliminate this factor entirely. Previous research by Warren (2021) addressed this concern by using weaker electrical stimulation (below MT), but this does not fully test the FFH, as changes in proprioceptive feedback may not be induced at those weak intensities. The discomfort issue could however be addressed by further optimising the fNMES parameters. As Efthimiou et al. (2023) noted there is no consensus on the optimal fNMES parameters, so further research is needed to determine the most comfortable combinations of waveform, pulse width, and stimulation frequency.

Third, a limitation of our design should be acknowledged, as we did not include positive images in the DAO condition and negative images in the ZM condition. This was intentional to reduce the number of trials and the amount of current delivered. However, it restricted our comparisons, such as the effects of fNMES-induced smiling while seeing negative images. Future research should delve deeper into these effects by employing different visual stimuli (e.g., complex, dynamic) and varying levels of fNMES intensity.

## 4.6 Conclusions

In summary, our study contributes valuable evidence to the growing body of literature supporting the efficacy of fNMES in influencing emotional experiences and physiology through precise facial feedback modulation. Furthermore, our exploration of the DAO muscle's role adds a novel dimension to this field, which was so far restricted to the effects of smile induction. Our research also sheds light on the interplay between emotional stimuli and the effects of fNMES-induced facial expressions on physiological markers, such as HR and

SCR. These findings are significant to the field as they replicate facial feedback effects, contributing to the ongoing discourse on the FFH. Moreover, our study highlights the potential for fNMES to effectively generate and influence emotions, with potential implications for diverse fields such as brain-computer interfaces and mental health (Goto et al., 2018; Kapadia et al., 2019).

## 4.7 Summary

Chapter 4 of the thesis explored a tenet of the FFH (see 'Chapter 1.3 The FFH today'), specifically that facial muscle feedback can initiate and modulate emotional states. The study consisted of 58 participants who received fNMES to two specific facial muscles, the Zygomaticus Major (ZM) and Depressor Anguli Oris (DAO), at varying intensities. The results confirmed that fNMES modulated emotional states as per the FFH, with more positive emotions reported after stimulation of the ZM than the DAO muscle. The study also found that the addition of congruent emotional images increased this effect, and fNMES intensity predicted arousal ratings and skin conductance responses.

The chapter delved into the historical context of FFH and its relevance in psychology and neuroscience. It outlined previous methods of manipulating facial muscle activity, such as voluntary posing or Botox injections, and their limitations. The chapter introduced fNMES as a controlled alternative to these methods.

In the study, a within-subjects design was used. The experiment consisted of a single session; participants received fNMES to two different muscles in separate but counterbalanced blocks. A square 70Hz biphasic waveform was delivered for 5–seconds to the ZM or DAO muscles (depending on the block). The stimulation was set at three different intensities: off, 50%, and 100% of the MT, the latter being the minimum current required to produce a visible muscle contraction. The initial 12 trials of each block involved

administering 5–seconds of fNMES to participants while they focused on a fixation cross, without any accompanying visual stimuli. This was followed by 24 trials where participants were shown a series of images. These images were neutral and emotionally charged, corresponding to the muscle being stimulated – positive images for the ZM block and negative ones for the DAO block. After each trial, participants were asked to report on three aspects: their emotional valence, arousal level, and any discomfort experienced from the fNMES. These reports were made using a 100-point visual analogue scale. There was a 20–second rest period to allow the muscles to return to rest and for the physiology to return to baseline. Throughout the session, faces, HR, and EDA of participants were continuously monitored and recorded.

Findings indicated a linear increase in positive emotional valence with higher fNMES intensities, especially when paired with congruent emotional images. This effect was more pronounced when fNMES was combined with emotionally congruent images. Crucially, this increase in positive feelings was also observed even in the absence of any visual stimulus, suggesting that fNMES alone can elicit emotional responses. While no significant changes were noted in block-wise HR or SCL when comparing different, the HR and SCR varied notably with fNMES intensity. Higher intensity stimulation elicited stronger skin conductance responses. Notably, in the ZM block, where participants experienced fNMES-induced smiling, there was a more pronounced skin conductance response, underscoring the potential cumulative effect of smiling on physiological responses, in line with the FFH.

Despite its strengths, the study was limited, such as the simulation of only one muscle for each expression and the discomfort induced by fNMES. Future research directions were suggested, including exploring different visual stimuli and fNMES intensities.

In conclusion, the chapter presented fNMES as an effective tool for investigating facial feedback effects, offering insights into the modulation of emotional experiences and

physiological responses. This research has potential implications for brain-computer interfaces and mental health applications.

# 5 Zygomaticus activation through facial neuromuscular electric stimulation (fNMES) induces happiness perception in ambiguous facial expressions and affects neural correlates of face processing

Themis Nikolas Efthimiou[1*], Joshua Baker[1], Alasdair Clarke[1], Arthur Elsenaar[2], Marc Mehu[3], Sebastian Korb[1,4*]

[1]Department of Psychology, University of Essex, Colchester, United Kingdom

[2]ArtScience Interfaculty, Royal Academy of Art, Royal Conservatory, The Hague, Netherlands

[3] Department of Psychology, Webster Vienna Private University, Vienna, Austria

[4] Department of Cognition, Emotion, and Methods in Psychology, University of Vienna, Austria

Correspondence:

*Themis Efthimiou, Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, United Kingdom. Email: t.efthimiou@essex.ac.uk.

*Sebastian Korb, Department of Psychology, University of Essex, Wivenhoe Park, Colchester CO4 3SQ, United Kingdom. Email: sebastian.korb@essex.ac.uk.

## 5.1 Abstract

The role of facial feedback in facial emotion recognition remains controversial, partly due to limitations of the existing methods to manipulate the activation of facial muscles, such as voluntary posing of facial expressions, or holding a pen-in-mouth. These procedures are indeed limited in their control over which muscles are (de)activated when and to what degree. To overcome these limitations and investigate in a more controlled way if facial emotion recognition is modulated by facial muscle activity, we used computer-controlled facial neuromuscular electrical stimulation (fNMES). In a pre-registered EEG experiment, ambiguous facial expressions were categorised as happy or sad by 47 participants. In half of the trials, weak smiling was induced through fNMES delivered to the bilateral Zygomaticus Major muscle for 500 ms. The likelihood of categorising ambiguous facial expressions as happy was significantly increased with fNMES, as shown with frequentist and Bayesian linear mixed models. Further, fNMES resulted in a reduction of P100, N170 and LPP amplitudes. These findings suggest that fNMES-induced facial feedback can bias facial emotion recognition and modulate the neural correlates of face processing. We conclude that fNMES has potential as a tool for studying the effects of facial feedback.

Keywords: fNMES, facial feedback, face perception, event-related potentials, embodiment

## 5.2 Introduction

Embodied cognition theories suggest that the recognition of facial expressions is facilitated by facial mimicry – i.e., the spontaneous imitation of perceived emotional faces – and the accompanying changes in facial feedback (Niedenthal, 2007; Wood, Rychlowska, et al., 2016). This has been supported by studies that activated or blocked facial muscles. For example, simulating a smile by holding a pen between the teeth can make people perceive happy faces and bodies faster (Marmolejo-Ramos et al., 2020), and improve working memory for ambiguous happy faces (Kuehne et al., 2021). Conversely, interfering with facial feedback by applying a hardening gel to the face reduces accuracy in matching emotional facial expressions (Wood, Lupyan, et al., 2016), and paralysing facial muscles with Botox injections makes slightly emotional facial expressions appear less emotional, and slows down their recognition (Baumeister et al., 2016).

Facial manipulation techniques can also influence the visual processing of emotional stimuli, as measured by event-related potentials (ERPs). When watching emotional faces, a larger P1 has been reported in trials with more facial mimicry (Achaibou et al., 2008), and a smaller P1 was found in individuals with high alexithymia traits when facial feedback was altered using restrictive facial gel masks (Schiano Lomoriello et al., 2021). Another component relevant to facial recognition is the N170 (Eimer, 2011). Sel et al. (2015) found that when participants simulated a smile, by holding a pen between the teeth, N170 amplitude to neutral facial expressions was increased, suggesting that the facial feedback manipulation affected early visual face processing. In contrast, Achaibou et al. (2008) reported reduced N170 amplitudes in trials with greater facial mimicry, and Schiano Lomoriello et al. (2021) found no significant N170 effects when modulating facial feedback through a hardening face gel. Holding a pen between the teeth may also enhance the N400 component to faces (J. D. Davis et al., 2017). Finally, the late positive potential (LPP) is modulated by the emotional

content, ambiguity, and intensity of faces (Calvo et al., 2013; Liu et al., 2012), but it remains unknown if it is also sensitive to facial feedback effects.

While the facial manipulation methods listed above have played a crucial role in investigating facial feedback effects, they suffer from certain limitations. For instance, Botox injections are an invasive procedure that is primarily administered to female participants, and its effects last several months. It therefore is not the ideal choice for non-invasively testing participants of both genders and capturing rapid effects of facial feedback manipulations. Further, participants often encounter difficulties in adhering to the experimenter's instructions (e.g., posing the exact intended facial expression), and compliance rates vary depending on the specific facial manipulation method employed (Coles et al., 2022). Lastly, modulating facial feedback at specific points in time and for set durations is either impossible or very difficult to achieve using the pen-in-mouth and other techniques discussed above.

Facial neuromuscular electrical stimulation (fNMES) generates controlled facial muscle activations and may thus help to overcome the limitations of the techniques used so far (Efthimiou et al., 2022, 2023). Indeed, fNMES allows researchers to selectively target specific muscles – while controlling for the time of onset, duration, and intensity of their activation – to generate movements associated with emotional facial expressions. fNMES to the *Zygomaticus Major* (ZM) and *Orbicularis Oculi* (OO) muscles was found to increase positive mood and reduce symptoms of depression (Kapadia et al., 2019; Warren, 2021; Zariffa et al., 2014). However, whether fNMES-induced facial feedback can modulate an individual's perception of facial stimuli remains to be investigated. Therefore, in this pre-registered study (osf.io/vbnyx), we set out to investigate whether the induction of a weak, short (500 ms) smile through fNMES can influence facial emotion recognition and modulate early visual face processing.

# 5.3 Methods

## 5.3.1 Participants

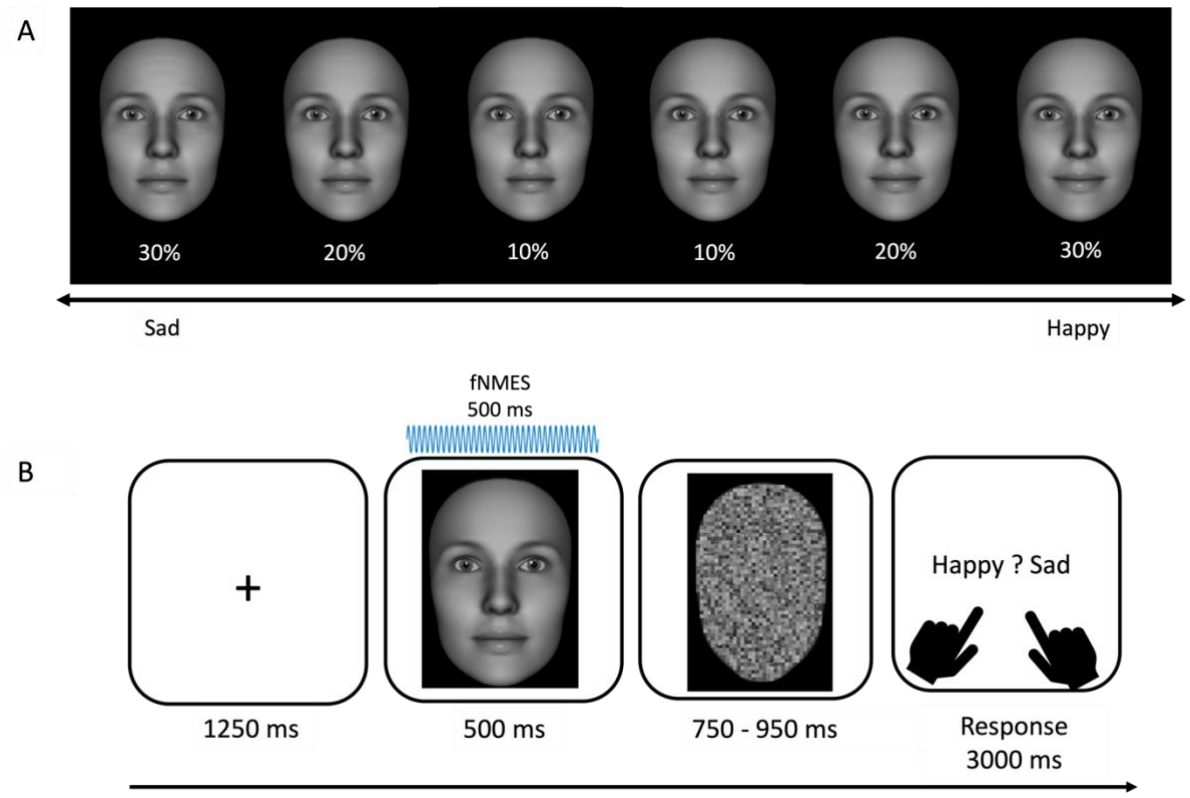
We recruited 47 mostly right-handed (4 left-handed, 3 ambidextrous) participants (23 females) aged 18 – 38 years ($M_{age}$ = 24.49, $SD_{age}$ = 5.03). All participants reported having good visual acuity, not having a history, or making current use of illicit and/or psychotropic drugs, being free of major heart conditions (e.g., pacemaker), and not having any current or past neurological or psychiatric disorders. An apriori power analysis based on a pilot study and data simulations with the package 'SimR' (Green & MacLeod, 2016) indicated that 40 participants are required to detect a main effect (ß = 0.08) of fNMES on emotion categorisation with 88% power (95% CI, [79.98 - 93.64]). For the EEG analysis, nine participants (five females) were excluded due to low-quality data, bringing the final sample size to 38 ($M_{age}$ = 24.7 years, $SD_{age}$ = 4.88). The study was approved by the local ethics committee (ETH1920-0847) and all participants provided written informed consent.

## 5.3.2 Materials

The stimulus set consisted of 20 avatar faces, 10 males and 10 females, on a black background. Faces were generated with the FaceGen software (www.facegen.com), and their emotional expressions were created based on FACS (Ekman, 2002) using the FACSGen software (Roesch et al., 2011; Krumhuber et al., 2012). The expressions of happiness included action units (AUs) 6, 7, and 12, while sadness included AUs 1, 4, 7, 11, and 15. Highly ambiguous to somewhat ambiguous expressions with 10%, 20%, or 30% happiness and sadness were shown (see Figure 19A), resulting in a total of 120 face stimuli, plus two additional avatars for practice trials. All face images were converted to greyscale and equalised in luminance using the SHINE toolbox in MATLAB (Willenbockel et al. 2010).

**Figure 19**

*Illustration of A) avatars and B) trial order*




*Note.* (A) Example of the stimuli used, here a female avatar, with emotional expressions changing from 30% sadness to 30% happiness in steps of 10%. (B) In each trial, participants viewed a fixation cross for 1250 ms, followed by an avatar face for 500 ms. In the fNMES on condition, electrical stimulation was delivered to the ZM muscle to induce a weak smile. In the off condition, there was no electrical stimulation and participants maintained a neutral expression. Thereafter, participants viewed a scrambled face for a jittered time interval of 750–950 ms, and finally, participants had up to 3000 ms to respond via button press to indicate the perceived emotion of the non-scrambled facial expression (happy or sad).

The Empathy Quotient (EQ; Lawrence et al., 2004), Autism-Spectrum Quotient (AQ; Baron-Cohen et al., 2006), Multidimensional Assessment of Interoceptive Awareness (MAIA; Mehling et al., 2018), and the PANAS questionnaire (Watson & Clark, 1994) were also measured.

### 5.3.3 Equipment and fNMES parameters

The delivery of fNMES to the bilateral ZM muscle was achieved using two constant-current electrical stimulators (Digitimer, DS5). A 500 ms long train of biphasic square pulses (100 μs biphasic pulse width, 14 ms delay between biphasic pulses) was delivered at 70 Hz using disposable Ag/AgCI electrodes measuring 16 × 19 mm (Ambu BlueSensor BRS). Stimulation intensity was below 2 RMS mA/cm² following safety guidelines (Efthimiou et al., 2023c). EEG data were sampled at 512 Hz using an eego sports amplifier (ANT Neuro), and a 64-electrodes waveguard cap – electrodes AFz and CPz served as ground and reference, respectively.

### 5.3.4 Procedure

The study consisted of a single session lasting approximately two hours, for which participants were compensated with a £25 voucher. Before the laboratory appointment, participants completed a survey administered via Qualtrics, where they were screened for exclusion criteria, provided basic demographic information, and filled out the MAIA, ASQ, and EQ questionnaires. The laboratory task was programmed in PsychoPy 3 (v3.2.4) (Peirce et al. 2019).

Upon arrival, participants were seated in a sound-attenuated booth and were positioned 60 cm from the centre of a 24.5-inch screen with a resolution of 1920 × 1080 and a refresh rate of 360 Hz. The experimenter cleaned the skin of the participants' cheeks using 70% isopropyl alcohol wipes. Two pairs of disposable electrodes were placed over the bilateral ZM muscles, following EMG guidelines (Fridlund & Cacioppo, 1986). To identify the best positioning of the electrodes and ensure that a weak smile could be induced comfortably, fNMES intensity was gradually increased until visible muscle contractions were

observed. On average, fNMES was delivered at 22.60 mA (*SD* = 3.62, range:14.25 – 33.75). Once the fNMES set up was completed, the EEG cap was gowned, and the task began.

Following the completion of the PANAS questionnaire, participants were provided with written instructions outlining the primary task, which included eight practice trials and a total of 650 experimental trials in pseudorandom order (maximum eight repetitions of the same fNMES conditions, and four repetitions of the same facial expression). The main task included 300 trials without fNMES, and 300 with fNMES starting at face onset and lasting for 500 ms. In 50 additional 'fNMES only' trials, stimulation was delivered without showing a face. The elements and timings for each trial can be seen in Figure 19B. Overall, the experiment lasted 50 minutes, including eight breaks with participants receiving feedback about their accuracy. During the calibration and task, participants were not able to see their faces, which were however filmed with a webcam.

After the main task, participants rated how (un)comfortable the fNMES had felt. As a reminder, they received another 500 ms of stimulation (without visual stimuli), and rated discomfort on a 100-point visual analogue scale with the anchors 0 – '*extremely comfortable'* to 100 – '*extremely uncomfortable'*, finally the PANAS was administered for a second time.

### 5.3.5 Data preparation and analyses

We followed our pre-registered pre-processing and analysis steps but also included additional exploratory analyses. Two participants failing two out of three test items were deemed inattentive and excluded from analysis. The MAIA, ASQ, and EQ were standardized using z-score transformation. All participants were retained for the emotion categorisation data, which was cleaned by removing trials with no response (i.e., did not respond within 3000 ms; .30% of all trials), and those with a reaction time < 100 ms or > 3 *SD* above the mean (4.67% of all trials).

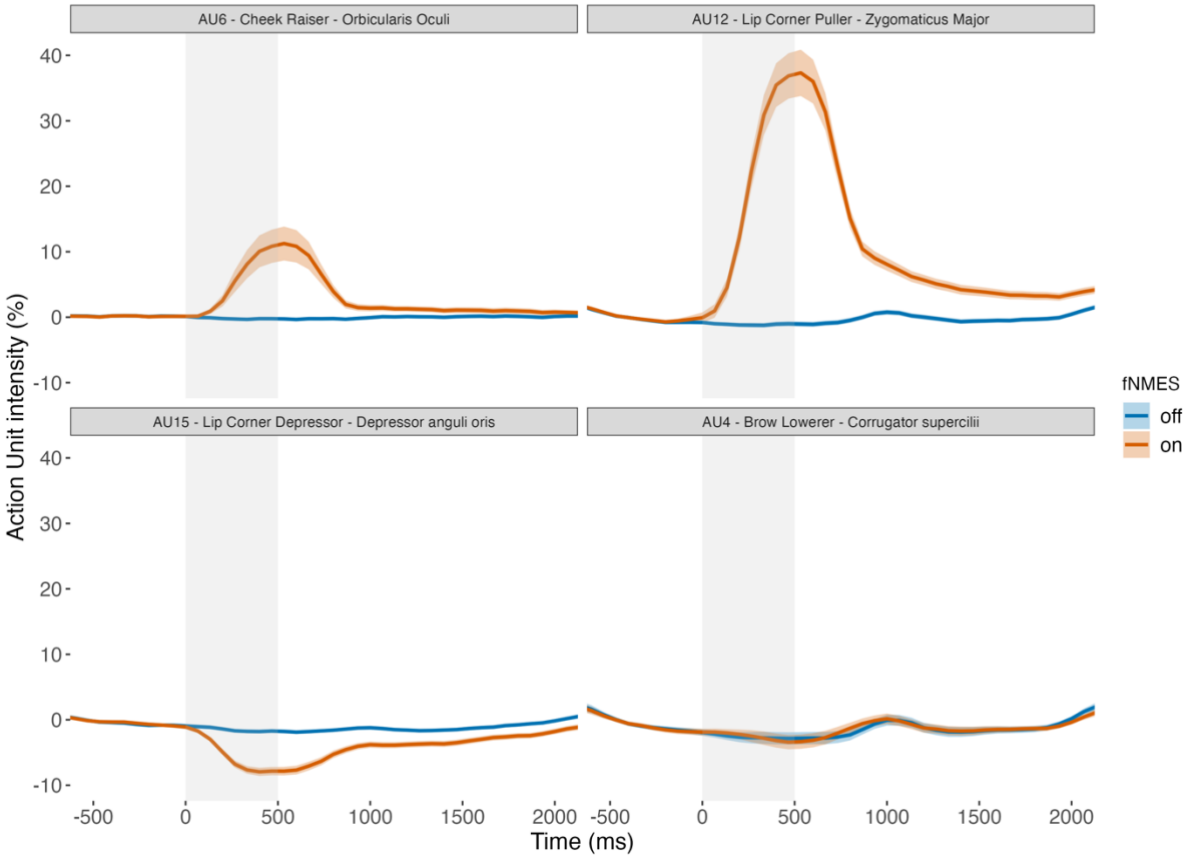
Statistical analyses were conducted in R (R Core Team, 2020) implementing mixed models with the lme4 (Bates et al., 2015) and lmerTest (Kuznetsova et al., 2017) packages. A first of our pre-registered models tested that fNMES would increase participants' choices of happiness. It included the fixed effects of emotion (six levels, entered as a continuous variable: the 30, 20, and 10% intensity levels of sadness were coded as -3, -2, and -1, while the 10, 20, and 30% intensity levels of happiness were coded as 1, 2, and 3) and fNMES (on, off; entered as a categorical predictor). The interaction was removed from the random effect's structure due to singular fits (see Appendix L), and the model formula was Choice ~ Emotion * fNMES + (Emotion + fNMES | Participant)). A follow-up analysis included several covariates to control for individual differences. A second pre-registered model tested if fNMES influences emotion choice mostly when stimulus emotion is ambiguous. The 30, 20, and 10% emotion intensities were coded as 0, .5, and 1 ambiguity, respectively. The formula of the model was: Choice ~ emotion + fNMES + Ambiguity + Emotion: fNMES + Emotion: Ambiguity + Ambiguity:fNMES + (1 | Participant).

An exploratory analysis examined whether fNMES-induced smiling altered participants' mood as measured by the PANAS pre- and post-task, using two separate linear regression models, one for positive and the second for negative affect.

The degree of fNMES-induced smiling was captured with video recordings (cut from 500 ms before to 2000 ms after fNMES onset) and estimated with FACS implemented in OpenFace (Baltrusaitis et al., 2018). The activation of AUs 6, 12, 4, and 15 during facial stimulation was thus obtained on a scale from 0 to 5, and baseline corrected using the first 1000 ms before face onset. This data was then averaged over the 1000 ms period to capture both the ramp-up and downtime (see Figure 20).

**Figure 20**

*Results from the OpenFace analysis*




*Note.* Baseline corrected results from the OpenFace analysis of video recordings (500 to 2000 ms) of participants' faces, based on the facial action coding system (FACS; Ekman et al., 2002). The activation of four AUs (AU6, AU12, AU15, AU4), averaged across all trials where algorithm confidence was > 95%, is shown for trials with (orange) and without (blue) fNMES. Notice how fNMES delivery (period indicated by the shaded area) resulted in a 40% activation of AU12, which corresponds to the ZM muscle, followed by a faint activation of AU6, and a relaxation of AU15 (an antagonistic muscle). Importantly, fNMES delivery did not result in AU4 activation (reflecting frowning), which would have been suggestive of a pain response or negative emotion induction. The shaded grey region on the line represents the standard error (SE).

## 5.3.6 EEG processing and analyses

The EEG data were analysed in MATLAB using the EEGLAB toolbox (Delorme & Makeig, 2004). We followed a previously established procedure for the cleaning of fNMES-

induced artefacts (Baker et al., 2023). All 650 trials were filtered with a 0.5 Hz high pass and 80 Hz low pass, channels with excessive noise or artefacts were identified through visual inspection and interpolated, line noise was removed using Zapline and Cleanline, and data was epoched from 500 ms before to 800 ms after stimulus onset. We performed independent component analysis (ICA) on the data using the runica function in EEGLAB and removed components representing blinks and fNMES artefacts (see Baker et al., 2023 for a detailed description of this approach). Trials were labelled for rejection if values in the pre-stimulus baseline for any channel exceeded +/- 100 µV. This was performed following the initial channel rejection step, and in all labelled cases, large slow-fluctuating oscillations were observed across all channels. The baseline period was chosen to not include the large amplitudes observed during fNMES. The data were finally filtered with a 40 Hz low pass filter and re-referenced to the common average.

Following pre-processing, we extracted average amplitudes for the following ERP components: P1 (averaged over O1/O2, 80 to 140 ms), N170 (averaged over P7, TP7, P8, TP8, 130 to 190 ms), and LPP (averaged over CPz, Pz, and POz, 450 to 650 ms). To identify the electrodes and times to derive component mean amplitudes, the standard deviation of all channels (mean of all trials from all participants) was plotted over time. Peak deviations were identified through visual inspection. Scalp topography at the timings of identified peaks allowed for the selection of electrode clusters. Finally, we extracted the same ERP component amplitudes from the fNMES-only trials and subtracted them from the fNMES-on trials, therefore removing somatosensory activations associated with receiving stimulation, and avoiding contamination of visual evoked potentials (for a similar analysis, see Galvez-Pol et al., 2020; Sel et al., 2014).

Linear mixed models were fitted for each ERP component including the fixed effects Emotion and fNMES (formula: Amplitude ~ Emotion * fNMES + (1 | Participant)). Contrasts

were set to sum and outputs were reported as type 3 ANOVAs. Post hoc comparisons were carried out with emmeans (Lenth, 2023).

## 5.4 Results

Ratings of discomfort provided to a single 500 ms period of fNMES at the end of the task were generally low ($M$ = 30.36, $SD$ = 18.71, range: 1.17 – 70.73). We began by checking whether fNMES-induced smiling altered mood, as measured with PANAS. Both linear regressions revealed no differences between pre- and post-task for positive (β = -0.98, 95% CI [-2.29, 0.34], $t(82) = 1.47$, $p = .145$) and negative affect (β = -2.38, 95% CI [-5.58, 0.81], $t(82) = 1.48$, $p = .142$). Overall, there were no changes in positive and negative affect at the start and end of the session.

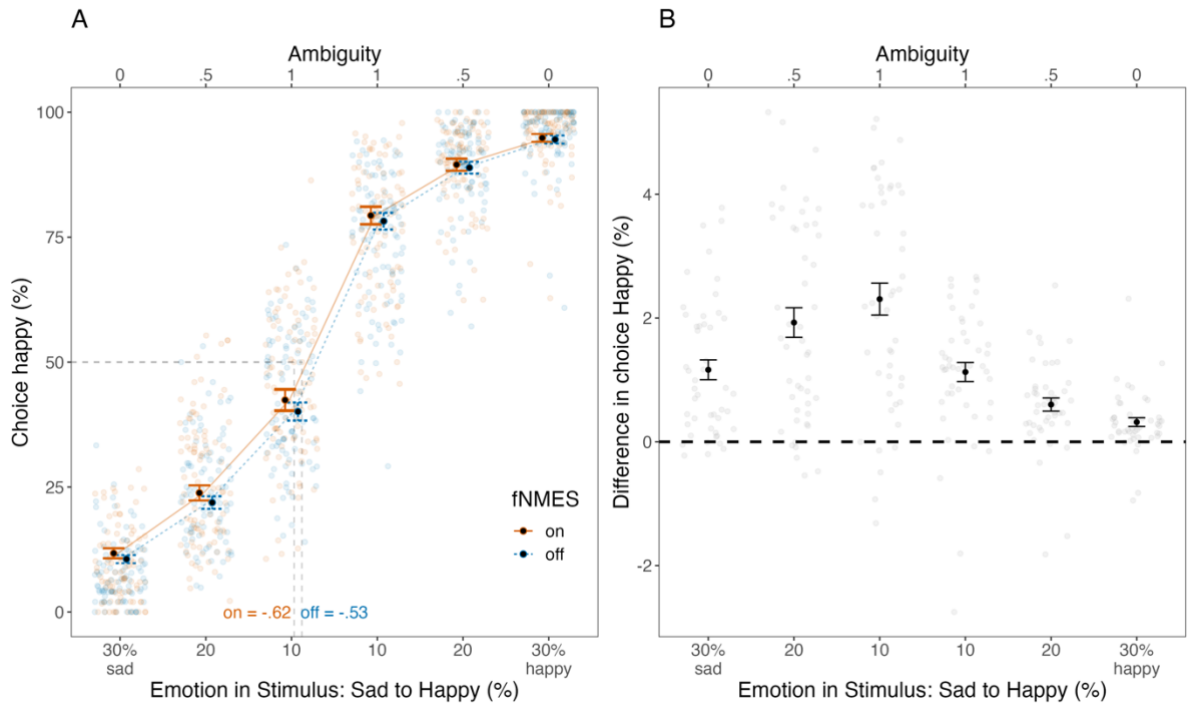
### 5.4.1 Emotion categorisation data

Our first pre-registered analysis was to predict choice by emotion and fNMES (conditional $R^2 = .59$, marginal $R^{2 =} .51$). A significant main effect of Emotion (β = 0.93, $z$ = 28.62, 95% CI [0.86, 0.99], $SE$ = 0.03, $p < .001$) indicated that participants followed instructions and were overall able to accurately recognise emotional facial expressions. Importantly, a significant main effect of fNMES was found (β = .09, $z$ = 2.46, 95% CI [0.02, 0.17], $SE$ = 0.03, $p = .014$), indicating, as predicted, that more faces were categorised as happy when fNMES was delivered to the smiling muscles (Figure 21A). The interaction between Emotion and fNMES was not statistically significant (β = -0.01, $z$ = 0.04, 95% CI [0.04, 0.04], $SE$ = 0.02, $p = .538$). Points of Subjective Equality (PSEs) showed that faces categorised as happy could contain more sadness when fNMES was delivered (on = -.62 compared to off = -.53; Figure 21A). A score computed by subtracting the percentage of faces categorised as happy in the fNMES on minus off condition was positive for all emotion levels

and was greater for sad and the most ambiguous expressions (the 10% ones), than for 20% and 30% happy faces (see Figure 21B).

**Figure 21**

*Predicted values for the main effect of fNMES*




*Note.* Predicted values for the main effect of fNMES on happy responses to facial stimuli varying from 30% sad to 30% happy. Panel (A) shows the percentage of happy responses across Emotion and fNMES, using the marginal means of the model. Individual dots display participants (jittered to improve visibility), and the dark point reflects the mean with standard error bars (SE). Panel (B) displays the mean difference (and standard error) in the percentage of happy responses between fNMES conditions (on minus off) across emotion levels. The shaded points represent participant means.

To control for a series of interindividual differences, the first model was followed up by exploratory analyses that also included several covariates (MAIA, EQ, ASQ, PANAS, fNMES-induced discomfort), participants' ratings of discomfort, and the questionnaire scores. The main effects of emotion and fNMES were still significant, and the not-distracting

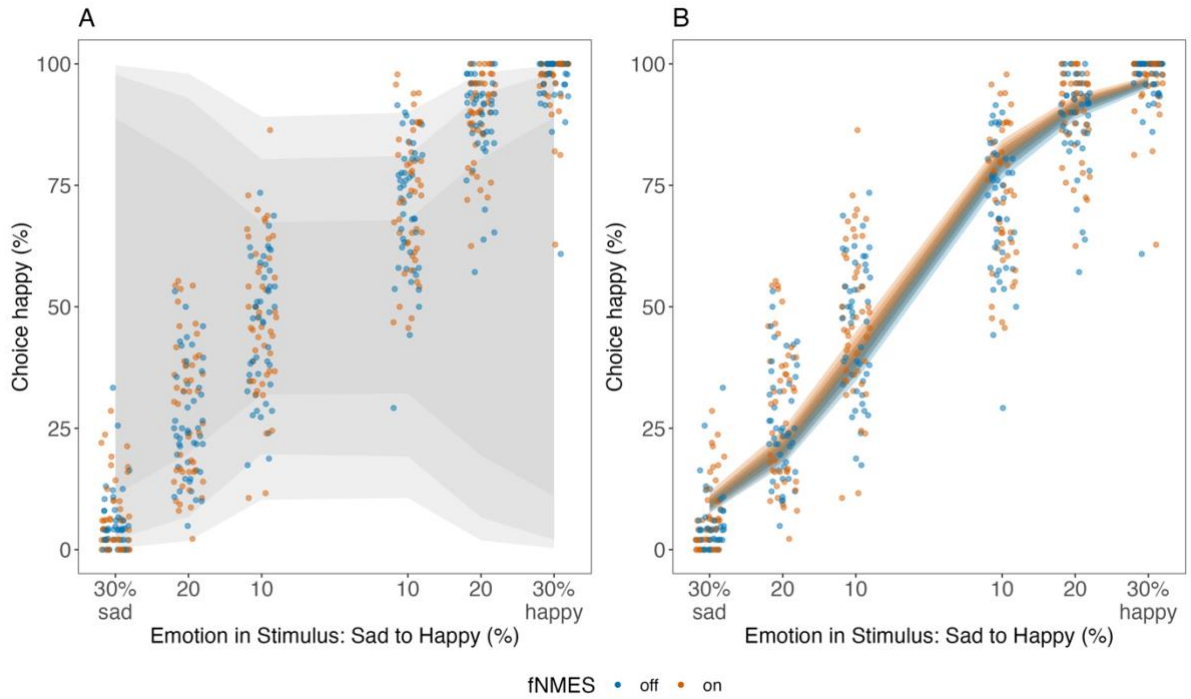
subscale from the MAIA was also significant (β = -0.20, *z* = 2.13, 95% CI [-0.38, 0.02], *SE* = 0.10, *p* = .033). This means that participants who were more in tune with unpleasant bodily sensations were more likely to categorise the face as happy, while participants who tended to ignore or distract from sensations of discomfort were less likely to do so. All other covariates were not significant (all *ps* > .130; Supplementary material B and C).

A second pre-registered model also included the fixed effect Ambiguity, where 30, 20, and 10% emotion intensity were coded as 0, .5, and 1 ambiguity. The model (conditional $R^2$ = .60, marginal $R^2$ =.56) revealed a main effect of Emotion (β = 1.09, *z* = 55.85, *SE* = 0.02, 95% CI [1.06, 1.14], *p* < .001) and an Ambiguity by Emotion interaction (β = -0.54, *z* = 18.58, *SE* = 0.03, 95% CI [-0.59, -0.48], *p* < .001). All other main and interaction effects, including the fNMES by Ambiguity interaction of interest, were not statistically significant (all βs < 0.09, all *ps* > .240).

Finally, we conducted a Bayesian GLMM analysis (not pre-registered), comparing two models. The full model on the response variable Choice (happy, sad) included the predictors fNMES, Emotion, and their interaction (formula: Choice ~ 0 + fNMES + fNMES:Emotion). A reduced model did not include fNMES (formula: Choice ~ Emotion). Both models included a random intercept for the grouping effect of participants (formula: 0 + fNMES + fNMES:Emotion | participant) and were fitted using the brm function from the brm package (Bürkner, 2017). We used weakly informative priors assigned to the fNMES conditions, with a prior distribution of normal (0, 0.5) indicating the effects were centred around zero with moderate uncertainty. To capture the interaction effect between fNMES and emotion, the coefficients were assigned normal priors of normal (0, 1). These priors indicate a belief that the interaction effects are centred around zero, with a higher uncertainty compared to the main effects (see Figure 22).

**Figure 22**

*Prior and posterior predictions for the group-level effects of the Bayesian GLMM*




*Notes.* Prior and posterior predictions for the group-level effects of the Bayesian GLMM. Panel A represents the fixed effects, showing the percentage of choice happiness based on the percentage of emotion in the stimulus ranging from sad to happy. The points are colour-coded by fNMES, and the shaded ribbon represents the uncertainty of the estimates. Panel B visualises the posterior predictions, with the ribbon showing uncertainty in the estimate, and points display individual participants (jittered for visibility).

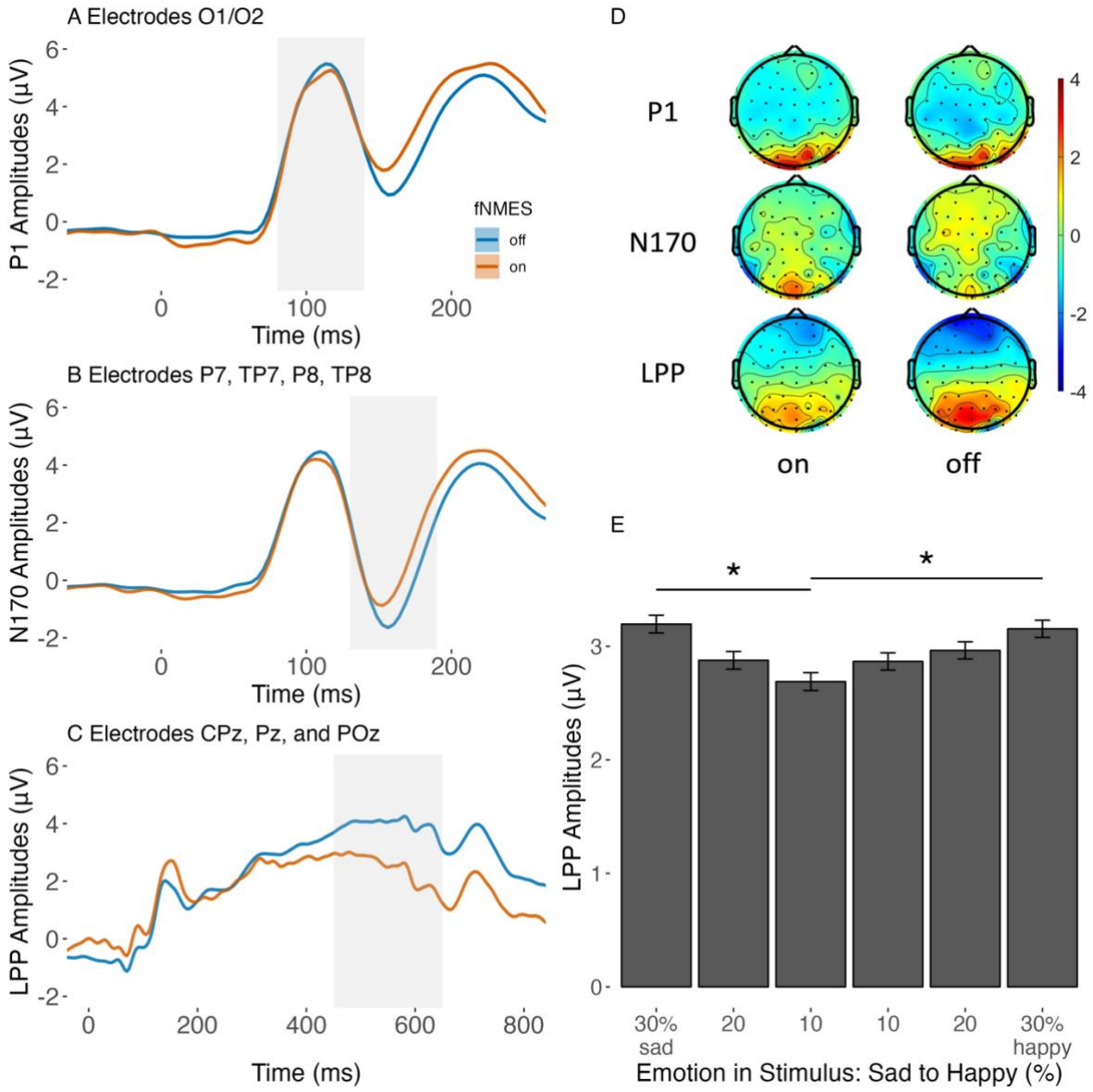
Model comparison was based on the computation of Leave-One-Out (LOO) and Widely Applicable Information Criterion (WAIC) weights. The LOO weights indicated the full model weight was .72, while the model without the effect of fNMES had a weight of .28. This suggests that the full model is favoured by the data, as it has a higher weight than the alternative model. Similarly, the WAIC weights also favoured the full model, with a weight of .72, compared to .28 for the model without the effect of fNMES. Overall, our Bayesian analysis indicated that the full model, which includes the effect of fNMES, is preferred by the data.

## 5.4.2 ERP analyses

For the P1 component (conditional $R^2$ = .92, marginal $R^2$ = .01), a statistically significant main effect of fNMES was found ($F$(1, 407) = 7.36, $p$ = .007), with larger amplitudes in the off ($M$ = 4.23, $SE$ = 0.46) compared to the on condition ($M$ = 4.02, $SE$ = 0.46). We did not observe significant effects of Emotion or fNMES by Emotion (all $Fs$ < 0.75 and all $ps$ > .586). The second model (conditional $R^2$ = .92, marginal $R^2$ of .01) on the N170 amplitude revealed a main effect of fNMES ($F$(1, 407) = 31.17, $p$ < .001), with larger negative amplitudes in the fNMES off ($M$ = -2.10, $SE$ = 0.46) compared to the on condition ($M$ = -1.66, $SE$ = 0.46). No other main or interaction effects were observed (all $Fs$ < 0.92 and all $ps$ > 0.47). For the late positive potential (LPP) (conditional $R^2$ = .76, marginal $R^2$ of .13) a significant main effect of fNMES was found ($F$(1, 407) = 231.84, $p$ < .001), with larger amplitudes in the off ($M$ = 3.60, $SE$ = 0.25) compared to the on condition ($M$ = 2.29, $SE$ = 0.25). A significant main effect of Emotion was also observed ($F$(5, 407) = 3.23, $p$ = .007). Bonferroni corrected posthoc comparisons revealed larger amplitudes for faces displaying 30% compared to 10% sadness ($t$(407) = 3.430, $p$ = .010, $M_{diff}$ = 0.51; 95% CI [0.22, 0.80]) and for faces displaying 30% happiness compared to 10% sadness ($t$(407) = 3.05, $p$ = .036, $M_{diff}$ = -0.45; 95% CI [-0.75 -0.16]). The interaction term was not statistically significant ($F$(5, 407) = 0.09, $p$ = .993). Figure 23 shows each ERP component's time series, topographies, and the main effect of emotion on the LPP component.

**Figure 23**

*Figures of ERP components*



*Note.* Panel (A) shows the time series of the ERP for the P1 component (80-140 ms), panel (B) shows the time series of the ERP for the N170 component (130-190 ms), and panel (C) shows the time series of the ERP for the LPP component (450-650 ms). The shaded grey area in each panel indicates the time region used for statistical analysis. Overall, after subtracting the fNMES-only trials, we observed a reduction in amplitude for all three components during fNMES on relative to fNMES off. Panel (D) shows the topography of each ERP component for its respective time, shaded in grey. Panel (E) shows the main effect of emotion on LPP amplitude and error bars show the standard error. * < .05.

## 5.5 Discussion

Whether the state of activation/relaxation of facial muscles can affect the visual perception and recognition of emotional faces remains debated (Hess & Fischer, 2014; Wood, Rychlowska, et al., 2016). Advancing on that debate might require using methods that allow modulating facial feedback with great precision, such as computer-controlled fNMES (Efthimiou et al., 2023). Promising results of fNMES' ability to modulate participants' felt emotions and mood have been reported (Zariffa et al., 2014; Kapadia et al., 2019; Warren, 2021). It remains unknown, however, if the activation of specific facial muscles with fNMES can modulate the recognition of others' facial expressions. We hypothesised that inducing a short and weak smile, by applying fNMES to the bilateral ZM muscle at the face onset and for 500 ms, would change face perception (measured with ERPs) and increase the likelihood of categorising emotionally ambiguous faces as happy.

Our main hypothesis was confirmed, as we demonstrated that by selectively engaging the ZM muscle through fNMES at stimulus onset, and for just 500ms, we can change the way people perceive facial expressions – making them see emotionally ambiguous faces as happy (or at least as more happy than sad). This is a uniquely novel result, which aligns with prior research demonstrating the impact of facial muscle activity on facial emotion perception (Achaibou et al., 2008; Korb et al., 2014; Kuehne et al., 2021; Sel et al., 2015).

We found that induction of a weak smile through fNMES leads to an increase of 2% (ß = 0.09) in the chance to categorise an ambiguous face as happy. This can be considered a small effect, which however stayed significant when statistically controlling for individual differences in positive or negative affective state, autistic traits, empathy, interoceptive awareness, and discomfort. A small effect was moreover expected based on the literature (Coles et al., 2019), and statistical power was computed accordingly, as detailed in the pre-registration. Nevertheless, these findings should be considered as preliminary evidence, as this is the first study to investigate the influence of fNMES on the processing of emotional facial expressions, and Bayesian results were not entirely conclusive.

To investigate the potential influence of affective priming, participants' affective states were assessed using the PANAS at both the start and end of the experiment. No statistically significant differences were observed between pre- and post-experiment PANAS scores, indicating no overall changes in affect after receiving fNMES to the ZM throughout many trials. Furthermore, recent research by Bulnes et al. (2023) sheds light on the drivers of facial feedback effects on face perception, specifically whether these effects emanate from motor matching or changes in affect. In their study, participants either mimicked observed facial expressions of happiness and anger or imagined experiencing the emotions conveyed by the facial expressions. The findings revealed that face imitation resulted in immediate changes in emotion recognition, whereas the group that imagined feeling the observed expression performed similarly to the control group. However, the group that imagined feeling the observed emotions exhibited improved performance on a subsequent emotion detection task administered at a later point in time. These findings suggest that both interventions exhibit task- and time-specific effects on emotion processing, with the imitation of observed facial expressions providing an immediate effect, while later effects are due to the imagining of the feelings. In our task, emotion categorisation was assessed immediately after facial muscle

stimulation, indicating that the induced bias is, speculatively, driven by motor matching rather than changes in affect.

Results from the ERP data indicated significantly smaller P1, N170, and LPP components during fNMES. A speculative explanation for this finding is that the fNMES-induced activation of smiling muscles shifted the relative weights of visual and proprioceptive processing: turning up the signal coming from facial muscles could reduce the visual system's workload in discerning facial details (Achaibou et al., 2008). Thus, the reduction in amplitude across all visual components may be attributed to the central nervous system prioritising the processing of proprioceptive signals induced by fNMES to the ZM. That is, visual processing is dampened given an alternative sensory input that might aid in resolving the ambiguous facial expression. This is also in line with recent work showing that mu desynchronisation to emotional faces – considered to reflect the engagement of the mirror neuron system – is reduced when participants hold a pen in their mouth (Birch-Hurst et al., 2022).

We also found a main effect of emotion on the LPP, with larger amplitudes when the faces were less ambiguous. This finding aligns well with previous research showing that this period is when the resolution of emotional ambiguity occurs (Calvo et al., 2013). No main effect of emotion was found for the P1 and N170 components, which is likely due to our stimulus set consisting of highly ambiguous facial expressions, which the early components are less sensitive to (Eimer, 2011; Hietanen & Astikainen, 2013). Moreover, the literature is mixed on whether P1 and N170 amplitudes are modulated by emotional expressions or not (Achaibou et al., 2008; Sel et al., 2014).

Notably, our facial manipulation technique did not interact with the emotional content of the facial expressions, in contrast to previous studies utilising the pen-in-mouth technique that showed increased N170 amplitudes to facial expressions during smile production (Kuehne et al., 2021; Sel et al., 2015). Several factors may account for this discrepancy.

Firstly, our sample size was determined based on a power analysis for the main effect of fNMES in the categorisation choices, potentially leading to an underpowered EEG analysis and the inability to detect an interaction between fNMES and the emotional content of facial expressions. Secondly, our facial manipulation differed from previous studies, which utilised the pen-in-mouth technique, whereas our study was the first to incorporate fNMES alongside EEG. Consequently, the functional implications of the observed fNMES main effects on ERPs remain unclear. To gain further insights into this phenomenon, future research should investigate the effects of stimulating different facial muscles, such as the *depressor anguli oris* or *corrugator* muscles, on visual processing.

This research contributes to the emerging field of fNMES applications in manipulating facial expressions and sheds light on the potential influence of subtle facial muscle stimulation on visual perception. Our behavioural findings have positive implications for facial feedback interventions that utilise posing as a method to reduce or manage distress (Ansfield, 2007) and address symptoms of depression (Finzi & Rosenthal, 2014, 2016; Fromage, 2018). Over-the-counter electrical stimulation devices, commonly used for pain management in the face, body, and craniofacial disorders (Efthimiou et al., 2023), may be harnessed to assist individuals with conditions that impede facial feedback, such as Bell's Palsy (Alakram & Puckree, 2010), Moebius syndrome (Stefani et al., 2019), and Parkinson's disease (Argaud et al., 2018). Furthermore, this technique holds promise for future research that can investigate the time course of facial feedback effects, specifically examining whether stimulus-congruent facial feedback occurs only after early visual processing has been completed (Halberstadt et al., 2009; Niedenthal, 2007).

The present study has several limitations that should be acknowledged. First, we only targeted the ZM muscle (AU12) to induce a weak smile, while a prototypical expression of happiness is stronger and often involves the activation of the OO muscle (AU6). This limited

focus may partially explain the weak effect of fNMES on categorisation choices observed in our study. Future research should explore the impact of targeting both AU12 and AU6 to induce a more robust effect of fNMES on emotional perception (although small changes in AU6 activity were observed during fNMES targeting the ZM, see Figure 20).

Second, our study was limited to investigating the effect of fNMES on positive facial expressions (smiling), while the impact of fNMES on negative expressions (frowning) remains unknown. Future research should explore whether fNMES can modulate the processing of negative emotions and how this effect may differ from that observed for positive emotions. Similarly, the absence of a non-face control condition limits our ability to definitively determine whether the observed effects are primarily driven by changes in felt emotion or motor matching. Future research incorporating a non-face control condition, such as neutral objects or non-facial stimuli, could help clarify this distinction especially as they do not induce spontaneous mimicry. If the effects are primarily attributed to changes in felt emotion, then these effects should be observed even in response to non-face stimuli, as the motor feedback from facial expressions would still be present. However, if the effects are primarily driven by motor matching mechanisms, then they would be specific to facial stimuli, as the motor feedback would only be relevant in the context of faces.

Third, it cannot be entirely ruled out, at this stage, that the main fNMES effect on the P1, N170, and LPP components is not at least partly due to our data treatment. Indeed, to remove somatosensory evoked potentials affecting central electrodes but possibly also occipitotemporal areas, brain activity during fNMES-only trials was subtracted from that during the trials including both fNMES and face presentation. The same correction was not applied to fNMES off trials, which did not contain somatosensory evoked activity. A potential way to overcome this problem is to compute difference scores between emotion levels (30% vs. 10%) and compare them across fNMES conditions. This approach did not result in

differences between fNMES conditions (see Supplementary material D), possibly due to the use of weak emotional expressions.

Finally, our study only administered fNMES at face onset and did not investigate the impact of altering the timing of fNMES delivery relative to the stimulus, which can be seen as a limitation. We focused on a single time point for fNMES stimulation to enhance statistical power and provide a first proof-of-concept for fNMES influence on visual perception. Future research should, however, attempt to investigate the effects of fNMES delivery at different time points during facial processing. For example, Pitcher et al. (2008) investigated the role of the visual and somatosensory cortex in facial emotion discrimination by delivering transcranial magnetic stimulation (TMS) in seven-time windows covering the time from 20 to 290 ms after the onset of an emotional face. The authors showed that emotion discrimination accuracy was only reduced after early (60 to 100 ms after face onset) inhibition of the right occipital face area, and somewhat later (100 to 170 ms) inhibition of the right somatosensory cortex. Our fNMES delivery period covered (and exceeded) these ranges but does not inform us when fNMES should best be delivered. It might even be that the effects of proprioceptive facial feedback on facial emotion recognition are more pronounced when fNMES is delivered later than the time window targeted here. Indeed, when shown emotional faces participants typically react by imitating them, but in the EMG signal the earliest occurrence of facial mimicry is around 200-300ms after stimulus onset (Achaibou et al., 2008; Korb et al., 2014) and a frequent finding is that facial mimicry becomes statistically significant even later than that, from 500 ms onwards (Dimberg, 1988). Therefore, delivering fNMES at 500 ms might prove even more effective, and in any case, could provide further insights into the temporal dynamics of facial feedback's influence on emotion recognition.

In conclusion, our study provides the first demonstration that providing controlled weak electrical stimulation to specific facial muscles, at a precise time and for a precise short

duration of 500ms, can shape how ambiguous facial expressions are perceived. This finding supports the notion that facial muscle activity and the processing of affect are inherently linked and have potential implications for the treatment of affective disorders, and the study of embodied cognitive processing.

## 5.6 Summary

In Chapter 5 of my PhD thesis, I explored how facial feedback influenced facial emotion recognition, specifically using fNMES to activate the ZM muscle. Compared to previous techniques such as voluntary posing or using a pen-in-mouth, this method offered more precise control over muscle activation in both time and space, enabling the study of how facial muscle activity influences facial emotion recognition.

For this pre-registered EEG experiment, 47 participants were included, determined based on a power analysis. Participants received brief (500 ms) 70Hz biphasic waveform fNMES to the ZM muscle at the onset of an ambiguous facial expression. The facial expression was categorised as happy or sad at a 500 ms presentation.

It was found that fNMES-induced smiling increased the probability of an ambiguous facial expression being categorised as happy compared to sad, suggesting that fNMES-induced facial feedback could bias facial emotion recognition. Furthermore, the results showed significant effects of fNMES on early visual processing of emotional stimuli, as measured by ERPs. Specifically, fNMES resulted in a reduction of P100, N170, and LPP amplitudes, suggesting that the activation of facial muscles through fNMES modulated the neural correlates of face processing.

The findings indicated that the state of facial muscles could affect the perception and recognition of emotional faces. By inducing a short, weak smile through fNMES, a change was observed in how people perceive facial expressions, making them see ambiguous faces as

happier. This aligned with previous research demonstrating the impact of facial muscle activity on facial emotion perception. The observed reduction in amplitude across all visual components of the ERPs suggested that the central nervous system might prioritize the processing of somatosensory signals over visual details when facial muscles are activated.

This research contributed to the field of facial feedback interventions and highlighted the potential of using fNMES as a tool in clinical and research settings. For instance, electrical stimulation devices commonly used for pain management could be employed to assist individuals with conditions impeding facial feedback. Additionally, the findings underscored the importance of considering the timing and nature of facial feedback effects in cognitive processing.

However, the study had limitations, including the focus on only the ZM muscle and the use of weak emotional expressions. Future research should explore the effects of stimulating different facial muscles and investigate whether fNMES can modulate the processing of negative emotions. Also, the timing of fNMES delivery relative to stimulus onset could be varied in future studies to understand the optimal period to deliver fNMES.

In summary, this chapter provided evidence that controlled electrical stimulation of specific facial muscles could shape the perception of facial expressions, supporting the link between facial muscle activity and the processing of affect. This has potential implications for treating affective disorders and studying embodied cognitive processing.

# 6 General Discussion and Conclusion

Chapter 1 introduced the premise that the FFH serves as a valid framework to explain how our facial expressions possess the capacity to exert influence over our emotional experiences and judgements. The FFH posits that the feedback loop between our facial muscles and brain can modify our emotional experience and judgements (Coles et al., 2019b; McIntosh, 1996). For instance, the act of smiling may elicit feelings of happiness, while adopting a frown can evoke a sense of sadness. Moreover, Chapter 1 asserted that the prevailing techniques for manipulating facial muscles are suboptimal for investigating the FFH. These traditional methodologies come with several limitations. For example, methods like the pen-in-mouth technique inadvertently recruit unrelated muscles, such as masticatory muscles, due to jaw clenching. Posing poses its challenges, as some participants might be unable to engage specific muscles. Furthermore, these approaches lack temporal precision, meaning muscle engagement may not synchronise adequately with a stimulus. Lastly, they do not provide accurate control over the muscle engagement activity to examine the strength of the expression of the outcome of interest.

To improve the researcher's ability to test the FFH, this thesis advocated for the adoption of fNMES as a more dependable approach to manipulating facial muscles. fNMES, characterised by its non-invasive nature, employs low-intensity electrical currents to activate facial muscles, thereby facilitating the induction of precise muscle contractions at different intensities and with temporal accuracy and flexibility. The empirical evidence collected as part of this thesis suggests that fNMES can successfully be used to modulate both felt (Chapter 3) and perceived (Chapter 4) emotion, while controlling for various psychological

factors, such as participants' traits of autism, empathy, alexithymia, and interoceptive awareness.

In this final chapter, I shall summarise the systematic review paper (Chapter 2), as well as scrutinise the extent to which each of the empirical experiments lends support to or challenges the hypothesis that fNMES can effectively induce facial feedback effects and test the tenets of the FFH. Furthermore, I shall explore how the findings from these experiments may contribute to the existing body of literature. It is essential in any academic pursuit to acknowledge the limitations of one's work. I will therefore incorporate into this concluding chapter a thoughtful consideration of the limitations of my work. To cap the discussion, I shall offer a new conceptual framework for understanding the functioning of fNMES in relation to the FFH, while also offering recommendations for future avenues of research.

## 6.1 Systematic review (Chapter 2)

The paper presented in Chapter 2 (Efthimiou et al., 2023c) describes a systematic review of the current body of literature across various fields that have utilised the application of electrical currents to the human face through surface electrodes, with a focus on the stimulation parameters and safety limits (i.e., the current density not exceeding RMS 2 $mA/cm^2$). The end goal was to introduce the psychological research community to the parameters and safety considerations for the application of fNMES. Indeed, while several NMES reviews and guides exist (Carson & Buick, 2019; Doucet et al., 2012; Maffiuletti, 2010; Peckham & Knutson, 2005), these do not incorporate the face, and therefore to my knowledge, this is the first systematic review of the literature in which NMES was applied to the face.

The systematic review offers comprehensive guidelines for researchers seeking to implement fNMES. These guidelines encompass the selection of stimulation devices, electrode placement, and optimal positioning relative to key muscle groups. Moreover, the

review provides insights into crucial parameters, including pulse width, waveform, and frequency, along with essential safety considerations. To further assist researchers in this endeavour, we provide a Shiny app capable of calculating current density based on these parameters. In addition, we summarised the results of a systematic review of the existing literature on this topic.

The systematic review of the literature retained 136 manuscripts and found that the most frequent use of fNMES was for pain relief, followed by facial paralysis recovery. Only three studies (2.20%) investigated the use of fNMES within the context of emotion modulation (Goto et al., 2018; Kapadia et al., 2019; Zariffa et al., 2014), which supports the need for further exploration of fNMES within this context. Interestingly, the face areas being stimulated varied widely, with combinations of upper, middle, and lower facial regions. This is promising for future work, as it indicates that any facial expressions can be generated with correct stimulation parameter tuning. However, most of the published papers did not provide sufficient information about their utilised stimulation parameters – this was an unfortunate realisation of this systematic review. However, this was not entirely surprising, as other researchers had also noted this issue (Maffiuletti, 2010). Current density calculations were feasible for only 8 of the 136 articles reviewed, presenting a significant yet inescapable restriction of our work. Consequently, this gives researchers an incomplete picture of the range of current densities applied across different muscles, complicating their ability to incorporate this information into their experimental designs.

Thus, Chapter 2 echoes the sentiment of previous papers (Maffiuletti, 2010; Pfeiffer et al., 2016), advocating for improved parameter reporting. The aim is to facilitate this by offering two user-friendly applications. Firstly, a Streamlit app (bitly.ws/UJNU) presents our review table complete with filters, highlighting key parameters, and enabling researchers to focus on their face area of interest. Secondly, a Shiny app (bit.ly/3lv78Z1) simplifies current

density calculations, encouraging researchers to align their parameters with safety guidelines and ensuring the inclusion of safety criteria in their reports, as demonstrated in Chapters 4 and 5.

## 6.2 Experiment 1 (Chapter 3)

In experiment 1 (Efthimiou et al., 2022) participants were presented with two vignettes with high and low levels of information about fNMES and its associated risks. Participants rated the probability of participating in fNMES research at the different information levels. Additionally, participants' prior knowledge and experience with electrical stimulation, personality traits, propensity for risk-taking, body image, and their need for affect were measured, as they might help predict participants' likelihood of taking part. The survey concluded with an open-ended question allowing participants to voice their specific concerns.

This study was carried out to investigate the potential concerns that participants may have at the prospect of receiving fNMES. The application of electrical current to the body can pose certain risks (Kono et al., 2018), and participants may either be aware of these risks or have an intuition about them. More importantly, however, fNMES can evoke negative connotations in the general population that extend beyond these risks, such as the perception that it is painful or can cause skin burns. Indeed, in the open question of the survey facial nerve damage and pain were the most common concerns reported (see Table 2). Fortunately, there have not been any major issues reported when applying electrical currents to the face. To date, only Kavanagh et al. (2012b) reported side effects of skin irritation that however faded after 30 minutes.

This experiment was important for several reasons. First, it may be difficult to recruit people and retain participants who fear fNMES, thus it is important to address their potential concerns. Second, because the primary interest in this thesis was to use fNMES to modulate emotion, I wanted to make sure that participants arrive at the lab in as much of a neutral state

as possible, and are not experiencing strong fear, anxiety, or excitement at the prospect of receiving fNMES.

Overall, this study revealed that concerns about potential burns, pain, and loss of muscle control significantly influenced participants' decision to take part in a study utilising fNMES. When participants were provided with detailed information about the risks of fNMES, their willingness to participate slightly declined, especially with heightened awareness of risks like burns and involuntary muscle movements. Although, men expressed fewer concerns than women did, notably about pain, these differences did not influence their overall willingness to join such studies. Moreover, factors like an individual's prior knowledge of electrical stimulation and their inherent propensity to worry about discomfort played a more substantial role in their decision-making than demographics. Despite these concerns, most participants still expressed a general willingness to participate in facial fNMES studies, suggesting the importance of adequately addressing potential risks and offering reassurance when recruiting for such research.

## 6.3 Experiment 2 (Chapter 4)

Experiment 2 (Efthimiou et al., 2023b) examined whether facial expressions of happiness and sadness, induced by fNMES, could influence, and modulate self-reported emotional experiences, both in the presence and absence of a (emotionally congruent) visual stimulus. Additionally, the study investigated if these fNMES-induced expressions elicited physiological changes in HR and EDA. While past experiments have indicated that manipulating facial expressions can shape emotional experiences, there have also been recent replication failures (see ‘Chapter 1: Debates about the FFH’). Even though fNMES has been employed in prior research within this domain, there are discernible methodological gaps. As a remedy, we used a straightforward test of the FFH recently developed by a diverse team of international collaborators, including both proponents and sceptics of the FFH (Coles et al.,

2022, 2023). Additionally, their data was made publicly available, enabling me to conduct simulation-based power analyses. By adhering to their methodology, we hoped to obtain the most reliable evaluation of the capacity of fNMES-induced expressions to reshape emotional experiences, especially given the consensus around this paradigm and the novelty of the fNMES technique.

The behavioural outcomes from our experiment affirmed that fNMES-induced expressions can indeed trigger associated emotions (happiness and sadness), even in the absence of a visual stimulus, aligning with the initiation principle of the FFH. This finding is remarkable as the notion that producing a facial expression can initiate an emotional feeling has been a point of strong debate (Cannon, 1927; Coles et al., 2019b). The findings were less clear; however, when emotional pictures were shown at the same time as fNMES was applied. This is because the emotional content of the image was the primary driver of the changes in self-reported valence. This may be ascribed to a design oversight because we chose not to include positive images in the DAO muscle activation conditions and excluded negative images in the ZM muscle activation scenarios to save time and limit the frequency of fNMES delivery. Although previous research, such as that by Warren (2021), has demonstrated that fNMES can modulate ongoing emotional states, these findings need further confirmation. Nevertheless, the potential use of fNMES in FFH research remains intriguing. A particularly compelling question is whether fNMES-induced facial expressions can influence emotional reactions to dynamic content such as videos and audio recordings, as earlier FFH research has shown. (Flack, 2006; Marmolejo-Ramos et al., 2020).

In terms of physiological responses, no significant changes were detected in HR and SCL. For SCR and HR trial-wise, we observed larger responses at the highest intensities of fNMES, driven by the startle response (as predicted). Furthermore, for SCR, a main effect of muscle was observed with larger responses in the ZM block but no changes in HR, contrary to

the literature (Ekman et al., 1983; Kraft & Pressman, 2012; L. Fredrickson & Levenson, 1998; Pressman et al., 2021). The blocks were counterbalanced, so the observed differences cannot be attributed to the order of blocks. Rather, these differences are possibly a result of the cumulative effect of ZM muscle stimulation over multiple trials. However, it is difficult to disentangle this as it could also, speculatively, be the electrodes over the muscle inducing feedback from the skin. Thereby, explaining the same —but smaller— effect in the off condition. Overall, the observation aligns with existing research, which suggests that emotions such as happiness and relaxation typically, result in more pronounced changes (Kreibig, 2010).

What was not observed was an interaction between muscle activity and the intensity of fNMES, which would have suggested that the effects on SCR are more significant when complete facial expressions are induced. A recent study by Pressman et al. (2021) investigated Duchenne smiles and grimacing on self-reported pain, HR, and EDA. Their findings may provide insight into why we did not observe changes. In their study, the largest changes in HR and EDA changes were in the Duchenne smile group, as noted previously, this involves the ZM and OO muscles. In the experiment, only the ZM muscle was stimulated, which may have caused the effect on physiology by the muscle to be too weak to detect. A second potential reason for the lack of changes by muscle by intensity (an interaction) in SCR could be that the intensity of the stimulation overshadowed its effects. In experiment 4, it was anticipated that such an interaction with muscle activity would lead to a more pronounced reduction in DAO when stimulated at 100% of MT. Nevertheless, the level of discomfort experienced may have been sufficient to negate any discernible differences that might have been caused by variations in expression.

In Experiment 2, it was shown that expressions induced by fNMES can trigger emotional states without the presence of an external emotional stimulus, which is in line with

FFH. However, the results regarding the extent to which fNMES can modulate emotions already elicited by a stimulus were less definitive. Additionally, the impact of fNMES on physiological modulation remained inconclusive.

## 6.4 Experiment 3 (Chapter 5)

Experiment 3 (Efthimiou et al., 2023a) investigated whether fNMES-induced smiling could alter how individuals perceive ambiguous facial expressions of happiness or sadness. Numerous studies have explored the facial feedback effect, examining its impact on the interpretation of facial expressions (see 'Chapter 1.4.1 Activation Studies'). However, this is the first of its kind, using fNMES to contract the muscle in synchrony with the onset of the picture of an emotional face on the screen, overcoming the weaknesses of previous research, as highlighted in Chapter 1. Furthermore, we explored whether these behavioural changes corresponded with neural changes since early visual processing is influenced by facial feedback and face stimuli. We delved into the neural underpinnings of these effects by ERPs, specifically focusing on the P100, N170, and LPP components.

In this experiment, a main effect of fNMES was found; participants exhibited an increased likelihood of categorising an ambiguous facial expression as happy when smiling was induced with fNMES, as opposed to when no fNMES was administered. This finding suggests that fNMES-induced smiles can indeed influence the perception of an ambiguous facial expressions. The ERP analysis revealed a decrease in all components during fNMES-induced smiling compared to when there was no fNMES delivered. Further, the emotional content of the facial expressions did not modulate the components.

Collectively, these findings shed light on how the activation of specific facial muscles through fNMES can influence the interpretation of ambiguous emotional facial expressions, making them appear happier. This study underscores the capacity of facial muscle activity to

shape the perception of emotional stimuli and validates fNMES as a valuable tool for investigating facial feedback effects.

## 6.5 General discussion and contributions

FNMES is not new, and this thesis is indebted to the efforts of Duchenne de Boulogne. Yet, as Chapter 2 illustrates, fNMES has been utilised to a surprisingly and regrettably limited extent within the field of psychological research. The underuse of fNMES can be attributed to various factors. Throughout the presentation of this research at conferences, colleagues have shown excitement about the work but have also voiced concerns about inducing pain. Therefore, Chapter 2 is dedicated to establishing clear, practical guidelines for those researchers who are intrigued by fNMES but hesitant about its application due to safety concerns. As explored in the section titled ‘6.6 Limitations and Future Directions’, it is not feasible to prescribe a one-size-fits-all set of parameters for all potential uses of fNMES. Nevertheless, it is hoped that by calculating current density as a standardised unit, researchers will be able to systematically compare parameters and assess comfort levels across different facial areas.

Building on the issues raised by researchers, as well as my reservations, an online experiment was conducted (see Chapter 3) before employing fNMES in the laboratory. This preliminary study explored the apprehensions of participants and examined possible mitigating factors (e.g., personality), including their familiarity and previous encounters with fNMES, and whether concerns differed between male and female participants. Overall, burns and loss of muscle control were the main concerns, which reduced participants' willingness to participate in fNMES research. To mitigate these risks and alleviate potential fears, we have implemented stringent safety protocols, including thorough pre-experiment testing for skin sensitivity, careful control of electrical current levels, and continuous monitoring throughout

the session. Furthermore, detailed explanations of the procedures and safety measures were provided to participants before the study to ensure they felt informed and secure.

In the subsequent section, I will discuss the overlapping elements of experiments 2 and 3 from my research. These experiments shed light on how facial expressions influence emotions and how we perceive them. Both experiments confirmed that fNMES can effectively stimulate the muscles associated with specific facial expressions, specifically activating the ZM muscle associated with smiling, known as AU12, which involves the raising of the corners of the mouth. Similarly, the stimulation of the DAO, referred to as AU15 was observed, which involves the pulling down of the lip corners, typically associated with expressions of sadness. However, it was noticed that the strength of the feedback from these facial actions did not change in proportion to the muscle activity levels. This may suggest a shortcoming in the automated FACS analysis using OpenFace (Baltrusaitis et al., 2018). As shown in Figure 16, the algorithm used for FACS showed a tendency for inconsistent ratings. The DAO muscle's actions were undervalued relative to the ZM muscle. Yet, when benchmarked against FaceReader (Noldus, 2014), another FACS coding tool, this trend was reversed, pointing to a potential algorithmic bias towards certain AUs. To enhance the reliability of our findings, future research replicating this study with integrated EMG as a measure of muscle activity would be a more precise measure of muscle activity. This would help confirm the effects, assuming any signal interference caused by fNMES can be effectively mitigated.

Another area of consideration is the underlying explanation for the results of Experiment 4, that participants showed a bias to happy faces when fNMES-induced a smile. It was suggested that the ability to recognise happiness was due to a simulation process, meaning that recognition occurred because the expressions matched the observed face. In Experiment 3 it was demonstrated that fNMES-induced expressions could generate changes

in emotional experience. Yet, the precise cause of these phenomena is unclear. The question is whether participants lean towards happy expressions because they experience a surge of happiness themselves or because of a congruence between their expression and the facial expression presented.

Indeed, clarifying this difference is still ongoing work. A recent, unpublished study by Bulnes et al. (2023) had participants either imitate or mentally simulate the emotion corresponding to an observed static facial expression for 5–seconds and then categorise the emotion immediately afterwards. In a follow-up task, participants watched videos that gradually transitioned from neutral expressions to those displaying anger or happiness, responding as soon as they perceived the change and identifying the expressed emotion. The authors report that in the first task, the imitation group had higher accuracy scores in recognising anger, but not happiness, in the static facial expressions. However, in the second task with dynamic facial expressions, the imitation group was slower to identify happiness and self-reported lower confidence in their judgment when determining the expressions of anger. Conversely, the mental simulation group was quicker but less accurate in anger detection, hinting at a possible speed-accuracy trade-off. The intervention's benefits were time-bound, with the imitation group performance being restricted in the first task but not the second, and the mental simulation group having reduced performance in the second task. Relating this to the experiments in this thesis, experiment 4 had a structure comparable to the imitation task, with participants judging the faces immediately after simulating a smile, suggesting the differences were due to simulation rather than actual feelings of happiness. Moreover, as our presentation period was a brief 500 ms compared to 5000 ms, it may not have allowed enough time for it to manifest as an emotional experience of happiness, which may take seconds to minutes. Indeed, in Experiment 4, I compared emotional states using the PANAS and found no differences between pre- and post-task measurements.

### 6.5.1 Assessing the Significance of Effect Sizes in Research Outcomes

The magnitude of the effects obtained in Chapters 4 and 5 can be considered small. On one hand, these effects and their magnitude are consistent with the literature (Coles et al., 2019b), while on the other hand, the question arises whether small effects justify the resources expended. This consideration is crucial when deliberating the merits of new research techniques and paradigms. Recently, it has been recognised that small effect sizes can be valuable (Funder & Ozer, 2019; Götz et al., 2022). Citing Götz et al. (2022) proposal that small effects have merit, does not serve as a justification for all small effect sizes but rather as a conversation starter on their potential significance (Primbs et al., 2023). Instead, as suggested by Primbs et al. (2023) the real-world importance of these small effects should be considered. Additionally, Anvari et al. (2023) emphasises the need to examine elements that may strengthen or weaken the effects of interest. Thus, it is crucial to understand, however, that these small effects observed with facial feedback should not undermine the potential applications and value of this research. The size of an effect should be interpreted in context; even a minor improvement can be a beacon of progress, particularly in a field grappling with replication challenges and in the early stages of employing novel techniques such as fNMES.

One potential method to enhance these effects is through repeated exposure; while the lab experiments in Chapters 3 and 4 focused on single sessions of fNMES, it is plausible that repeated sessions could result in more durable benefits. This is supported by Kapadia et al. (2019), who found that multiple fNMES sessions helped reduce depressive symptoms, suggesting that small effects can accumulate into significant improvements through consistent use. Secondly, fNMES may have a more pronounced benefit for individuals with certain neurological conditions or emotional dysregulation disorders (amplification through interaction). For example, patients with facial paralysis or MBS may experience greater benefits due to their lack of spontaneous facial mimicry—a deficit that fNMES can help

address. When these effects are evaluated on a broad scale, they might appear negligible but could be quite profound for these subgroups (counteraction through interaction). A final scenario of amplification, based on one of the key strengths of fNMES, is the timing of delivery. Spontaneous facial mimicry occurs at approximately 300 ms after stimulus onset (Dimberg, 1988; Dimberg et al., 2000), and in these experiments, the period of fNMES overlaps this. There may be a period in which is more optimal to stimulate as demonstrated by the strongest EMG activity produced at 500 ms for the ZM muscle during the observation of faces (Korb, 2010), thus one may speculate if the onset was in synchrony with that peak activity effects may be strengthened.

On the other hand, there may have been counteracting mechanisms in the laboratory experiments. As with other stimuli, individuals might become habituated to fNMES over time. If the stimulation is repeated frequently (i.e., multiple trials), the novelty of the sensation can diminish, leading to a reduced neuromuscular response, and a potentially smaller impact on emotional experience and recognition. Furthermore, some individuals might psychologically or physically resist muscle movements induced by fNMES, which could manifest in less cooperative behaviour during the stimulation or a conscious or subconscious resistance to the treatment, diminishing its effectiveness. As highlighted in Chapter 2, one of the primary concerns expressed in the online experiment was the induction of involuntary facial movements. A final counteracting mechanism may have been the presence of a webcam. The primary reason for incorporating webcams was to monitor participants for their safety and to verify the proper placement of the electrodes during the session and for FACS coding. However, existing literature indicates that the visible presence of a camera can mask typical facial feedback effects (Noah et al., 2018).

In sum, the small effects we report should be viewed not as limitations but as stepping stones that demonstrate the nuanced ways in which fNMES can be leveraged, especially when

tailored to the needs of individual patients or specific research questions. I strongly believe that methodical testing is the bedrock of scientific advancement, particularly in the intricate domain of psychological research where small changes can have far-reaching implications.

## 6.6 Limitations and future directions

The application of fNMES within the field of psychology has remained relatively underexplored, leaving several important questions to be addressed in this section. Two primary aspects warrant examination: the technical aspects of fNMES and its potential role in psychological research.

From a technical standpoint, the experiments were limited to the stimulation of the DAO and ZM muscles, both situated in the lower face. However, a critical area deserving of investigation that is more extensive is the systematic exploration of the facial muscles that can be effectively stimulated. This approach is not unprecedented; Waller et al. (2008) conducted a similar inquiry for invasive facial electrical stimulation, where they methodically targeted each facial muscle, providing detailed descriptions of their ability to induce contractions and the associated sensations, such as levels of pain. In the context of fNMES, a parallel effort is essential to grant researchers a comprehensive understanding of which muscles can be effectively activated in concert to produce distinct facial expressions. Such an endeavour would provide invaluable insights into the potential for precision and specificity in manipulating facial expressions through fNMES.

Furthermore, the selection of stimulation parameters was a carefully considered process, drawing upon a blend of prior research findings and pragmatic considerations. These practical considerations encompassed the imperative need to avoid line noise and to minimise potential artefacts in our EEG setup. While the parameter choices were informed by a combination of existing knowledge, such as waveform shape, as investigated by Ilves et al. (2018), and the previously mentioned practical constraints, a consensus on several parameters

is yet to be reached. For instance, the frequency of stimulation plays a pivotal role in determining the smoothness and naturalness of the resulting muscle contractions. Excessively low frequencies can lead to jittery movements, while overly high frequencies may induce discomfort or even pain. Likewise, the pulse width, another crucial parameter, influences the comfort level during stimulation. The question of whether these parameters vary across different muscles remains an open and intriguing avenue of exploration. While one might assume that due to their small size, facial muscles could share parameters, recent anatomical research has revealed significant intra-variability among facial muscles (De Bonnecaze et al., 2019). Therefore, the goal for an optimal set of parameters, accounting for both the intricacies of specific muscles and the broader aim of achieving natural and smooth expressions, remains an ongoing challenge. Further research and refinement in this area can lead to the development of more precise and effective stimulation protocols, ultimately enhancing the utility of fNMES in psychological research.

We will now shift our focus to the application of fNMES in psychological research. It should be noted that experiments 2 and 3 employed relatively simple experimental designs deliberately, aiming to offer clear and robust tests of the FFH amidst the replication crisis, ensuring the strength and reliability of the results. Building on this groundwork, future research with more intricate designs can delve deeper into the nuances of fNMES.

Experiment 3 revealed that fNMES-induced smiling influenced the perception of ambiguous facial expressions. However, given that this was the first study of its kind, the experimental design had inherent limitations. Now that we have established the efficacy of fNMES in this context, there exists an opportunity for refining and optimising the design. One evident path forward involves the replication of the study with different facial expressions, or the recruitment of multiple facial muscles associated with distinct expressions. Expanding the

scope of this research in this manner can produce a more comprehensive understanding of how fNMES can be effectively employed to manipulate various aspects of facial expressions.

To fully harness the potential benefits of fNMES, researchers might consider incorporating multiple stimulation periods relative to the presentation of visual stimuli. For instance, investigating whether the effects become more pronounced when synchronised with the peak of spontaneous facial mimicry processes or determining if stimulation before visual stimuli (e.g., faces or bodies) might serve to prime participants, subsequently lowering the threshold for the perception of facial stimuli. By further exploring the temporal aspects of fNMES application, researchers can unlock a deeper understanding of its mechanisms and effects within the domain of psychological research.

## 6.7 Conclusions

To conclude, it is essential to contemplate the thesis' primary contributions to the scientific community and the broader knowledge landscape. My work began with examining facial manipulation techniques, emphasising their constraints while advocating for fNMES as a more advanced and effective tool for exploring facial feedback effects. Chapters 2 and 3 serve as a practical guide for researchers detailing how to utilise fNMES effectively, and what to watch out for when recruiting participants to overcome their potential concerns. The two lab-based experiments (Chapters 4 and 5) demonstrated that fNMES can be effectively applied in the laboratory testing human participants in two ways, to generate and influence an emotional experience, and to modulate facial emotion recognition in accordance with the FFH. In sum, this will provide researchers with the tools required to implement fNMES in their lab with the confidence that they can explore facial feedback effects.

This thesis introduced fNMES as a novel method of facial manipulation, primarily to explore the principles of the FFH. I conclude by advocating that fNMES can be effectively employed in a laboratory environment and is safe for human participants. Moreover, evidence

from two laboratory-based experiments supports the idea that fNMES-induced expressions can influence participants' behaviour, much like other facial manipulation techniques. However, fNMES offers the added advantages of precise timing and accurate targeting of specific muscles. While the neural and physiological correlates were not clearly established, this might be attributable to various factors. I hope this persuades the reader of the immense potential of fNMES in psychological research.

# 7 Appendices

## 7.1 Chapter 2

### 7.1.1 Appendix A Formulae for safety calculations

We here provide formulas relevant to fNMES, which can be used to determine safety parameters, as well as to compare across studies.

NMES can cause the underlying (skin) tissue to heat up, which can lead to discomfort, pain, and in extreme cases burning. Heat is dependent on current, resistance and time:

$$H = I^2Rt$$

Where H is the heat expressed in Joules [J], I is current in Amperes [A], R is resistance in Ohms [Ω], and t is time in seconds [s] (Kono et al., 2018).

The International Electrotechnical Commission (IEC) is an organisation devoted to the development of international standards for all electrical, electronic, and related technologies, which also provides safety guidelines for devices that apply electricity to the human body. To prevent skin burns, the standard IEC 60601-2-10 recommends that the maximal current density injected into the human body does not exceed RMS 2 mA/cm2, which considers the electrode size as measured in cm2.

RMS stands for Root Mean Square, which is, as its name indicates, the root of the mean of the squared waveform. The waveform can be considered in terms of voltage (V), or current (I). RMS is the effective value of V or I; it is usually associated with the power that a waveform transmits because the electrical power calculation is dependent on the square of either voltage or current and the resistance load:

$$P = I^2R = \frac{V^2}{R}$$

This power is measured in Watts [W]. In electronic systems, the resistance (R) is constant, and therefore the time variations in power depend only on the squares of the current or voltage waveforms. Nevertheless, calculating the impedance of the human body is challenging due to individual differences in anatomical features and changes in skin conductance due to environmental factors, such as room temperature. Therefore, one should be careful when estimating the power of NMES.

The RMS of a waveform can be calculated using different parameters. Since the IEC standard indicates the power of current applied per cm2, we will consider the waveform based on current, which can be instant or apparent. Instant current is the current at a certain point in time. Apparent current is calculated by considering a set of instant currents over a period.

O'Connor et al. (2020) proposed to calculate Irms of electrical stimulation as a function of instant current I, electrical pulse frequency (f), and phase duration (τ ) as follows:

$$I_{rms} = I\sqrt{2f\tau}$$

In this configuration, f is the pulse frequency (Hz) and τ includes the up and down phases of a biphasic pulse, as well as an inter-pulse interval in between. Importantly, O'Connor et al. (2020) counted the inter-pulse interval to the up phase, when it represented a period of zero charge (personal communication). When the inter-pulse interval is small, as was the case here, this difference is probably negligible. However, if the inter-pulse off period is large, the result of this calculation would be rather conservative. In other words, it would give a higher value than the true RMS.

For a more precise calculation, one should refer to the actual summation of all the instant currents over a period. This would be expressed as:

$$i_{rms} = \sqrt{\frac{\int_0^T i(t)^2\, dt}{T}}$$

Where i is the instant current, and T is the size of the window (i.e., the period) over which the RMS is calculated. Where i(t) is the instant current at a time t. T could be chosen as the cycle of one stimulation pulse plus its off period or as the duration of a train of stimulation pulses (e.g., with biphasic waveforms). For a discrete signal with sample frequency f, the integral can be replaced by the sum of the squares of individual instant current samples:

$$i_{rms} = \sqrt{\frac{\sum_0^T i(t)^2}{T}}$$

With this equation, the RMS of any waveform shape can be calculated. If the NMES current pulses are designed as a square signal in a canonical form, its apparent average can be calculated using the Pulse Width Modulation (PWM) method. Then, for a waveform in a cycle T the apparent current average is:

$$\mathrm{i_{average}} = \mathrm{D} * \mathrm{i_{max}}$$

Where D is the Duty Cycle calculated as the percentage of the time when the waveform is on. Since the waveform is in a canonical squared function, D is simply calculated as:

$$D = \frac{t_o n}{t_{cycle}}$$

To transform between the PWD iaverage and the Irms, the following formula should be used:

$$I_{rms} = \frac{1}{\sqrt{D}} i_{average}$$

Where $\frac{1}{\sqrt{D}}$ is the so-called form factor of the signal.

Finally, the irms can be divided by the electrode area to compare it to the 2 RMS mA/cm2 described by the safety guidelines (EN 60601-2-10:2000). Researchers would need to be careful not to inject more power than the specification.

The amount of current exerted over time represents the charge (Q), which is measured in Coulombs (C). The charge divided by (electrode) area is called charge density Dc, and it is usually reported in μC/cm2. Shannon (1992) defined a model that can be used to assess whether the charge injected into the skin per phase of the NMES waveform would be safe. This model is obtained by plotting charge per phase (μC/ph) vs. charge density per phase (μC/cm2/ph). The boundary of safe zones is defined by a constant (K), which is typically set to 1.5. Recommended values would fall below the line defined below (Shannon, 1992).

$$log(D_C) = k - log(Q)$$

Following these guidelines provides an initial account of safety. Nevertheless, we advise NMES researchers to proceed with caution, as it is challenging to account for all situations and individual differences such as gender and body mass. NMES should not be used before understanding all relevant safety issues.

# 7.2 Chapter 3:

## 7.2.1 Appendix B Vignette – low level of information

The first hypothetical study presented with minimal information about facial NMES.

"Imagine the following situation: You are invited to a research laboratory to take part in a paid (£10 per hour) psychological experiment about emotions. This study will use facial neuromuscular electrical stimulation, a safe and non-painful technique, to stimulate certain parts of your face with weak electrical impulses."

### 7.2.2 Appendix C Vignette – high level of information

Hypothetical study 2 with high levels of information about facial NMES and its' risks.

"PLEASE READ CAREFULLY, as you will have to answer questions based on the text below. We will now provide you with a more detailed description of what NMES is, and of how we plan to use it in a hypothetical, planned research experiment. What is NMES: Neuromuscular Electric Stimulation (NMES), also known as TENS (Transcutaneous Electrical Nerve Stimulation), has been used for some time, especially in the field of physiotherapy and rehabilitation, including in the face. NMES can be used to induce muscle contractions, as it simulates the natural activation of a muscle. How do we intend to use NMES: For the purpose of a planned experiment, four electrodes will be placed on your lower face. These are medically suitable, self-adhesive electrodes, which are disposed after each use. They are used for light electrical muscle stimulation, which takes place with medically certified and computer-controlled stimulators. You will receive NMES over specific facial muscles, mostly in short periods of approximately 1 second, and for a maximum total duration of 30 minutes. You will be compensated with £10 per hour. You are allowed to stop participating at any time. Side effects and Risks: Discomfort, Pain: Most of the time, facial NMES will feel like a slight, non-painful tingling sensation. However, it can sometime feel unpleasant, and occasionally induce brief painful sensations. The level of pain/discomfort depends on many factors, including individual differences in pain sensitivity. Marks, burns: The risk of getting skin burns exists, but is very low, as long as safety measures are followed, and stimulation limits are not exceeded. In some cases, however, light skin redness due to irritation can occur under the electrodes. This should disappear after few hours. Loss of control: Be aware that your muscles will move without you controlling it. Your facial muscles may also feel tight and tired at the end of the experiment. Although not a health risk, these phenomena can be unpleasant for some people. Other: For people with heart problems, a

pacemaker or other implantable heart device, NMES may be dangerous and is not recommended. It is also not recommended during pregnancy. PLEASE READ CAREFULLY, as you will have to answer questions based on the text above."

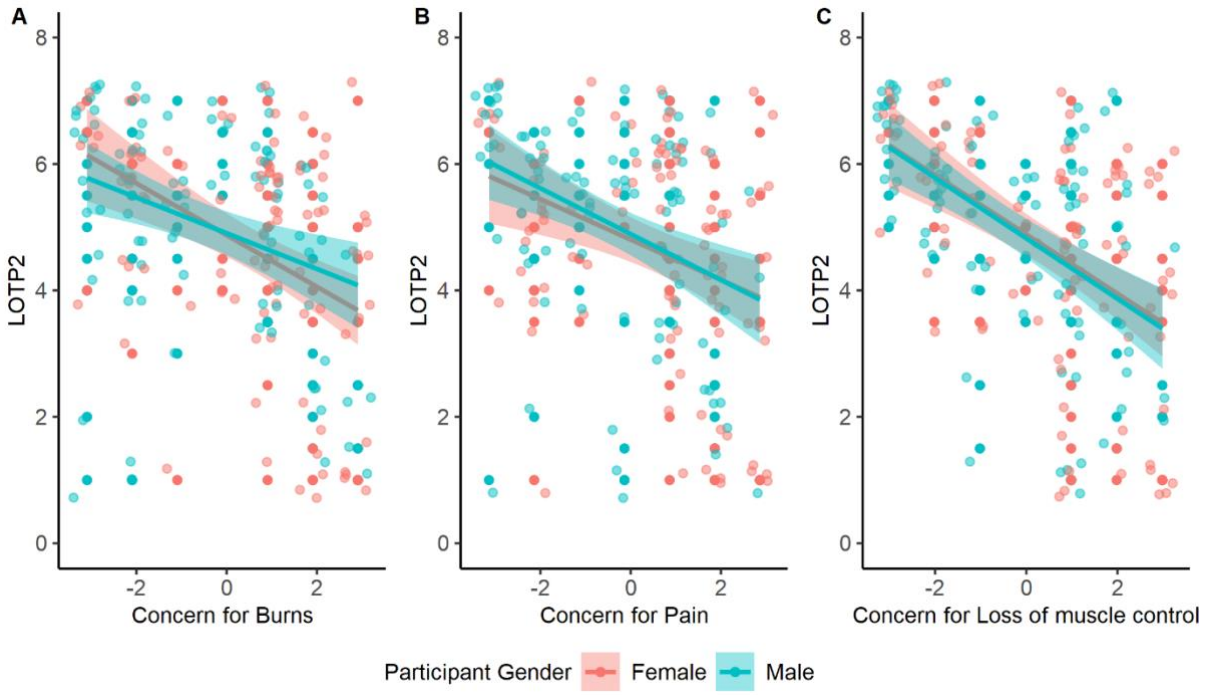
## 7.2.3 Appendix D Full model from moderated linear mixed effects regressions

Table of full model results from moderated linear mixed effects regressions examining whether specific concern (pain, burns, and LoC) predict LOTP2 from 182 participants. F-values are from ANOVAs with Satterthwaite method degrees of freedom.

| Model | Term | Result |
|---|---|---|
| Gender *Burns | - | $R^2$ = .16, F(3, 178) = 11.27, $p$ < .001, adj. $R^2$ = .15 |
| | Gender | β = -0.03, 95% CI [-00.51, 0.45], $t$(178) = -0.12, $p$ = .905 |
| | Burns | β = -0.16, 95% CI [-0.54, 0.23], $t$(178) = -0.80, $p$ = .425 |
| | Burns – Gender | β = 0.13, 95% CI [-0.37, 0.12], $t$(178) = 1.01, $p$ = .313 |
| Gender * Pain | - | $R^2$ = .14, F(3, 178) = 9.70, $p$ < .001, adj. $R^2$ = .13 |
| | Gender | β = 0.09, 95% CI [-0.57, .40], $t$(178) = -0.35, $p$ = .726 |
| | Pain | β = -0.41, 95% CI [-0.83, -.02], $t$(178) = -1.90, $p$ = .059 |
| | Gender - Pain | β = -0.04, 95% CI [-0.22, .30], $t$(178) = -0.33, $p$ = .744 |
| Gender * Loss of muscle control | - | $R^2$ = .27, $F$(3, 178) = 22.26, $p$ < .001, adj. $R^2$ = .26 |
| | Gender | β = -0.06, 95% CI [-0.39, .51], $t$(178) = 0.27, $p$ = .790 |
| | Loss of muscle control | β = -0.49, 95% CI [-0.86, -.12], $t$(178) = -2.58, $p$ = .011 |
| | Gender - Loss of muscle control | β = -0.01, 95% CI [-0.22, .24], $t$(178) = -0.08, $p$ = .937 |

## 7.2.4 Appendix E Figures of moderated regression LOTP and concerns

Plots of the moderated regression results examining whether specific concerns (Burns, Pain, and loss of muscle control) interacted with the participant's gender to predict LOTP2. Model fit is shown by the red line, shading shows 95% confidence interval.



## 7.2.5 Appendix F Summary of model on full sample size

Results from multiple linear regression on 201 participants. The table shows significant results after the backwards elimination. F-values are from ANOVAs with Satterthwaite method for calculating degrees of freedom.

| Model | Term | Result |
|---|---|---|
| LOTP1 | - | $R^2$ = .08, F(2, 198) = 8.69, p < .001, adj. $R^2$ = .07 |
| | MAIA | β = -0.32, 95% CI [.05, .60], t(195) = 2.30, $p$ = .023 |
| | Theoretical knowledge | β = .002, 95% CI [5.68e-03, .03], t(195) = 3.03, $p$ = .003 |
| LOTP2 | - | $R^2$ = .31, $F$(5, 195) = 17.74, $p$ < .001, adj. $R^2$ = .30 |
| | Burns | β = -0.14, 95% CI [-.26, -.02], $t$(195) = -2.34, $p$ = .021 |
| | LoC | β = -0.27, 95% CI [-.40, -.14], $t$(195) = -4.03, $p$ < .001 |
| | MAIA | β = -0.30, 95% CI [.02, .59], $t$(195) = 2.10, $p$ = .037 |
| | Theoretical knowledge | β = 0.02, 95% CI [6.75e-03, .03], $t$(195) = 3.29, $p$ = .001 |
| | NAQ avoidance | β = 0.18, 95% CI [.03, .34], $t$(195) = 2.38, $p$ = .019 |

### 7.2.6 Appendix G The complete Qualtrics survey

# fNMES Study 1 - SONA

# Survey Flow

**Block: Section 1 Information Sheet and Consent Form (3 Questions)**

**EmbeddedData**
**idValue will be set from Panel or URL.**

**Standard: Section 2 Demographics (5 Questions)**
**Standard: Section 2 Motivation to take part (3 Questions)**
**Standard: Section 3 Electrical stimulation experience (6 Questions)**
**Standard: Section 4 - Standardised Questionnaires (5 Questions)**
**Standard: fNMES 2 (11 Questions)**
**Standard: Debriefing and end (2 Questions)**

Page Break

Start of Block: Section 1 Information Sheet and Consent Form

Information Sheet **Information Sheet** My name is Themis Efthimiou, and I am a PhD student in the Department of Psychology at the University of Essex. Together with my colleague's Dr Sebastian Korb and Dr Paul Hanel, we would like to invite you to take part in this research study called "Attitudes towards receiving facial neuromuscular electrical stimulation". **Please take time to read the following information carefully. Description** Before you decide whether to take part, it is important for you to understand why the research is being done and what it will involve. The purpose of the study is to better understand your views and beliefs regarding facial neuromuscular electrical stimulation. You will be asked, what concerns you have about a hypothetical study, which uses facial neuromuscular electrical stimulation. Further, you will be asked to complete five questionnaires, related to personality, body awareness and image, and risk-taking. **Duration** The study will take approximately 15 minutes. **Eligibility Requirements** You are eligible to take part in the study if you are 18 - 45 years old and are currently living in the UK. **Withdrawal** Your participation is voluntary, and you will be free to withdraw from the project at any time without giving any reason and without penalty, by closing the browser. Incomplete responses will be considered withdrawn and deleted. It will not be possible to delete your data after you have completed the experiment because the data are stored anonymously, so it will not be possible to identify your data. **Data gathered** We will collect the following data, demographic information (age, gender, education level), concerns regarding a hypothetical study, and individual differences on different measures (described above) on five questionnaires**.** Your data will be fully anonymous so that it is not possible to identify you from our stored data. We are using your data to explore user concerns toward receiving facial neuromuscular electrical stimulation. Your data will be gathered by Qualtrics. Our legal basis for storing your consent form is that you have consented to it. The data controller is the University of Essex. Essex University's Data Protection Officer can be contacted on dpo@essex.ac.uk. Your anonymous data may be published in scientific journal articles and shared in permanent, publicly accessible archives accessible from any country. **Funding** The research is funded by the Austrian-Science Fund. **Ethics information** This study has been approved by the University of Essex Faculty of Science and Health Ethics Subcommittee and had been given approval with the following Application ID: ERAMS reference: ETH2021-0744. **Concerns and complaints** If you have any concerns about any aspect of the study or you have a complaint, in the first instance please contact the Principal Investigators of the project (see contact details below). If you are still concerned or you think your complaint has not been addressed to your satisfaction, please contact the Director of Research in the Principal Investigator's department (see below). If you are still not satisfied, please contact the University's Research Governance and Planning Manager (Sarah Manning-Press). Contact details Principal investigators Dr Sebastian Korb (sebastian.korb@essex.ac.uk) Dr Paul Hanel (p.hanel@essex.ac.uk) Director of Research, Dept of Psychology Prof Silke Paulmann (paulmann@essex.ac.uk) University of Essex Research Governance and Planning Manager Sarah Manning-Press, Research & Enterprise Office, University of Essex, Wivenhoe Park, CO4 3SQ, Colchester. Email: sarahm@essex.ac.uk. Phone: 01206-873561

Consent Form **Attitudes towards receiving facial neuromuscular electrical stimulation Researcher: Themis Efthimiou Principal Investigators: Dr Sebastian Korb and Dr Paul Hanel**

**Consent Form**

| | You need to agree with all responses to participate (1) |
|---|---|
| 1. I confirm that I have read, and I understand the Information Sheet labelled ETH2021-0744. (1) | ○ |
| 2. I understand that no personal identifiable data will be collected. (2) | ○ |
| 3. I understand that my participation is voluntary and that I am free to withdraw from the project at any time without giving any reason and without penalty. I understand that my data cannot be deleted after I have completed the experiment because the data are stored anonymously, so it will not be possible to identify my data. (3) | ○ |
| 4. I understand that my fully anonymised data will be used for the research purposes outlined above and provided in detail at the end of the survey. (4) | ○ |
| 5. I understand that the anonymised data collected about me will be used to support other research in the future and may be made publicly available to benefit other researchers. (5) | ○ |
| 6. I agree to take part in the above study. (8) | ○ |

Page Break

Time_con Timing
First Click (1)
Last Click (2)
Page Submit (3)
Click Count (4)

**End of Block: Section 1 Information Sheet and Consent Form**

**Start of Block: Section 2 Demographics**

Age What is your age (in years)?

▼ 18 (18) ... 45 (45)

Gender What is your gender?

- ○ Male (1)
- ○ Female (2)
- ○ Other (3)
- ○ Prefer not to say (4)

Ethnicity How would you best describe your ethnic origin?

- White (1)
- Asian or Asian British (2)
- Black or Black British (3)
- Mixed (4)
- Other (5)

---

X→

Education What is the highest level of education you have completed?

- GCSEs or equivalent (typically exams at the age 16) (1)
- A-Levels or equivalent (typically exams at the age 18) (2)
- University undergraduate programme (3)
- University post-graduate programme (4)
- Doctoral degree (5)

---

*Display This Question:*

*If What is the highest level of education, you have completed? = University undergraduate programme*

*Or What is the highest level of education you have completed? = University post-graduate programme*

*Or What is the highest level of education you have completed? = Doctoral degree*

Subject What subject did you study?

_____

End of Block: Section 2 Demographics

Start of Block: Section 2 Motivation to take part

Descriptor Imagine the following situation:
You are invited to a research laboratory to take part in a paid (£10 per hour) psychological experiment about emotions. This study will use facial neuromuscular electrical stimulation, a safe and non-painful technique, to stimulate certain parts of your face with weak electrical impulses.

LOTP How likely are you to take part in a study involving facial neuromuscular electrical stimulation?

- ○ Extremely unlikely (1)
- ○ Moderately unlikely (2)
- ○ Slightly unlikely (3)
- ○ Neither likely nor unlikely (4)
- ○ Slightly likely (5)
- ○ Moderately likely (6)
- ○ Extremely likely (7)

SR_Concerns Please describe your concerns, if you were to receive facial neuromuscular electrical stimulation (one or two sentences)?

_____

End of Block: Section 2 Motivation to take part

Start of Block: Section 3 Electrical stimulation experience

Knowledge_ES Please rate your knowledge of electrical stimulation:

| | Beginner 0 10 20 30 40 50 60 70 80 90 100 Expert |
|---|---|
| Theoretical () |  |
| Practical () |  |

Page Break

Received_E-shock Have you ever received an accidental electrical shock?

- ○ Yes (1)
- ○ No (2)
- ○ Unsure (3)

Page Break

*Display This Question:*

*If have you ever received an accidental electrical shock? = Yes*

shock_recency How recently did you receive this accidental shock?

- In the last week (1)
- In the last month (2)
- In the last 3 months (3)
- In the last 6 months (4)
- In the last year or longer (6)

Page Break

Received_ES Have you ever received electrical stimulation, using a purpose-built device?

- ○ Yes (1)
- ○ No (2)
- ○ Unsure (3)

Page Break

*Display This Question:*

*If have you ever received electrical stimulation, using a purpose-built device? = Yes*

Reason_electric What was the reason you received electrical stimulation

- Medical (1)
- Research purposes (2)
- Cognitive enhancement (3)
- Other (4)

*Display This Question:*

*If What was the reason you received electrical stimulation = Other*

ES_type Please specify the reason you received electrical stimulation

_____

**End of Block: Section 3 Electrical stimulation experience**

**Start of Block: Section 4 - Standardised Questionnaires**

NFA **Please indicate the extent to which you agree with the following statements:**

| | Totally disagree (1) | (2) | (3) | Neither disagree nor agree (4) | (5) | (6) | Totally agree (7) |
|---|---|---|---|---|---|---|---|
| I feel that I need to experience strong emotions regularly. (1) | | | | | | | |
| If I reflect on my past, I see that I tend to be afraid of feeling emotions. (2) | | | | | | | |
| I find strong emotions overwhelming and therefore try to avoid them. (3) | | | | | | | |
| Emotions help people get along in life. (4) | | | | | | | |
| I think that it is important to explore my feelings. (5) | | | | | | | |
| It is important for me to know how others are feeling. (6) | | | | | | | |
| I would prefer not to experience either the lows or highs of emotions. (7) | | | | | | | |
| I do not know how to handle my emotions, so I avoid them. (8) | | | | | | | |

| |
|---|
| Emotions are dangerous—they tend to get me into situations that I would rather avoid. (9) |
| It is important for me to be in touch with my emotions. (10) |
| It is important that you select totally agree (test item). (11) |

Page Break

MAIA

**Below you will find a list of statements. Please indicate how often each statement applies to you generally in daily life.**

| | Never (1) | (2) | (3) | (4) | Always (5) |
|---|---|---|---|---|---|
| When I feel physical pain, I become upset. (113) | ○ | ○ | ○ | ○ | ○ |
| I start to worry that something is wrong if I feel any discomfort. (114) | ○ | ○ | ○ | ○ | ○ |
| It is important that you select Never (test item) (115) | ○ | ○ | ○ | ○ | ○ |
| I can notice an unpleasant body sensation without worrying about it. (116) | ○ | ○ | ○ | ○ | ○ |
| I can stay calm and not worry when I have feelings of discomfort or pain. (117) | ○ | ○ | ○ | ○ | ○ |
| When I am in discomfort or pain, I can't get it out of my mind. (118) | ○ | ○ | ○ | ○ | ○ |

Page Break

DOSPERT **For each of the following statements, please indicate the likelihood that you would engage in the described activity or behaviour if you were to find yourself in that situation. Provide a rating from Extremely Unlikely to Extremely Likely, using the following scale**

| | Extremely unlikely (1) | Moderately unlikely (2) | Slightly unlikely (3) | Neither likely nor unlikely (4) | Slightly likely (5) | Moderately likely (6) | Extremely likely (7) |
|---|---|---|---|---|---|---|---|
| Drinking heavily at a social function. (1233) | | | | | | | |
| Engaging in unprotected sex. (1236) | | | | | | | |
| Driving a car without wearing a seat belt. (1237) | | | | | | | |
| Riding a motorcycle without a helmet. (1238) | | | | | | | |
| Sunbathing without sunscreen. (1270) | | | | | | | |
| Walking home alone at night in an unsafe area of town. (1271) | | | | | | | |

Page Break

BICI, **please respond to each item by indicating how often you experience the described feelings or how often you perform the described behaviours.**

| | Never (1) | Sometimes (2) | About half the time (3) | Most of the time (4) | Always (5) |
|---|---|---|---|---|---|
| I am dissatisfied with some aspect of my appearance. (1212) | ○ | ○ | ○ | ○ | ○ |
| I spend a significant amount of time checking my appearance in the mirror. (1213) | ○ | ○ | ○ | ○ | ○ |
| I feel others are speaking negatively of my appearance. (1214) | ○ | ○ | ○ | ○ | ○ |
| I am reluctant to engage in social activities when my appearance does not meet my satisfaction. (1215) | ○ | ○ | ○ | ○ | ○ |
| I feel there are certain aspects of my appearance that are extremely unattractive. (1216) | ○ | ○ | ○ | ○ | ○ |
| I buy cosmetic products to try to improve my appearance. (1217) | ○ | ○ | ○ | ○ | ○ |
| I seek reassurance from others about my appearance. (1218) | ○ | ○ | ○ | ○ | ○ |
| I feel there are certain aspects of my appearance I would like to change. (1219) | ○ | ○ | ○ | ○ | ○ |
| I am ashamed of some part of my body. (1220) | ○ | ○ | ○ | ○ | ○ |

| | | | | | |
|---|---|---|---|---|---|
| I compare my appearance to that of fashion models or others. (1221) | ○ | ○ | ○ | ○ | ○ |
| I try to camouflage certain flaws in my appearance. (1222) | ○ | ○ | ○ | ○ | ○ |
| I examine flaws in my appearance. (1223) | ○ | ○ | ○ | ○ | ○ |
| It is important that you select About half the item (test item). (1224) | ○ | ○ | ○ | ○ | ○ |
| I have bought clothing to hide a certain aspect of my appearance. (1225) | ○ | ○ | ○ | ○ | ○ |
| I feel others are more physically attractive than me. (1226) | ○ | ○ | ○ | ○ | ○ |
| I have considered consulting/consulted some sort of medical expert regarding flaws in my appearance. (1227) | ○ | ○ | ○ | ○ | ○ |
| I have been embarrassed to leave the house because of my appearance. (1228) | ○ | ○ | ○ | ○ | ○ |
| I fear that others will discover my flaws in appearance. (1229) | ○ | ○ | ○ | ○ | ○ |
| I have missed social activities because of my appearance. (1230) | ○ | ○ | ○ | ○ | ○ |

| | |
|---|---|
| I have avoided looking at my appearance in the mirror. (1231) |  |

Page Break

Big5 **Here are a number of characteristics that may or may not apply to you. Please indicate how much each statement accurately describes you.**

| | Very inaccurate (1) | Moderately inaccurate (2) | Neither accurate nor inaccurate (3) | Moderately accurate (4) | Very accurate (5) |
|---|---|---|---|---|---|
| Have frequent mood swings. (16) | ○ | ○ | ○ | ○ | ○ |
| Have a vivid imagination. (17) | ○ | ○ | ○ | ○ | ○ |
| Am relaxed most of the time. (18) | ○ | ○ | ○ | ○ | ○ |
| Am not interested in abstract ideas. (19) | ○ | ○ | ○ | ○ | ○ |
| Get upset easily. (20) | ○ | ○ | ○ | ○ | ○ |
| Have difficulty understanding abstract ideas. (21) | ○ | ○ | ○ | ○ | ○ |
| Seldom feel blue. (22) | ○ | ○ | ○ | ○ | ○ |
| Do not have a good imagination. (23) | ○ | ○ | ○ | ○ | ○ |

Page Break

End of Block: Section 4 - Standardised Questionnaires

Start of Block: fNMES 2

Hypo_study PLEASE READ CAREFULLY, as you will have to answer questions based on the text below. We will now provide you with a more detailed description of what NMES is, and of how we plan to use it in a **hypothetical**, planned research experiment. **What is NMES:** Neuromuscular Electric Stimulation (NMES), also known as TENS (Transcutaneous Electrical Nerve Stimulation), has been used for some time, especially in the field of physiotherapy and rehabilitation, including in the face. NMES can be used to induce muscle contractions, as it simulates the natural activation of a muscle. **How do we intend to use NMES:** For the purpose of a planned experiment, four electrodes will be placed on your lower face. These are medically suitable, self-adhesive electrodes, which are disposed after each use. They are used for light electrical muscle stimulation, which takes place with medically certified and computer-controlled stimulators. You will receive NMES over specific facial muscles, mostly in short periods of approximately 1 second, and for a maximum total duration of 30 minutes. You will be compensated with £10 per hour. You are allowed to stop participating at any time. **Side effects and Risks: Discomfort, Pain**: Most of the time, facial NMES will feel like a slight, non-painful tingling sensation. However, it can sometime feel unpleasant, and occasionally induce brief painful sensations. The level of pain/discomfort depends on many factors, including individual differences in pain sensitivity. **Marks, burns**: The risk of getting skin burns exists, but is very low, as long as safety measures are followed, and stimulation limits are not exceeded. In some cases, however, light skin redness due to irritation can occur under the electrodes. This should disappear after few hours. **Loss of control**: Be aware that your muscles will move without you controlling it. Your facial muscles may also feel tight and tired at the end of the experiment. Although not a health risk, these phenomena can be unpleasant for some people. **Other**: For people with heart problems, a pacemaker or other implantable heart device, NMES may be dangerous and is not recommended. It is also not recommended during pregnancy. PLEASE READ CAREFULLY, as you will have to answer questions based on the text above.

Time_hypo Timing
First Click (1)
Last Click (2)
Page Submit (3)
Click Count (4)

Page Break

NMES_understanding in the study just described, how many electrodes will be used?

- 2 electrodes (1)
- 4 electrodes (2)
- 6 electrodes (3)

NMES_understanding_2 In the study just described, in which part of the face is going to be stimulated?

- Upper (1)
- Lower (2)

NMES_understanding_3 Who cannot take part in the study just described?

- Pregnant people (1)
- Depressed individuals (2)
- People aged 25+ (3)

Page Break

LOTP_2 How likely are you to take part in a study involving facial neuromuscular electrical stimulation?

- Extremely unlikely (1)
- Moderately unlikely (2)
- Slightly unlikely (3)
- Neither likely nor unlikely (4)
- Slightly likely (5)
- Moderately likely (6)
- Extremely likely (7)

Page Break

LOTP_3 Do you intend to take part in a study involving facial neuromuscular electrical stimulation, if offered the possibility?

- I would never want to participate (1)
- - (2)
- - (3)
- I am undecided about participating (4)
- - (5)
- - (6)
- I absolutely want to participate (7)

Page Break

SR_concerns_2 What are your concerns about taking part in a study involving facial neuromuscular electrical stimulation?

_____

_____

_____

_____

_____

Page Break

Specific_concerns If I took part in a study involving facial neuromuscular electrical stimulation, I would be concerned about:

| | Strongly disagree (1) | Disagree (2) | Somewhat disagree (3) | Neither agree nor disagree (4) | Somewhat agree (5) | Agree (6) | Strongly agree (7) |
|---|---|---|---|---|---|---|---|
| Getting burned (2) | | | | | | | |
| Being in pain (3) | | | | | | | |
| Losing control over my muscle (4) | | | | | | | |

SR_concerns_3 Do you have any concerns that were not listed above?

_____

_____

_____

_____

_____

Time_concerns Timing
First Click (1)
Last Click (2)
Page Submit (3)
Click Count (4)

**End of Block: fNMES 2**

**Start of Block: Debriefing and end**

Q35 This is the end of the survey.
Thank you very much for taking part, we greatly appreciate your contribution.
This survey was interested in exploring the concerns participants have when considering whether to take part in a facial electrical stimulation study. Further, we aim to explore how one's willingness to take part differs across, gender, education level, personality, risk-taking, and body awareness.

You are more than welcome to discuss your feelings about taking part in the survey below. If you have any questions/concerns or wish to find out more about the results of the study once the data has been analysed then send an email to: Themis Efthimiou (t.efthimiou@essex.ac.uk).

If you have any further concerns, please feel free to contact the principal investigator, Dr Sebastian Korb (sebastian.korb@essex.ac.uk).

---

Debrief

Do you have any comments?

_____

_____

_____

_____

_____

**End of Block: Debriefing and end**

# 7.3 Chapter 4

## 7.3.1 Appendix H Information sheet provided to participants

Participant Information Sheet

Title of the Project: Neuromuscular electric stimulation and social cognition

Research Team: Dr Sebastian Korb, Themis Efthimiou, Dr Joshua Baker

We would like to invite you to take part in this research study called "User experiences and comfort with facial Neuromuscular Electrical Stimulation". Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

Inclusion/exclusion criteria

You are eligible to take part in the study if you are between 18 and 45 years old, and if you have good visual acuity (with or without glasses/contact lenses).

You cannot take part in the study if you do not correspond to the inclusion criteria, or if you have a history of or make current (last month) use of illicit and/or psychotropic drugs, if you have been diagnosed with a neurological or psychiatric condition, if you have any major heart conditions (e.g., pacemaker), or if you wear a beard (as this precludes attaching electrodes to the face).

What is the purpose of the study?

The purpose of the study is to find out how stimulation of certain areas of the face impacts your comfort and physiological responses. We will use "neuromuscular electrical stimulation" (NMES, a safe and non-painful technique) to stimulate certain parts of your face with weak electrical impulses.

Results are expected to be relevant for our understanding of the physiological effects and the general applicability of facial NMES.

Why have I been invited to participate?

The study is part of a larger project, which includes several experiments, runs for 3 years, and involves the testing of several hundreds of participants. You have been invited to participate in this study because you correspond to the inclusion/exclusion criteria.

Inclusion criteria: age 18-45 years; good visual acuity (with or without glasses/contact lenses).

Exclusion criteria: history or current use of illicit and/or psychotropic drugs, known major heart condition (e.g., pacemaker), current or past neurological or psychiatric disorder; beard (as this precludes attaching electrodes to the face).

Do I have to take part?

Your participation in the study is entirely voluntary. If you do decide to take part, you will be asked to provide written consent. You have the right to withdraw at any time for whatever reason and without explanation or penalty. If you are a student, your withdrawal will have no impact on your marks, assessments, or future studies. You can also ask that your data be deleted at any time, up to six months after your participation.

If you wish to withdraw from the study, or have any other concerns, you only need to inform the experimenter(s) orally.

It is also possible that the experimenter or other members of the research team may decide to terminate your participation in the study prematurely without your prior consent. The reasons for this may be that you do not meet the requirements of the study or that the investigator has the impression that further participation in the study is not in your interest.

What will happen to me if I take part?

Your participation in the study consists of 1 appointment at the research laboratory (duration about 1.5 – 2 hours). You will be welcomed and tested by the principal investigator of the project, or by members of his team.

We will introduce you to the NMES procedure and verify your NMES threshold. You will then complete a task at the computer. Over several trials, you will receive facial NMES for a duration of 5–seconds at various intensities. At the end of each stimulation period, we will ask you some questions about your experience with facial NMES e.g., how comfortable it was. Your face will be video recorded throughout.

Up to 4 electrodes will place in the lower part of your face. These are medically suitable, self-adhesive electrodes, which are either cleaned or disposed of after each use. They are used for light electrical stimulation of the corresponding parts of your face, which takes place with medically certified and computer-controlled stimulators. Thereby NMES simulates the natural activation of a muscle.

In this study, the aim is not to produce strong muscle contractions, but rather to slightly stimulate certain parts of the face. We calibrate the NMES for each participant, by gradually increasing its intensity until a slight muscle contraction becomes visible. During the stimulation, you will feel a tingling sensation. This can sometimes feel uncomfortable but is of short duration and has no long-term consequences. Importantly, rest assured that we follow international guidelines about electrical stimulation and have extensively and successfully pre-tested the stimulation parameters. We will also always monitor your wellbeing.

After the electrodes have been set up, we will attach additional electrodes to your non-dominant hand to measure your heart rate and skin response. You will then participate in a task where you will receive facial NMES and report on your experience. During the task, you will either see a blank screen or an image with positive and negative content. Please be aware that some of these images might be disturbing, but they come from a scientifically recognised database and have been thoroughly used in research. Once the task is complete, the electrodes will be repositioned, and the task will be repeated a second time.

What are the possible disadvantages and risks of taking part?

There are no health risks associated with NMES as long as limits are not exceeded, and safety measures are followed. NMES, also known as TENS (Transcutaneous Electrical Nerve Stimulation), has been used for some time, especially in the field of physiotherapy and rehabilitation, including in the face.

Medical stimulators and electrodes are used for this study. During the initial calibration phase, the stimulation intensity is gradually increased, until a clear muscle activation is visible. This can sometimes lead to an unpleasant feeling and occasionally to brief pain sensations. In that case we adjust the electrode position, until the optimal and most comfortable NMES experience is obtained. Importantly, the NMES impulses are of short duration (few seconds) and are not harmful to your health.

Please inform the experimenter(s) and/or the lead investigators if you experience any major symptoms, side effects, sickness, or injuries.

What are the possible benefits of taking part?

By participating, you can gain insight into scientific psychological and neuroscientific practice. You will also contribute to a better scientific understanding of the basis of human behaviour, and in the development of facial NMES.

What information will be collected?

We will collect the following data: your responses to the computer tasks (e.g., response times and accuracy), your basic demographics (age, gender, etc.), video recording of your face during the computer tasks, heart rate, electrodermal activity from your non-dominant hand, and your self-report responses on some self-report questionnaires measuring mood and personality characteristics (e.g., empathy).

Your data will be pseudonymised, i.e., you will be assigned already at time of testing an anonymous ID code, under which the data will be stored. This means that it is not possible

for anyone who does not have the "key" to draw conclusions about your person. Your video recordings will never be shared outside of the researchers' team and will not be published.

Only the researchers involved in the study will have access to the data "key", and thus to the confidential data (e.g., your name and contact details). These persons are subject to the obligation of secrecy.

You will also not be mentioned by name in any publications of the data of this study.

Will my information be kept confidential?

All your information will be kept confidential. Already at data collection, your data will be associated with a letter/number code. We will thus strip any identifying information out of the experimental data but keep a master list that gives the identity of each participant. The master list will be stored on a secure institutional server, the anonymised data will be stored independently of the participant's name and contact details. All digital data will be kept on password-protected computers and data storages. All paper sheets (where applicable) will be kept in locked closets/rooms at the university and will only be accessible by the members of the research team.

Aggregated anonymous data may be uploaded to a dedicated research repository (e.g., OSF) at the time of publication of the corresponding papers.

Your data will be for 10 years after the completion of the project and will be destroyed after that (electronic files will be deleted, paper sheets will be shredded).

What is the legal basis for using the data and who is the Data Controller?

By signing written consent, you provide the legal basis for the processing of your data. Essex University's Data Protection Officer can be contacted at dpo@essex.ac.uk.

What should I do if I want to take part?

If you want to participate in this study, please write an email to psynmes@gmail.com, and provide us with your full name and telephone number. We will contact you as soon as possible.

What will happen to the results of the research study?

The results of the research are expected to be published as a journal article and/or used as a conference paper/presentation. The results may also be part of a university dissertation or thesis (Master's, PhD). Importantly, any results will be anonymised, and you will not be identifiable.

Who is funding the research?

This research is funded through a grant by the Austrian Science Fund (FWF) awarded to the principal investigator.

Who has reviewed the study?

This study has been approved by the University of Essex Faculty of Science and Health Ethics Subcommittee, ERAMS reference: ETH2122-1966.

Concerns and Complaints

For any concerns regarding the study, you can also contact the principal investigator of the project, Sebastian Korb using the contact details below. Should you still be concerned, or should you think that your complaint has not been addressed to your satisfaction, or should you feel that you cannot approach the principal investigator, please contact the departmental Director of Research in the department responsible for this project, Silke Paulmann (Email: paulmann@essex.ac.uk). If you are still not satisfied, please contact the University's Research Governance and Planning Manager, Sarah Manning-Press (Email: sarahm@essex.ac.uk). Please include the ERAMS reference: ETH2122-0049.

## 7.3.2 Appendix I OASIS Database Images

This appendix lists the images extracted from the OASIS database and used in the experiment. The table includes the image category, emotion, mean valence, and mean arousal as classified in the original OASIS standardisation. Positive images were only shown in the ZM block and negative images were only shown in the DAO block. images were split between the two blocks, but no image was shown to the participant more than once to avoid emotional habituation in their response.

| Image | Category | Emotion | Mean Valence | Mean Arousal |
|---|---|---|---|---|
| dog 6 | animal | positive | 6.49 | 5.03 |
| lake 9 | scene | positive | 6.41 | 4.11 |
| flowers 2 | object | positive | 5.95 | 3.46 |
| wedding 4 | object | positive | 5.81 | 3.12 |
| cat 5 | animal | positive | 6.22 | 4.86 |
| beach 1 | scene | positive | 6.37 | 4.74 |
| barrels 1 | object | neutral | 4.21 | 2.47 |
| cotton swabs | object | neutral | 4.06 | 1.86 |
| cups 2 | object | neutral | 4.14 | 2.20 |
| fence 2 | object | neutral | 4.22 | 2.30 |
| Fire hydrant 1 | object | neutral | 4.20 | 2.33 |
| keyboard 1 | object | neutral | 4.17 | 2.15 |
| cups 1 | object | neutral | 4.28 | 2.03 |
| office supplies 2 | object | neutral | 4.09 | 1.84 |
| sidewalk 6 | object | neutral | 2.83 | 1.92 |
| bark 5 | object | neutral | 4.20 | 2.06 |
| skyscraper 1 | scene | neutral | 4.13 | 2.25 |
| roofing 3 | object | neutral | 3.93 | 2.08 |
| dog 26 | animal | negative | 1.30 | 4.86 |
| garbage dump 2 | scene | negative | 1.60 | 3.78 |

| | | | | |
|---|---|---|---|---|
| car accident 2 | object | negative | 1.97 | 4.09 |
| dog 24 | animal | negative | 1.89 | 4.77 |
| war 8 | scene | negative | 1.72 | 5.14 |
| plane crash 4 | object | negative | 2.05 | 4.11 |
| bird 3 | animal | positive | 6.04 | 3.43 |
| beach 7 | scene | positive | 6.07 | 4.31 |
| galaxy 7 | scene | positive | 6.06 | 4.50 |
| dog 12 | animal | positive | 6.29 | 4.41 |
| nature 1 | scene | positive | 6.12 | 4.43 |
| sunset 3 | scene | positive | 6.12 | 3.71 |
| yarn 4 | object | neutral | 4.20 | 1.98 |
| sidewalk 1 | scene | neutral | 4.31 | 2.30 |
| storage 2 | object | neutral | 4.01 | 2.25 |
| wall 3 | object | neutral | 4.06 | 1.81 |
| paperclips 3 | object | neutral | 4.05 | 1.84 |
| paper 2 | object | neutral | 4.09 | 1.93 |
| tornado 3 | scene | negative | 2.66 | 4.68 |
| pigeon 6 | animal | negative | 2.32 | 3.82 |
| flood 3 | scene | negative | 2.29 | 4.29 |
| destruction 10 | scene | negative | 2.10 | 3.59 |
| jail 4 | scene | negative | 2.11 | 3.43 |
| injury 3 | person | negative | 1.97 | 4.70 |
| rocks 3 | object | neutral | 4.31 | 2.20 |
| cardboard 2 | object | neutral | 4.31 | 2.20 |
| sidewalk 3 | scene | neutral | 4.30 | 2.23 |
| socks 1 | object | neutral | 4.20 | 1.90 |
| yarn 1 | object | neutral | 2.60 | 1.87 |
| roofing 2 | object | neutral | 4.06 | 2.13 |

## 7.3.3 Appendix J Model comparisons for covariates

| Fit1 | AIC | BIC | Fit2 | AIC | BIC | *p* |
|---|---|---|---|---|---|---|
| fNMES + fNMES:image | 1866 | 1895 | fNMES + fNMES:image + TAS | 1866 | 1900 | .230 |
| fNMES + fNMES:image | 1910 | 1940 | fNMES + fNMES:image + Negative Affect | 1912 | 1946 | .718 |
| fNMES + fNMES:image | 1910 | 1940 | fNMES + fNMES:image + Positive Affect | 1897 | 1932 | < .001 |
| fNMES + fNMES:image + Positive Affect | 1897 | 1932 | fNMES + fNMES:image + Positive Affect + Discomfort | 1762 | 1801 | < .001 |

*Note*. The simplest model, including a main effect of fNMES and an fNMES by image interaction, was compared to models including as covariates TAS, the positive and negative affect subscales of the PANAS (measured at the beginning of the experiment), and ratings of discomfort in each trial. The best-fitting model included both positive affect and discomfort. Please note that the simplest model in the first and second rows differ because two participants had incomplete TAS data ($n$ = 56). These two participants were excluded from the simplest model because TAS did not improve the model. However, they were added back to later comparisons ($n$ = 58).

## 7.3.4 Appendix K Model splitting muscle and fNMES intensity

An LMM was conducted to predict self-reported valence with the following predictors fNMES intensity, muscle, image, PANAS, and discomfort ($R^2$ = 0.71; marginal $R^2$ = 0.31). The output is reported as type 3 ANOVAs with posthoc comparisons conducted using the emmeans package with a Bonferroni correction applied.

The main effect of muscle is statistically significant ($F$(1, 963) = 95.74, $p$ < .001. Overall, self-reported valence was higher in the ZM compared to the DAO conditions ($M_{diff}$ = -0.30, SE = 0.03, $t$(962) = 9.79, $p$ < .001. A second main effect of image is statistically significant ($F$(2, 962) = 18.54, $p$ < .001. Overall, self-reported valence was higher in the no-image compared to the congruent ($M_{diff}$ = -0.19, SE = 0.04, $t$(962) = 4.92, $p$ < .001) image condition and the neutral image condition ($M_{diff}$ = -0.21, $SE$ = 0.04, $t$(962) = 5.56, $p$ < .001).

The interaction between fNMES intensity and muscle is statistically ($F$(2, 962) = 26.96, p < .001). Posthoc comparisons revealed that self-reported valence was higher in the ZM condition when fNMES intensity was 50 ($M_{diff}$ = -0.48, SE = 0.05, $t$(963) = 8.96, $p$ < .001) and 100% ($M_{diff}$ = -0.44, $SE$ = 0.05, $t$(962) = 8.34, p < .001) of MT. No difference in valence between the two muscles emerged when fNMES was off ($M_{diff}$ = 0.02, $SE$ = 0.05, t(962) = 0.33, $p$ = .742).

The interaction between muscle and image is statistically significant ($F$(2, 963) = 67.07, $p$ < .001). Posthoc comparisons revealed valence was higher in the zm compared to the DAO conditions when the image was congruent in emotion ($M_{diff}$ = -0.81, $SE$ = 0.05, $t$(963) = 15.02, $p$ < .001). No other statistically significant differences emerged (all $ts$ > -1.14 and all $ps$ > .255.

A three-way interaction between fNMES intensity, muscle, and the image type was statistically significant ($F$(4, 962) = 16.25, $p$ < .001) see Table below for decomposition.

Post-hoc comparisons with a Bonferroni correction between muscles (dao – zm) for each fNMES and image condition.

| fNMES intensity | Image | $M_{diff}$ | *SE* | *t* | *df* | *p* |
|---|---|---|---|---|---|---|
| 0 | Congruent | -0.03 | 0.09 | 0.34 | 962 | .735 |
| 50 | | -1.36 | 0.09 | 14.63 | 964 | < .001 |
| 100 | | -1.02 | 0.09 | 11.12 | 962 | < .001 |
| 0 | Neutral | 0 | 0.09 | 0.01 | 962 | .989 |
| 50 | | -0.03 | 0.09 | 0.37 | 962 | .709 |
| 100 | | -0.08 | 0.09 | 0.82 | 962 | .414 |
| 0 | No image | 0.08 | 0.09 | 0.90 | 962 | .369 |
| 50 | | -0.04 | 0.09 | 0.40 | 962 | .693 |
| 100 | | -0.23 | 0.09 | 2.48 | 962 | .013 |

*Note.* Shaded cells indicate statistically significant results. Negative mean differences indicate that self-reported valence is higher in the ZM compared to the DAO condition.

# 7.4 Chapter 5

## 7.4.1 Appendix L Summary of model with full random effects structure

Output from the lmerTest model for the pre-registered model which included an interaction between the predictor's emotion and fNMES in the random effects structure. This model resulted in a singular fit.

Model summary for the pre-registered analysis, which included a full random effects structure.

| | Choice | | |
|---|---|---|---|
| Predictors | β | CI 95% | *p* |
| (Intercept) | 0.49 | 1.36 – 1.96 | <.001 |
| Emotion | 0.92 | 2.37 – 2.67 | <.001 |
| fNMES | 0.10 | 1.02 – 1.19 | .020 |
| Emotion * fNMES | 0.91 | 0.97 – 1.06 | .660 |
| Random Effects | | | |
| $\sigma^2$ | 3.29 | | |
| $\tau_{00\ participant}$ | 0.37 | | |
| $\tau_{11\ participant.Emotion}$ | 0.03 | | |
| $\tau_{11\ participant.fNMES}$ | 0.01 | | |
| $\tau_{11\ participant.Emotion:fNMES}$ | 0.00 | | |
| $\rho_{01}$ | 0.45 | | |
| | 0.76 | | |
| | 0.01 | | |

| $N_{participant}$ | 47 |
|---|---|
| Observations | 26811 |
| Marginal $R^2$ / Conditional $R^2$ | .55 / NA |

## 7.4.2 Appendix M Summary of GLMM including covariates measured before the lab session

Summary of a Generalised Linear Mixed Model (GLMM) predicting participants' choice with covariates. We fitted a GLMM ($n$ = 45) to predict Choice (happy or sad) with the predictor variables in the table below. Formula: Choice ~ Emotion * fNMES + ASQ + EQ + MAIA Noticing + MAIA not-worrying + MAIA Attention regulation + MAIA Emotional Awareness + MAIA not-Distracting + MAIA Self-regulation + MAIA Body Listening + MAIA Body trusting + (Emotion + fNMES | participant).

Summary of the model including the MAIA, ASQ, and EQ questionnaire. Shaded rows show statistically significant results.

| Predictor | β | *SE* | *z* | *p* |
|---|---|---|---|---|
| Emotion | 1.96 | 0.07 | 28.23 | < .001 |
| fNMES | 0.09 | 0.04 | 2.41 | .016 |
| ASQ | -0.15 | 0.10 | -1.51 | .130 |
| EQ | 0.02 | 0.10 | .16 | .875 |
| MAIA: Noticing | -0.02 | 0.10 | -.23 | .817 |
| MAIA: Not-Worrying | -0.04 | 0.10 | -.39 | .698 |
| MAIA: Attention regulation | -0.05 | 0.12 | -.44 | .661 |
| MAIA: Emotional Awareness | 0.04 | 0.11 | .34 | .732 |
| MAIA: Not-Distracting | -0.19 | .09 | -2.13 | .033 |
| MAIA: Self-Regulation | 0.08 | .12 | .71 | .478 |
| MAIA: Body Listening | -0.05 | .13 | -.43 | .670 |
| MAIA: Body trusting | 0.10 | .10 | 1.02 | .390 |
| Emotion * fNMES | 0.01 | .04 | .16 | .874 |

## 7.4.3 Appendix N Summary of GLMM including covariates measured during the lab session

Summary of the Generalised Linear Mixed Model (GLMM) predicting participants' choice with covariates. We fitted a GLMM ($n$ = 41) to predict Choice (happy or sad) with the predictor variables in the table below. Formula: Choice ~ Emotion * fNMES + Positive Affect + Negative Affect + Discomfort + (Emotion + fNMES | participant).

Summary of the model including the covariates PANAS and discomfort. Shaded rows show statistically significant results.

| Predictor | β | *SE* | *z* | *p* |
|---|---|---|---|---|
| Emotion | 2.00 | 0.07 | 27.27 | < .001 |
| fNMES | -0.01 | 0.02 | 2.38 | .017 |
| Positive Affect Time 1 | 0.12 | 0.09 | 1.27 | .204 |
| Negative Affect Time 1 | -.01 | 0.09 | -0.13 | .894 |
| Discomfort | -0.07 | 0.10 | -0.67 | .502 |
| Emotion * fNMES | -0.02 | 0.02 | -0.77 | .443 |

## 7.4.4 Appendix O Summary of t-tests after applying subtraction method

To make sure the fNMES-only subtraction method did not contribute to the main fNMES effects found on each ERP component, we calculated four emotion difference scores, controlling for fNMES. Specifically, we subtracted the average activity in response to 10% happy and sad faces (the most ambiguous emotion levels) from the activity elicited by 30% happy/sad faces (the least ambiguous emotion levels). We did this for each component (P1, N170, and LPP) and for each fNMES condition (e.g., fNMES on and fNMES off; for the equation see below). We then compared these difference scores for the fNMES on and off conditions.

Happy On = fNMES on (30% happy – (average of 10% Happy and 10% Sad)

Happy Off = fNMES off (30% happy – (average of 10% Happy and 10% Sad)

Sad On = fNMES on (30% happy – (average of 10% Happy and 10% Sad)

Sad Off = fNMES off (30% happy – (average of 10% Happy and 10% Sad)

Paired sample t-tests comparing fNMES off to on, for each ERP component, after computing difference scores between emotion levels.

| Component | Emotion | *t* | CIs 95% | $M_{diff}$ | *p* |
|---|---|---|---|---|---|
| P1 | Happy | -0.39 | -0.46, 0.32 | -0.08 | .699 |
| | Sad | -0.16 | -0.47, 0.40 | -0.04 | .871 |
| N170 | Happy | -1.17 | -0.61, 0.04 | -2.85 | .084 |
| | Sad | -0.04 | -0.34, 0.33 | -0.01 | .965 |
| LPP | Happy | -0.29 | 0.36, 0.27 | -0.05 | .769 |
| | Sad | 0.30 | -0.23, 0.31 | 0.04 | .767 |

*Note.* All t-tests have a *df* of 37.

# 8 References

Abdelatief, E. E. M. (2020). Effect of Transcutaneous Electrical Nerve Stimulation and Faradic Current Stimulation on the Recovery of Bell's Palsy. *International Journal of Human Movement and Sports Sciences*, *8*(6), 369–379. https://doi.org/10.13189/saj.2020.080608

Abe, T., & Loenneke, J. P. (2019). The Influence of Facial Muscle Training on the Facial Soft Tissue Profile: A Brief Review. *Cosmetics*, *6*(3), 50. https://doi.org/10.3390/cosmetics6030050

Abraham, A., Alabdali, M., Alsulaiman, A., Breiner, A., Barnett, C., Katzberg, H. D., & Bril, V. (2016). Repetitive facial nerve stimulation in myasthenia gravis 1 min after muscle activation is inferior to testing a second muscle at rest. *Clinical Neurophysiology*, *127*(10), 3294–3297.

Abu-Khaber, H. A., Abouelela, A. M. Z., & Abdelkarim, E. M. (2013). Effect of electrical muscle stimulation on prevention of ICU acquired muscle weakness and facilitating weaning from mechanical ventilation. *Alexandria Journal of Medicine*, *49*(4), Article 4. https://doi.org/10.4314/bafm.v49i4

Achaibou, A., Pourtois, G., Schwartz, S., & Vuilleumier, P. (2008). Simultaneous recording of EEG and facial muscle reactions during spontaneous emotional mimicry. *Neuropsychologia*, *46*(4), 1104–1113. https://doi.org/10.1016/j.neuropsychologia.2007.10.019

Adelmann, P. K., & Zajonc, R. B. (1989). Facial Efference and the Experience of Emotion. *Annual Review of Psychology*, *40*(1), 249–280. https://doi.org/10.1146/annurev.ps.40.020189.001341

Adour, K. K., Ruboyianes, J. M., Trent, C. S., Von Doersten, P. G., Quesenberry, C. P., Byl, F. M., & Hitchcock, T. (1996). Bell's Palsy Treatment with Acyclovir and Prednisone Compared with Prednisone Alone: A Double-Blind, Randomized, Controlled Trial. *Annals of Otology, Rhinology & Laryngology*, *105*(5), 371–378. https://doi.org/10.1177/000348949610500508

Alabas, O. A., Tashani, O. A., Tabasam, G., & Johnson, M. I. (2012). Gender role affects experimental pain responses: A systematic review with meta-analysis. *European Journal of Pain*, *16*(9), 1211–1223. https://doi.org/10.1002/j.1532-2149.2012.00121.x

Alakram, P., & Puckree, T. (2010). Effects of electrical stimulation on house-brackmann scores in early bells palsy. *Physiotherapy Theory and Practice*, *26*(3), Article 3. https://doi.org/10.3109/09593980902886339

Alaoui-Ismaïli, O., Robin, O., Rada, H., Dittmar, A., & Vernet-Maury, E. (1997). Basic Emotions Evoked by Odorants: Comparison Between Autonomic Responses and Self-Evaluation. *Physiology & Behavior*, *62*(4), 713–720. https://doi.org/10.1016/S0031-9384(97)90016-0

Albert, S. M., & Duffy, J. (2012). Differences in Risk Aversion between Young and Older Adults. *Neuroscience and Neuroeconomics*, *2012*(1), 10.2147/NAN.S27184. https://doi.org/10.2147/NAN.S27184

Alon, G., Levitt, A. F., & McCarthy, P. A. (2007). Functional Electrical Stimulation Enhancement of Upper Extremity Functional Recovery During Stroke Rehabilitation: A Pilot Study. *Neurorehabilitation and Neural Repair*, *21*(3), 207–215. https://doi.org/10.1177/1545968306297871

Alyassiri, A. M. H., & Zaidan, T. F. (2019). Comparison between the beneficial Effects of Low Level Laser Therapy (Diode Laser) and Transcutenous Electrical Nerve Stimulation in Recovery of Patients with Bell's palsy. *Indian Journal of Forensic*

*Medicine & Toxicology*, *13*(1), Article 1. https://doi.org/10.5958/0973-9130.2019.00065.3

Ansfield, M. E. (2007). Smiling When Distressed: When a Smile Is a Frown Turned Upside Down. *Personality and Social Psychology Bulletin*, *33*(6), 763–775. https://doi.org/10.1177/0146167206297398

Anvari, F., Kievit, R., Lakens, D., Pennington, C. R., Przybylski, A. K., Tiokhin, L., Wiernik, B. M., & Orben, A. (2023). Not All Effects Are Indispensable: Psychological Science Requires Verifiable Lines of Reasoning for Whether an Effect Matters. *Perspectives on Psychological Science*, *18*(2), 503–507. https://doi.org/10.1177/17456916221091565

Appel, M., Gnambs, T., & Maio, G. R. (2012). A Short Measure of the Need for Affect. *Journal of Personality Assessment*, *94*(4), 418–426. https://doi.org/10.1080/00223891.2012.666921

Appel, M., & Richter, T. (2010). Transportation and Need for Affect in Narrative Persuasion: A Mediated Moderation Model. *Media Psychology*, *13*(2), 101–135. https://doi.org/10.1080/15213261003799847

Argaud, S., Vérin, M., Sauleau, P., & Grandjean, D. (2018). Facial emotion recognition in Parkinson's disease: A review and new hypotheses. *Movement Disorders*, *33*(4), 554–567. https://doi.org/10.1002/mds.27305

Arpin, D. J., Ugiliweneza, B., Forrest, G., Harkema, S. J., & Rejc, E. (2019). Optimizing Neuromuscular Electrical Stimulation Pulse Width and Amplitude to Promote Central Activation in Individuals With Severe Spinal Cord Injury. *Frontiers in Physiology*, *10*, 1310. https://doi.org/10.3389/fphys.2019.01310

Atchley, P., Atwood, S., & Boulton, A. (2011). The choice to text and drive in younger drivers: Behavior may shape attitude. *Accident Analysis & Prevention*, *43*(1), 134–142. https://doi.org/10.1016/j.aap.2010.08.003

Atlas, L. Y., & Wager, T. D. (2012). How expectations shape pain. *Neuroscience Letters*, *520*(2), 140–148. https://doi.org/10.1016/j.neulet.2012.03.039

Baad-Hansen, L., List, T., Jensen, T. S., & Svensson, P. (2006). Increased pain sensitivity to intraoral capsaicin in patients with atypical odontalgia. *Journal of Orofacial Pain*, *20*(2).

Baad-Hansen, L., List, T., Kaube, H., Jensen, T. S., & Svensson, P. (2006). Blink reflexes in patients with atypical odontalgia and matched healthy controls. *Experimental Brain Research*, *172*(4), Article 4. https://doi.org/10.1007/s00221-006-0358-1

Baduni, A., & Krishnamoorthy, B. (2017). Treatment of hemifacial spasm in patient with hemifacial atrophy using combination therapy (ultrasound therapy and TENS): A case report. *The Korean Journal of Pain*, *30*(4), Article 4. https://doi.org/10.3344/kjp.2017.30.4.304

Baijens, L. W. J., Speyer, R., Roodenburg, N., & Manni, J. J. (2008). The effects of neuromuscular electrical stimulation for dysphagia in opercular syndrome: A case study. *European Archives of Oto-Rhino-Laryngology*, *265*(7), Article 7. https://doi.org/10.1007/s00405-007-0516-5

Baker, J., Efthimiou, T., Scherer, R., Gartus, A., Elsenaar, A., Mehu, M., & Korb, S. (2023). Measurement of the N170 during facial neuromuscular electrical stimulation (fNMES). *Journal of Neuroscience Methods*, 109877. https://doi.org/10.1016/j.jneumeth.2023.109877

Balagopal, P. G., George, N. A., & Sebastian, P. (2012). Anatomic Variations of the Marginal Mandibular Nerve. *Indian Journal of Surgical Oncology*, *3*(1), 8–11. https://doi.org/10.1007/s13193-011-0121-3

Balconi, M., Pala, F., Manenti, R., Brambilla, M., Cobelli, C., Rosini, S., Benussi, A., Padovani, A., Borroni, B., & Cotelli, M. (2016). Facial feedback and autonomic responsiveness reflect impaired emotional processing in Parkinson's Disease. *Scientific Reports*, *6*(1), Article 1. https://doi.org/10.1038/srep31453

Baldwin, E. R. L., Klakowicz, P. M., & Collins, D. F. (2006). Wide-pulse-width, high-frequency neuromuscular stimulation: Implications for functional electrical stimulation. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *101*(1), 228–240. https://doi.org/10.1152/japplphysiol.00871.2005

Balmaseda, M. T., Fatehi, M. T., Koozekanani, S. H., & Sheppard, J. S. (1987). Burns in functional electric stimulation: Two case reports. *Archives of Physical Medicine and Rehabilitation*, *68*(7), 452–453.

Baltrusaitis, T., Zadeh, A., Lim, Y. C., & Morency, L.-P. (2018). OpenFace 2.0: Facial Behavior Analysis Toolkit. *2018 13th IEEE International Conference on Automatic Face & Gesture Recognition (FG 2018)*, 59–66. https://doi.org/10.1109/FG.2018.00019

Barlow, D. H., Sauer-Zavala, S., Carl, J. R., Bullis, J. R., & Ellard, K. K. (2014). The Nature, Diagnosis, and Treatment of Neuroticism: Back to the Future. *Clinical Psychological Science*, *2*(3), 344–365. https://doi.org/10.1177/2167702613505532

Baron-Cohen, S., Hoekstra, R. A., Knickmeyer, R., & Wheelwright, S. (2006). The Autism-Spectrum Quotient (AQ)—Adolescent Version. *Journal of Autism and Developmental Disorders*, *36*(3), 343–350. https://doi.org/10.1007/s10803-006-0073-6

Barrett, L. F., Adolphs, R., Marsella, S., Martinez, A. M., & Pollak, S. D. (2019). Emotional Expressions Reconsidered: Challenges to Inferring Emotion From Human Facial Movements. *Psychological Science in the Public Interest*, *20*(1), 1–68. https://doi.org/10.1177/1529100619832930

Barsalou, L. W. (2008). Grounded Cognition. *Annual Review of Psychology*, *59*(1), 617–645.

Barsalou, L. W. (2010). Grounded Cognition: Past, Present, and Future. *Topics in Cognitive Science*, *2*(4), 716–724. https://doi.org/10.1111/j.1756-8765.2010.01115.x

Bates, D., Mächler, M., Bolker, B., & Walker, S. (2015). Fitting Linear Mixed-Effects Models Using lme4. *Journal of Statistical Software*, *67*(1), Article 1. https://doi.org/10.18637/jss.v067.i01

Baumeister, J.-C., Papa, G., & Foroni, F. (2016). Deeper than skin deep – The effect of botulinum toxin-A on emotion processing. *Toxicon*, *118*, 86–90. https://doi.org/10.1016/j.toxicon.2016.04.044

Beffara, B., Ouellet, M., Vermeulen, N., Basu, A., Morisseau, T., & Mermillod, M. (2012). Enhanced embodied response following ambiguous emotional processing. *Cognitive Processing*, *13*(S1), 103–106. https://doi.org/10.1007/s10339-012-0468-6

Benoliel, R., Zaidan, S., & Eliav, E. (2011). Acupuncture modulates facial warm sensory thresholds. *Journal of Orofacial Pain*, *25*(1).

Bentin, S., Allison, T., Puce, A., Perez, E., & McCarthy, G. (1996). Electrophysiological Studies of Face Perception in Humans. *Journal of Cognitive Neuroscience*, *8*(6), 551–565. https://doi.org/10.1162/jocn.1996.8.6.551

Bentsianov, B., & Blitzer, A. (2004). Facial anatomy. *Clinics in Dermatology*, *22*(1), 3–13. https://doi.org/10.1016/j.clindermatol.2003.11.011

Bergenheim, A. T., Hariz, M. I., Laitinen, L. V., Olivecrona, M., & Rabow, L. (1991). Relation between sensory disturbance and outcome after retrogasserian glycerol rhizotomy. *Acta Neurochirurgica*, *111*, 114–118.

Bergquist, A. J., Clair, J. M., & Collins, D. F. (2011). Motor unit recruitment when neuromuscular electrical stimulation is applied over a nerve trunk compared with a muscle belly: Triceps surae. *Journal of Applied Physiology (Bethesda, Md.: 1985)*, *110*(3), 627–637. https://doi.org/10.1152/japplphysiol.01103.2010

Biasiucci, A., Franceschiello, B., & Murray, M. M. (2019). Electroencephalography. *Current Biology*, *29*(3), R80–R85. https://doi.org/10.1016/j.cub.2018.11.052

Birch-Hurst, K., Rychlowska, M., Lewis, M. B., & Vanderwert, R. E. (2022). Altering Facial Movements Abolishes Neural Mirroring of Facial Expressions. *Cognitive, Affective, & Behavioral Neuroscience*, *22*(2), 316–327. https://doi.org/10.3758/s13415-021-00956-z

Bischoff, C., Liscic, R., Meyer, B., Machetanz, J., & Conrad, B. (1993). Magnetically elicited blink reflex: An alternative to conventional electrical stimulation. *Electromyography and Clinical Neurophysiology*, *33*, 265–269.

Blais, A.-R., & Weber, E. U. (2006). A Domain-Specific Risk-Taking (DOSPERT) scale for adult populations. *Judgment and Decision Making*, *1*(1), 15.

Blouin, J.-S., Walsh, L. D., Nickolls, P., & Gandevia, S. C. (2009). High-frequency submaximal stimulation over muscle evokes centrally generated forces in human upper limb skeletal muscles. *Journal of Applied Physiology*, *106*(2), 370–377. https://doi.org/10.1152/japplphysiol.90939.2008

Boelhouwer, A. J. W., Gregorič, M., Van den Bosch, W. E. J., Schomaker, L. R. B., & Brunia, C. H. M. (1982). Habituation of the human blink reflex: The effect of stimulus frequency and the state of arousal. *Physiological Psychology*, *10*, 325–330.

Boiardi, A., Bussone, G., Caccia, M. R., & Rocca, E. (1975). Electrophysiological Evidence for a Neurohormonal Dependence in the Changes of the Late Glabellar Response in Man. *European Neurology*, *13*(6), Article 6. https://doi.org/10.1159/000114707

Borodic, G. E., Cozzolino, D., Ferrante, R., Wiegner, A. W., & Young, R. R. (1991). Innervation Zone of Orbicularis Oculi Muscle and Implications for Botulinum A Toxin Therapy: *Ophthalmic Plastic & Reconstructive Surgery*, *7*(1), Article 1. https://doi.org/10.1097/00002341-199103000-00007

Bour, L. J., Aramideh, M., & Ongerboer De Visser, B. W. (2000). Neurophysiological aspects of eye and eyelid movements during blinking in humans. *Journal of Neurophysiology*, *83*(1), 166–176.

Brown, B. C., McKenna, S. P., Siddhi, K., McGrouther, D. A., & Bayat, A. (2008). The hidden cost of skin scars: Quality of life after skin scarring. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *61*(9), 1049–1058. https://doi.org/10.1016/j.bjps.2008.03.020

BS IEC 60479-1:2018. (2019). Effects of current on human beings and livestock. General Aspects. BSI.

Buck, R. (1980). Nonverbal behavior and the theory of emotion: The facial feedback hypothesis. *Journal of Personality and Social Psychology*, *38*(5), 811–824. https://doi.org/10.1037/0022-3514.38.5.811

Bulnes, L. C., Mariën, P., Vandekerckhove, M., & Cleeremans, A. (2019). The effects of Botulinum toxin on the detection of gradual changes in facial emotion. *Scientific Reports*, *9*(1), 11734. https://doi.org/10.1038/s41598-019-48275-1

Bulnes, L. C., Vandenthoren, L., Cleeremans, A., & Vandekerckhove, M. (2023). The effects of repeated facial motor and affective matching on Identification and detection of static and dynamic facial expressions. PsyArXiv. https://doi.org/10.31234/osf.io/8tqwr

Bürkner, P.-C. (2017). brms: An R Package for Bayesian Multilevel Models Using Stan. *Journal of Statistical Software*, *80*, 1–28. https://doi.org/10.18637/jss.v080.i01

Byrnes, J. P., Miller, D. C., & Schafer, W. D. (1999). Gender differences in risk taking: A meta-analysis. *Psychological Bulletin*, *125*(3), 367–383. https://doi.org/10.1037/0033-2909.125.3.367

Cacho, A., Tordera, C., & Colmenero, C. (2022). Use of Transcutaneous Electrical Nerve Stimulation (TENS) for the Recovery of Oral Function after Orthognathic Surgery. *Journal of Clinical Medicine*, *11*(12), Article 12. https://doi.org/10.3390/jcm11123268

Calder, A. J. (Ed.). (2011). *The Oxford handbook of face perception*. Oxford University Press.

Calvo, M. G., Marrero, H., & Beltrán, D. (2013). When does the brain distinguish between genuine and ambiguous smiles? An ERP study. *Brain and Cognition*, *81*(2), 237–246. https://doi.org/10.1016/j.bandc.2012.10.009

Cannon, W. B. (1927). The James-Lange Theory of Emotions: A Critical Examination and an Alternative Theory. *The American Journal of Psychology*, *39*(1/4), 106–124. JSTOR. https://doi.org/10.2307/1415404

Carpenter, S. M., & Niedenthal, P. M. (2019). Disrupting facial action increases risk taking. *Emotion*, No Pagination Specified-No Pagination Specified. https://doi.org/10.1037/emo0000597

Carson, R. G., & Buick, A. R. (2019). Neuromuscular electrical stimulation-promoted plasticity of the human brain. *The Journal of Physiology*. https://doi.org/10.1113/JP278298

Casanova-Molla, J., León, L., Castillo, C. D., & Valls-Solé, J. (2011). Reinnervation by the contralateral facial nerve in patients with peripheral facial palsy. *Muscle & Nerve*, *44*(6), 923–929.

Cattaneo, L., & Pavesi, G. (2014). The facial motor system. *Neuroscience & Biobehavioral Reviews*, *38*, 135–159. https://doi.org/10.1016/j.neubiorev.2013.11.002

Cheong, J. H., Xie, T., Byrne, S., & Chang, L. J. (2021). *Py-Feat: Python Facial Expression Analysis Toolbox* (arXiv:2104.03509). arXiv. https://doi.org/10.48550/arXiv.2104.03509

Chia, L.-G. (1997). Late blink reflex changes in lesions of thalamus and internal capsule. *Neurology*, *49*(3), Article 3. https://doi.org/10.1212/WNL.49.3.874

Choi, J.-B. (2016). Effect of neuromuscular electrical stimulation on facial muscle strength and oral function in stroke patients with facial palsy. *Journal of Physical Therapy Science*, *28*(9), 2541–2543. https://doi.org/10.1589/jpts.28.2541

Cobo, J. L., Abbate, F., de Vicente, J. C., Cobo, J., & Vega, J. A. (2017). Searching for proprioceptors in human facial muscles. *Neuroscience Letters*, *640*, 1–5. https://doi.org/10.1016/j.neulet.2017.01.016

Cobo, J. L., Solé-Magdalena, A., Junquera, S., Cobo, T., Vega, J. A., & Cobo, J. (2019). The Proprioception in the Muscles Supplied by the Facial Nerve. *Selected Topics in Facial Nerve Disorders*. https://doi.org/10.5772/intechopen.84463

Cobo, J. L., Solé-Magdalena, A., Menéndez, I., de Vicente, J. C., & Vega, J. A. (2017). Connections between the facial and trigeminal nerves: Anatomical basis for facial muscle proprioception. *JPRAS Open*, *12*, 9–18. https://doi.org/10.1016/j.jpra.2017.01.005

Coelho, G. L. de H., Hanel, P. H. P., Vilar, R., Monteiro, R. P., Gouveia, V. V., & Maio, G. R. (2018). Need for Affect and Attitudes Toward Drugs: The Mediating Role of Values. *Substance Use & Misuse*, *53*(13), 2232–2239. https://doi.org/10.1080/10826084.2018.1467454

Coles, N. A., Gaertner, L., Frohlich, B., Larsen, J. T., & Basnight-Brown, D. M. (2023). Fact or artifact? Demand characteristics and participants' beliefs can moderate, but do not fully account for, the effects of facial feedback on emotional experience. *Journal of Personality and Social Psychology*, *124*(2), 287–310. https://doi.org/10.1037/pspa0000316

Coles, N. A., Larsen, J. T., Kuribayashi, J., & Kuelz, A. (2019a). Does Blocking Facial Feedback Via Botulinum Toxin Injections Decrease Depression? A Critical Review and Meta-Analysis. *Emotion Review*, *11*(4), 294–309. https://doi.org/10.1177/1754073919868762

Coles, N. A., Larsen, J. T., & Lench, H. C. (2019b). A meta-analysis of the facial feedback literature: Effects of facial feedback on emotional experience are small and variable. *Psychological Bulletin*, *145*(6), 610–651. https://doi.org/10.1037/bul0000194

Coles, N. A., March, D. S., Marmolejo-Ramos, F., Larsen, J. T., Arinze, N. C., Ndukaihe, I. L. G., Willis, M. L., Foroni, F., Reggev, N., Mokady, A., Forscher, P. S., Hunter, J. F., Kaminski, G., Yüvrük, E., Kapucu, A., Nagy, T., Hajdu, N., Tejada, J., Freitag, R. M. K., … Liuzza, M. T. (2022). A multi-lab test of the facial feedback hypothesis by the Many Smiles Collaboration. *Nature Human Behaviour*, *6*(12), Article 12. https://doi.org/10.1038/s41562-022-01458-9

Collet, C., Vernet-Maury, E., Delhomme, G., & Dittmar, A. (1997). Autonomic nervous system response patterns specificity to basic emotions. *Journal of the Autonomic Nervous System*, *62*(1), 45–57. https://doi.org/10.1016/S0165-1838(96)00108-7

Collins, D. F., Refshauge, K. M., Todd, G., & Gandevia, S. C. (2005). Cutaneous receptors contribute to kinesthesia at the index finger, elbow, and knee. *Journal of Neurophysiology*, *94*(3), 1699–1706. https://doi.org/10.1152/jn.00191.2005

Conte, A., Fabbrini, G., Belvisi, D., Marsili, L., Di Stasio, F., & Berardelli, A. (2010). Electrical activation of the orbicularis oculi muscle does not increase the effectiveness of botulinum toxin type A in patients with blepharospasm: Botulinum toxin type A in blepharospasm. *European Journal of Neurology*, *17*(3), Article 3. https://doi.org/10.1111/j.1468-1331.2009.02840.x

Conti, P. C. R., Stuginski-Barbosa, J., Bonjardim, L. R., Soares, S., & Svensson, P. (2014). Contingent electrical stimulation inhibits jaw muscle activity during sleep but not pain intensity or masticatory muscle pressure pain threshold in self-reported bruxers: A pilot study. *Oral Surgery, Oral Medicine, Oral Pathology and Oral Radiology*, *117*(1), Article 1. https://doi.org/10.1016/j.oooo.2013.08.015

Cooper, A. J., Smillie, L. D., & Corr, P. J. (2010). A confirmatory factor analysis of the Mini-IPIP five-factor model personality scale. *Personality and Individual Differences*, *48*(5), 688–691. https://doi.org/10.1016/j.paid.2010.01.004

Cooper, M. L., Agocha, V. B., & Sheldon, M. S. (2000). A Motivational Perspective on Risky Behaviors: The Role of Personality and Affect Regulatory Processes. *Journal of Personality*, *68*(6), 1059–1088. https://doi.org/10.1111/1467-6494.00126

Corbet, T., Iturrate, I., Pereira, M., Perdikis, S., & Millán, J. del R. (2018). Sensory threshold neuromuscular electrical stimulation fosters motor imagery performance. *NeuroImage*, *176*, 268–276. https://doi.org/10.1016/j.neuroimage.2018.04.005

Cross, M. P., Acevedo, A. M., Leger, K. A., & Pressman, S. D. (2023). How and why could smiling influence physical health? A conceptual review. *Health Psychology Review*, *17*(2), 321–343. https://doi.org/10.1080/17437199.2022.2052740

Cross, M. P., Gheorma, L., & Pressman, S. D. (2019). Contrasting Experimentally Device-Manipulated and Device-Free Smiles. *Frontiers in Psychology*, *10*. https://doi.org/10.3389/fpsyg.2019.02297

Cui, H., Yu, H., Huang, X., Wu, L., Zhong, W., Gou, Y., Cao, X., Liu, Y., Hong, Y., Zhang, S., Zhan, M., Li, G., & Yang, Z. (2021). Electroacupuncture and Transcutaneous Electrical Nerve Stimulation Induced Sensations in Bell's Palsy Patients: A Quantitative Current Intensity Analysis. *Frontiers in Neuroscience*, *15*, 692088. https://doi.org/10.3389/fnins.2021.692088

Currier, W. D. (1963). XXII Effects of Electronic Stimulation of the VII Nerve: I. On Senescent Changes of the Face. *Annals of Otology, Rhinology & Laryngology*, *72*(2), 289–306. https://doi.org/10.1177/000348946307200201

da Silva, C., Costa, G., Aguiar, A., Camargo, M., Fernandes, K., Oliveira, M., & da Silva, R. (2022). Effect of the Use of a Cream with Leucine and Lactic Acid Associated with Electrostimulation in Contouring and Facial Tonus: A Randomized Clinical Controlled Trial. *Cosmetics*, *9*(2), Article 2. https://doi.org/10.3390/cosmetics9020036

Darwin, C. (1872). The expression of the emotions in man and animals. *London: Murray.(2nd*.

Darwin, C., & Prodger, P. (1998). *The Expression of the Emotions in Man and Animals*. Oxford University Press.

Davis, J. D., Winkielman, P., & Coulson, S. (2015). Facial Action and Emotional Language: ERP Evidence that Blocking Facial Feedback Selectively Impairs Sentence Comprehension. *Journal of Cognitive Neuroscience*, *27*(11), 2269–2280. https://doi.org/10.1162/jocn_a_00858

Davis, J. D., Winkielman, P., & Coulson, S. (2017). Sensorimotor simulation and emotion processing: Impairing facial action increases semantic retrieval demands. *Cognitive, Affective, & Behavioral Neuroscience*, *17*(3), 652–664. https://doi.org/10.3758/s13415-017-0503-2

Davis, J. I., Senghas, A., Brandt, F., & Ochsner, K. N. (2010). The effects of BOTOX injections on emotional experience. *Emotion (Washington, D.C.)*, *10*(3), 433–440. https://doi.org/10.1037/a0018690

Davis, J. I., Senghas, A., & Ochsner, K. N. (2009). How Does Facial Feedback Modulate Emotional Experience? *Journal of Research in Personality*, *43*(5), 822–829. https://doi.org/10.1016/j.jrp.2009.06.005

De Bonnecaze, G., Vergez, S., Chaput, B., Vairel, B., Serrano, E., Chantalat, E., & Chaynes, P. (2019). Variability in facial-muscle innervation: A comparative study based on electrostimulation and anatomical dissection. *Clinical Anatomy*, *32*(2), 169–175. https://doi.org/10.1002/ca.23081

De Giorgi, I., Castroflorio, T., Sartoris, B., & Deregibus, A. (2017). The use of conventional transcutaneous electrical nerve stimulation in chronic facial myalgia patients. *Clinical Oral Investigations*, *21*, 275–280.

de Sire, A., Marotta, N., Agostini, F., Drago Ferrante, V., Demeco, A., Ferrillo, M., Inzitari, M. T., Pellegrino, R., Russo, I., & Ozyemisci Taskiran, O. (2022). A telerehabilitation approach to chronic facial paralysis in the COVID-19 pandemic scenario: What role for electromyography assessment? *Journal of Personalized Medicine*, *12*(3), 497.

de Tommaso, M., Sciruicchio, V., Spinelli, A., Specchio, N., Difruscolo, O., Puca, F., & Specchio, L. M. (2001). Features of the blink reflex in individuals at risk for Huntington's disease. *Muscle & Nerve*, *24*(11), Article 11. https://doi.org/10.1002/mus.1177

Delorme, A., & Makeig, S. (2004). EEGLAB: An open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *Journal of Neuroscience Methods*, *134*(1), 9–21. https://doi.org/10.1016/j.jneumeth.2003.10.009

Demchenko, I., Desai, N., Iwasa, S. N., Gholamali Nezhad, F., Zariffa, J., Kennedy, S. H., Rule, N. O., Cohn, J. F., Popovic, M. R., Mulsant, B. H., & Bhat, V. (2023). Manipulating facial musculature with functional electrical stimulation as an intervention for major depressive disorder: A focused search of literature for a proposal. *Journal of NeuroEngineering and Rehabilitation*, *20*(1), 64. https://doi.org/10.1186/s12984-023-01187-8

DeYoung, C. G. (2013). The neuromodulator of exploration: A unifying theory of the role of dopamine in personality. *Frontiers in Human Neuroscience*, *7*. https://doi.org/10.3389/fnhum.2013.00762

DeYoung, C. G. (2015). Openness/intellect: A dimension of personality reflecting cognitive exploration. In *APA handbook of personality and social psychology, Volume 4: Personality processes and individual differences* (pp. 369–399). American Psychological Association. https://doi.org/10.1037/14343-017

Di Lernia, D., Serino, S., & Riva, G. (2016). Pain in the body. Altered interoception in chronic pain conditions: A systematic review. *Neuroscience & Biobehavioral Reviews*, *71*, 328–341. https://doi.org/10.1016/j.neubiorev.2016.09.015

Didier, H. A., Cappellari, A. M., Gaffuri, F., Curone, M., Tullo, V., Didier, A. H., Giannì, A. B., & Bussone, G. (2019). The role of electrophysiological investigations of masticatory muscles in patients with persistent idiopathic facial pain. *Neurological Sciences*, *40*(S1), Article S1. https://doi.org/10.1007/s10072-019-03770-1

Dimberg, U. (1988). Facial electromyography and the experience of emotion. *Journal of Psychophysiology*, *2*(4), 277–282.

Dimberg, U., & Söderkvist, S. (2011). The Voluntary Facial Action Technique: A Method to Test the Facial Feedback Hypothesis. *Journal of Nonverbal Behavior*, *35*(1), 17–33. https://doi.org/10.1007/s10919-010-0098-6

Dimberg, U., Thunberg, M., & Elmehed, K. (2000). Unconscious Facial Reactions to Emotional Facial Expressions. *Psychological Science*, *11*(1), 86–89. https://doi.org/10.1111/1467-9280.00221

Doheny, E. P., Caulfield, B. M., Minogue, C. M., & Lowery, M. M. (2008). The effect of subcutaneous fat thickness on the efficacy of transcutaneous electrical stimulation. *2008 30th Annual International Conference of the IEEE Engineering in Medicine and Biology Society*, 5684–5687. https://doi.org/10.1109/IEMBS.2008.4650504

Doheny, E. P., Caulfield, B. M., Minogue, C. M., & Lowery, M. M. (2010). Effect of subcutaneous fat thickness and surface electrode configuration during neuromuscular electrical stimulation. *Medical Engineering & Physics*, *32*(5), 468–474. https://doi.org/10.1016/j.medengphy.2010.03.004

Donnellan, M. B., Oswald, F. L., Baird, B. M., & Lucas, R. E. (2006). The Mini-IPIP Scales: Tiny-yet-effective measures of the Big Five Factors of Personality. *Psychological Assessment*, *18*(2), 192–203. https://doi.org/10.1037/1040-3590.18.2.192

Doucet, B. M., Lam, A., & Griffin, L. (2012). Neuromuscular Electrical Stimulation for Skeletal Muscle Function. *The Yale Journal of Biology and Medicine*, *85*(2), 201–215.

Doucet, B. M., & Mettler, J. A. (2018). Pilot Study Combining Electrical Stimulation and a Dynamic Hand Orthosis for Functional Recovery in Chronic Stroke. *The American Journal of Occupational Therapy: Official Publication of the American Occupational Therapy Association*, *72*(2), 7202345030p1-7202345030p6. https://doi.org/10.5014/ajot.2018.025007

D'Souza, A., & Ng, C. L. (2020). Applied Anatomy for Botulinum Toxin Injection in Cosmetic Interventions. *Current Otorhinolaryngology Reports*, *8*(4), 336–343. https://doi.org/10.1007/s40136-020-00308-4

Duchenne, G.-B. (1862). Mécanisme de la physionomie humaine: Où, Analyse électro-physiologique de l'expression des passions. J.-B. Baillière.

Duclos, S. E., Laird, J. D., Schneider, E., Sexter, M., Stern, L., & Van Lighten, O. (1989). Emotion-specific effects of facial expressions and postures on emotional experience. *Journal of Personality and Social Psychology*, *57*(1), 100–108. https://doi.org/10.1037/0022-3514.57.1.100

Duncan, J. W., & Laird, J. D. (1980). Positive and reverse placebo effects as a function of differences in cues used in self-perception. *Journal of Personality and Social Psychology*, *39*(6), 1024–1036. https://doi.org/10.1037/h0077721

Dupré, D., Krumhuber, E. G., Küster, D., & McKeown, G. J. (2020). A performance comparison of eight commercially available automatic classifiers for facial affect recognition. *PLOS ONE*, *15*(4), e0231968. https://doi.org/10.1371/journal.pone.0231968

Efthimiou, T. N., Baker, J., Clarke, A., Elsenaar, A., Mehu, M., & Korb, S. (2023a). Zygomaticus activation through facial neuromuscular electric stimulation (fNMES) induces happiness perception in ambiguous facial expressions and affects neural correlates of face processing. PsyArXiv. https://doi.org/10.31234/osf.io/38whf

Efthimiou, T. N., Baker, J., Elsenaar, A., Mehu, M., & Korb, S. (2023b). Smiling and frowning induced by facial neuromuscular electrical stimulation (fNMES) modulate felt emotion and physiology. PsyArXiv. https://doi.org/10.31234/osf.io/vec8f

Efthimiou, T. N., Hanel, P. H. P., & Korb, S. (2022). Volunteers' concerns about facial neuromuscular electrical stimulation. *BMC Psychology*, *10*(1), 117. https://doi.org/10.1186/s40359-022-00827-3

Efthimiou, T. N., Hernandez, M. P., Elsenaar, A., Mehu, M., & Korb, S. (2023c

). Application of facial neuromuscular electrical stimulation (fNMES) in psychophysiological research: Practical recommendations based on a systematic review of the literature. *Behavior Research Methods*. https://doi.org/10.3758/s13428-023-02262-7

Eimer, M. (2011). *The Face-Sensitive N170 Component of the Event-Related Brain Potential*. Oxford University Press. https://doi.org/10.1093/oxfordhb/9780199559053.013.0017

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia*, *45*(1), 15–31. https://doi.org/10.1016/j.neuropsychologia.2006.04.022

Ekman. (1973). Universal Facial Expressions in Emotion. *Studia Psychologica; Bratislava*, *15*(2), 140–147.

Ekman, & Davidson, R. J. (1990). The Duchenne Smile: Emotional Expression and Brain Physiology II. 12.

Ekman, P. (2007). The Directed Facial Action Task: Emotional responses without appraisal. In *Handbook of emotion elicitation and assessment* (pp. 47–53). Oxford University Press.

Ekman, P., Friesen, W. V., & Hager, J. C. (2002). The Facial Action Coding System: A Technique for the Measurement of Facial Movement. San Francisco, CA: Consulting Psychologists Press. San Francisco, CA: Consulting Psychologists Press.

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic nervous system activity distinguishes among emotions. *Science*, *221*(4616), 1208–1210.

El Ansari, W., Dibba, E., & Stock, C. (2014). Body Image Concerns: Levels, Correlates and Gender Differences among Students in the United Kingdom. *Central European Journal of Public Health*, *22*(2), 106–117. https://doi.org/10.21101/cejph.a3944

El-Ebiary, H. M. (1971). PROGNOSIS IN BELL'S PALSY. *Rheumatology*, *11*(3), Article 3. https://doi.org/10.1093/rheumatology/11.3.111

Eliav, E., Teich, S., Nitzan, D., El Raziq, D. A., Nahlieli, O., Tal, M., Gracely, R. H., & Benoliel, R. (2003). Facial arthralgia and myalgia: Can they be differentiated by trigeminal sensory assessment? *Pain*, *104*(3), 481–490.

Elsenaar, A. (2010). *Facial hacking: The twisted logic of electro-facial choreography* [Doctoral, Nottingham Trent University]. http://irep.ntu.ac.uk/id/eprint/205/

Elsenaar, A., & Scha, R. (2002). Electric Body Manipulation as Performance Art: A Historical Perspective. *Leonardo Music Journal*, *12*, 17–28. JSTOR.

Esteban, A., & Prieto, J. (1999). Unmasking of the trigemino-accessory reflex in accessory facial anastomosis. *Journal of Neurology, Neurosurgery & Psychiatry*, *67*(3), 379–383.

Fargher, K. A., & Coulson, S. E. (2017). Effectiveness of electrical stimulation for rehabilitation of facial nerve paralysis. *Physical Therapy Reviews*, *22*(3–4), 169–176. https://doi.org/10.1080/10833196.2017.1368967

Farronato, M., Farronato, D., Giannì, A. B., Inchingolo, F., Nucci, L., Tartaglia, G. M., & Maspero, C. (2022). Effects on Muscular Activity after Surgically Assisted Rapid Palatal Expansion: A Prospective Observational Study. *Bioengineering*, *9*(8), 361.

Feher, J. (2012). 4.3—Cutaneous Sensory Systems. In J. Feher (Ed.), *Quantitative Human Physiology (Second Edition)* (pp. 389–399). Academic Press. https://doi.org/10.1016/B978-0-12-800883-6.00035-5

Ferreira, A. P. de L., Costa, D. R. A. da, Oliveira, A. I. S. de, Carvalho, E. A. N., Conti, P. C. R., Costa, Y. M., & Bonjardim, L. R. (2017). Short-term transcutaneous electrical nerve stimulation reduces pain and improves the masticatory muscle activity in temporomandibular disorder patients: A randomized controlled trial. *Journal of Applied Oral Science*, *25*, 112–120.

Ferreira, M. C., Salles, A. G., Gimenez, R., & Soares, M. F. D. (2004). Complications with the use of botulinum toxin type a in facial rejuvenation: Report of 8 cases. *Aesthetic Plastic Surgery*, *28*, 441–444.

Figner, B., & Weber, E. U. (2011). Who Takes Risks When and Why?: Determinants of Risk Taking. *Current Directions in Psychological Science*, *20*(4), 211–216. https://doi.org/10.1177/0963721411415790

Findler, G., & Feinsod, M. (1982). Sensory evoked response to electrical stimulation of the trigeminal nerve in humans. *Journal of Neurosurgery*, *56*(4), Article 4. https://doi.org/10.3171/jns.1982.56.4.0545

Finzi, E., & Rosenthal, N. E. (2014). Treatment of depression with onabotulinumtoxinA: A randomized, double-blind, placebo controlled trial. *Journal of Psychiatric Research*, *52*, 1–6. https://doi.org/10.1016/j.jpsychires.2013.11.006

Finzi, E., & Rosenthal, N. E. (2016). Emotional proprioception: Treatment of depression with afferent facial feedback. *Journal of Psychiatric Research*, *80*, 93–96. https://doi.org/10.1016/j.jpsychires.2016.06.009

Fisch, U. (1980). Maximal Nerve Excitability Testing vs Electroneuronography. *Archives of Otolaryngology - Head and Neck Surgery*, *106*(6), Article 6. https://doi.org/10.1001/archotol.1980.00790300040008

Flack, W. (2006). Peripheral feedback effects of facial expressions, bodily postures, and vocal expressions on emotional feelings. *Cognition and Emotion*, *20*(2), 177–195. https://doi.org/10.1080/02699930500359617

Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *WIREs Cognitive Science*, *4*(3), 319–325. https://doi.org/10.1002/wcs.1226

Fridlund, A. J., & Cacioppo, J. T. (1986). Guidelines for human electromyographic research. *Psychophysiology*, *23*(5), 567–589. https://doi.org/10.1111/j.1469-8986.1986.tb00676.x

Friesen, E., & Ekman, P. (1978). Facial action coding system: A technique for the measurement of facial movement. *Palo Alto*, *3*(2), 5.

Fromage, G. (2018). Exploring the effects of botulinum toxin type A injections on depression. *Journal of Aesthetic Nursing*, *7*(6), 315–317. https://doi.org/10.12968/joan.2018.7.6.315

Fukumoto, I., Tanaka, M., Uchiyama, H., Nakagawa, Y., Shi, X., Hasegawa, A., & Guo, Y. (2001). A study on the rehabilitation of cognitive function and short-term memory in patients with Alzheimer's disease using transcutaneous electrical nerve stimulation. *Frontiers of Medical and Biological Engineering*, *11*(4), Article 4. https://doi.org/10.1163/156855701321138905

Funder, D. C., & Ozer, D. J. (2019). Evaluating Effect Size in Psychological Research: Sense and Nonsense. *Advances in Methods and Practices in Psychological Science*, *2*(2), 156–168. https://doi.org/10.1177/2515245919847202

Galvez-Pol, A., Calvo-Merino, B., & Forster, B. (2020). Revealing the body in the brain: An ERP method to examine sensorimotor activity during visual perception of body-related information. *Cortex*, *125*, 332–344. https://doi.org/10.1016/j.cortex.2020.01.017

Gandiglio, G., & Fra, L. (1967). Further observations on facial reflexes. *Journal of the Neurological Sciences*, *5*(2), 273–285. https://doi.org/10.1016/0022-510X(67)90136-0

Geissler, P. R., & McPhee, P. M. (1986). Electrostimulation in the treatment of pain in the mandibular dysfunction syndrome. *Journal of Dentistry*, *14*(2), 62–64. https://doi.org/10.1016/0300-5712(86)90053-9

George, M. S., Sackeim, H. A., Rush, A. J., Marangell, L. B., Nahas, Z., Husain, M. M., Lisanby, S., Burt, T., Goldman, J., & Ballenger, J. C. (2000). Vagus nerve stimulation: A new tool for brain research and therapy∗. *Biological Psychiatry*, *47*(4), 287–295. https://doi.org/10.1016/S0006-3223(99)00308-X

Gilman, S., & Arbor, A. (1983). Handbook of physiology. Section 1: The nervous system, vol II. Motor control, parts 1 and 2. Section editors: John M. Brookhart and Vernon B. Mountcastle volume editor: Vernon B. Brooks Bethesda, MD, American Physiological Society, 1981 1480 pp, illustrated. *Annals of Neurology*, *13*(1), 111–111. https://doi.org/10.1002/ana.410130130

Ginatempo, F., De Carli, F., Todesco, S., Mercante, B., Sechi, G. P., & Deriu, F. (2018). Effects of acute trigeminal nerve stimulation on rest EEG activity in healthy adults. *Experimental Brain Research*, *236*(11), 2839–2845. https://doi.org/10.1007/s00221-018-5338-8

Gittins, J., Martin, K., Sbeldrick, J., Reddy, A., & Tbean, L. (1999). Electrical Stimulation as a Therapeutic Option to Improve Eyelid Function in Chronic Facial Nerve Disorders. 40(3).

Gobbo, M., Maffiuletti, N. A., Orizio, C., & Minetto, M. A. (2014). Muscle motor point identification is essential for optimizing neuromuscular electrical stimulation use. *Journal of NeuroEngineering and Rehabilitation*, *11*, 17. https://doi.org/10.1186/1743-0003-11-17

Goto, T., Tag, B., Kunze, K., Dingler, T., & Assoc Comp Machinery. (2018). *Towards Enhancing Emotional Responses to Media using Auto-Calibrating Electric Muscle Stimulation (EMS)* (WOS:000511407100028). AUGMENTED HUMAN 2018: PROCEEDINGS OF THE 9TH AUGMENTED HUMAN INTERNATIONAL CONFERENCE. https://doi.org/10.1145/3174910.3174939

Götz, F. M., Gosling, S. D., & Rentfrow, P. J. (2022). Small Effects: The Indispensable Foundation for a Cumulative Psychological Science. *Perspectives on Psychological Science*, *17*(1), 205–215. https://doi.org/10.1177/1745691620984483

Green, P., & MacLeod, C. J. (2016). SIMR: An R package for power analysis of generalized linear mixed models by simulation. *Methods in Ecology and Evolution*, *7*(4), 493–498. https://doi.org/10.1111/2041-210X.12504

Grosprêtre, S., Gueugneau, N., Martin, A., & Lepers, R. (2017). Central Contribution to Electrically Induced Fatigue depends on Stimulation Frequency. *Medicine and Science in Sports and Exercise*, *49*(8), 1530–1540. https://doi.org/10.1249/MSS.0000000000001270

Gündüz, A., Uyanık, Ö., Ertürk, Ö., Sohtaoğlu, M., & Kızıltan, M. E. (2016). Mentalis muscle related reflexes. *Neurological Sciences*, *37*(5), Article 5. https://doi.org/10.1007/s10072-015-2455-z

Haginomori, S.-I., Wada, S.-I., Takamaki, A., Nonaka, R., Takenaka, H., & Takubo, T. (2008). A new method for measuring compound muscle action potentials in facial palsy: A preliminary study. *Muscle & Nerve*, *37*(6), Article 6. https://doi.org/10.1002/mus.21034

Halberstadt, J., Winkielman, P., Niedenthal, P. M., & Dalle, N. (2009). Emotional conception: How embodied emotion concepts guide perception and facial action. *Psychological Science*, *20*(10), 1254–1261.

Hansson, P., & Ekblom, A. (1983). Transcutaneous electrical nerve stimulation (TENS) as compared to placebo TENS for the relief of acute oro-facial pain: *Pain*, *15*(1), 157–165. https://doi.org/10.1016/0304-3959(83)90015-5

Hansson, P., & Ekblom, A. (1984). Afferent stimulation induced pain relief in acute oro-facial pain and its failure to induce sufficient pain reduction in dental and oral surgery: *Pain*, *20*(3), Article 3. https://doi.org/10.1016/0304-3959(84)90016-2

Hansson, P., Ekblom, A., Thomsson, M., & Fjellner, B. (1986). Influence of naloxone on relief of acute oro-facial pain by transcutaneous electrical nerve stimulation (TENS) or vibration. *Pain*, *24*(3), 323–329. https://doi.org/10.1016/0304-3959(86)90118-1

Happak, W., Liu, J., Burggasser, G., Flowers, A., Gruber, H., & Freilinger, G. (1997). Human facial muscles: Dimensions, motor endplate distribution, and presence of muscle fibers with multiple motor endplates. *The Anatomical Record*, *249*(2), 276–284. https://doi.org/10.1002/(SICI)1097-0185(199710)249:2<276::AID-AR15>3.0.CO;2-L

Harrant, V., & Vaillant, N. G. (2008). Are women less risk averse than men? The effect of impending death on risk-taking behavior. *Evolution and Human Behavior*, *29*(6), 396–401. https://doi.org/10.1016/j.evolhumbehav.2008.05.003

Harris, C. R., & Jenkins, M. (2006). Gender Differences in Risk Assessment: Why do Women Take Fewer Risks than Men? *Judgment and Decision Making*, *1*(1), 16.

Hatfield, E., Cacioppo, J. T., & Rapson, R. L. (1993). Emotional Contagion. *Current Directions in Psychological Science*, *2*(3), 96–100. https://doi.org/10.1111/1467-8721.ep10770953

Hennenlotter, A., Dresel, C., Castrop, F., Ceballos-Baumann, A. O., Baumann, A. O. C., Wohlschläger, A. M., & Haslinger, B. (2009). The link between facial feedback and neural activity within central circuitries of emotion—New insights from botulinum toxin-induced denervation of frown muscles. *Cerebral Cortex*, *19*(3), 537–542. https://doi.org/10.1093/cercor/bhn104

Hess, U., & Fischer, A. (2014). Emotional Mimicry: Why and When We Mimic Emotions. *Social and Personality Psychology Compass*, *8*(2), 45–57. https://doi.org/10.1111/spc3.12083

Hess, U., & Fischer, A. (2022). Emotional mimicry as social regulator: Theoretical considerations. *Cognition & Emotion*, 1–9. https://doi.org/10.1080/02699931.2022.2103522

Hietanen, J. K., & Astikainen, P. (2013). N170 response to facial expressions is modulated by the affective congruency between the emotional expression and preceding affective picture. *Biological Psychology*, *92*(2), 114–124. https://doi.org/10.1016/j.biopsycho.2012.10.005

Hutto, J. R., & Vattoth, S. (2015). A Practical Review of the Muscles of Facial Mimicry With Special Emphasis on the Superficial Musculoaponeurotic System. *American Journal of Roentgenology*, *204*(1), W19–W26. https://doi.org/10.2214/AJR.14.12857

Hwang, K., Yang, S. C., & Song, J. S. (2015). Communications Between the Trigeminal Nerve and the Facial Nerve in the Face: A Systematic Review. *Journal of Craniofacial Surgery*, *26*(5), 1643–1646. https://doi.org/10.1097/SCS.0000000000001810

Hyvärinen, A., Tarkka, I. M., Mervaala, E., Pääkkönen, A., Valtonen, H., & Nuutinen, J. (2008). Cutaneous Electrical Stimulation Treatment in Unresolved Facial Nerve Paralysis: An Exploratory Study. *American Journal of Physical Medicine & Rehabilitation*, *87*(12), 992–997. https://doi.org/10.1097/PHM.0b013e318186bc74

Ilves, M., Lylykangas, J., Rantanen, V., Mäkelä, E., Vehkaoja, A., Verho, J., Lekkala, J., Rautiainen, M., & Surakka, V. (2019). Facial muscle activations by functional electrical stimulation. *Biomedical Signal Processing and Control*, *48*, 248–254. https://doi.org/10.1016/j.bspc.2018.10.015

Ilves, M., Rantanen, V., Venesvirta, H., Lylykangas, J., Vehkaoja, A., Mäkelä, E., Verho, J., Lekkala, J., Rautiainen, M., & Surakka, V. (2020). Functional electrical stimulation for facial pacing: Effects of waveforms on movement intensity and ratings of discomfort. *Biomedical Signal Processing and Control*, *60*, 101992. https://doi.org/10.1016/j.bspc.2020.101992

Insausti-Delgado, A., López-Larraz, E., Omedes, J., & Ramos-Murguialday, A. (2020). Intensity and Dose of Neuromuscular Electrical Stimulation Influence Sensorimotor Cortical Excitability. *Frontiers in Neuroscience*, *14*, 593360. https://doi.org/10.3389/fnins.2020.593360

Insausti-Delgado, A., López-Larraz, E., Omedes, J., & Ramos-Murguialday, A. (2021). Intensity and Dose of Neuromuscular Electrical Stimulation Influence Sensorimotor Cortical Excitability. *Frontiers in Neuroscience*, *14*, 593360. https://doi.org/10.3389/fnins.2020.593360

Ito, T. A., Chiao, K. W., Devine, P. G., Lorig, T. S., & Cacioppo, J. T. (2006). The Influence of Facial Feedback on Race Bias. *Psychological Science*, *17*(3), 256–261. https://doi.org/10.1111/j.1467-9280.2006.01694.x

Iwatsu, K., Yamada, S., Iida, Y., Sampei, H., Kobayashi, K., Kainuma, M., & Usui, A. (2015). Feasibility of Neuromuscular Electrical Stimulation Immediately After Cardiovascular Surgery. *Archives of Physical Medicine and Rehabilitation*, *96*(1), 63–68. https://doi.org/10.1016/j.apmr.2014.08.012

Jadidi, F., Wang, K., Arendt-Nielsen, L., & Svensson, P. (2011). Effects of different stimulus locations on inhibitory responses in human jaw-closing muscles: EFFECTS OF DIFFERENT STIMULUS LOCATIONS ON INHIBITORY RESPONSES. *Journal of Oral Rehabilitation*, *38*(7), 487–500. https://doi.org/10.1111/j.1365-2842.2010.02177.x

James, W. (1884). II.—WHAT IS AN EMOTION ? *Mind*, *os-IX*(34), 188–205. https://doi.org/10.1093/mind/os-IX.34.188

Johnson, M. I., Paley, C. A., Jones, G., Mulvey, M. R., & Wittkopf, P. G. (2022). Efficacy and safety of transcutaneous electrical nerve stimulation (TENS) for acute and chronic pain in adults: A systematic review and meta-analysis of 381 studies (the meta-TENS study). *BMJ Open*, *12*(2), e051073. https://doi.org/10.1136/bmjopen-2021-051073

Kapadia, N., Zivanovic, V., Moineau, B., Downar, J., Zariffa, J., & Popovic, M. R. (2019). Functional electrical stimulation of the facial muscles to improve symptoms in individuals with major depressive disorder: Pilot feasibility study. *BioMedical Engineering OnLine*, *18*(1), Article 1. https://doi.org/10.1186/s12938-019-0730-6

Kavanagh, E., Kimock, C., Whitehouse, J., Micheletta, J., & Waller, B. M. (2022a). Revisiting Darwin's comparisons between human and non-human primate facial signals. *Evolutionary Human Sciences*, *4*, e27. https://doi.org/10.1017/ehs.2022.26

Kavanagh, S., Newell, J., Hennessy, M., & Sadick, N. (2012b). Use of a neuromuscular electrical stimulation device for facial muscle toning: A randomized, controlled trial. *Journal of Cosmetic Dermatology*, *11*(4), 261–266. https://doi.org/10.1111/jocd.12007

Kehrer, A., Engelmann, S., Bauer, R., Taeger, C., Grechenig, S., Kehrer, M., Prantl, L., Tamm, E. R., Bleys, R. L. a. W., & Mandlik, V. (2018). The nerve supply of zygomaticus major: Variability and distinguishing zygomatic from buccal facial nerve branches. *Clinical Anatomy*, *31*(4), 560–565. https://doi.org/10.1002/ca.23044

Keillor, J. M., Barrett, A. M., Crucian, G. P., Kortenkamp, S., & Heilman, K. M. (2002). Emotional experience and perception in the absence of facial feedback. *Journal of the International Neuropsychological Society: JINS*, *8*(1), 130–135.

Khamis, M., Schuster, N., George, C., & Pfeiffer, M. (2019). ElectroCutscenes: Realistic Haptic Feedback in Cutscenes of Virtual Reality Games Using Electric Muscle

Stimulation. *Proceedings of the 25th ACM Symposium on Virtual Reality Software and Technology*, 1–10. https://doi.org/10.1145/3359996.3364250

Kim, H.-S., Kho, H.-S., Kim, Y.-K., Lee, S.-W., & Chung, S.-C. (2000). Reliability and characteristics of current perception thresholds in the territory of the infraorbital and inferior alveolar nerves. *Journal of Orofacial Pain*, *14*(4).

Kim, J., & Choi, J. Y. (2016). The effect of subthreshold continuous electrical stimulation on the facial function of patients with Bell's palsy. *Acta Oto-Laryngologica*, *136*(1), 100–105.

Kim, K.-E., Oh, S. H., Lee, S.-U., & Chung, S. G. (2009). Application of isometric load on a facial muscle – The zygomaticus major. *Clinical Biomechanics*, *24*(8), Article 8. https://doi.org/10.1016/j.clinbiomech.2009.06.008

Kim, M. J., Neta, M., Davis, F. C., Ruberry, E. J., Dinescu, D., Heatherton, T. F., Stotland, M. A., & Whalen, P. J. (2014). Botulinum toxin-induced facial muscle paralysis affects amygdala responses to the perception of emotional expressions: Preliminary findings from an A-B-A design. *Biology of Mood & Anxiety Disorders*, *4*(1), 11. https://doi.org/10.1186/2045-5380-4-11

Kono, M., Takahashi, T., Nakamura, H., Miyaki, T., & Rekimoto, J. (2018). Design Guideline for Developing Safe Systems that Apply Electricity to the Human Body. *ACM Transactions on Computer-Human Interaction*, *25*(3), 19:1-19:36. https://doi.org/10.1145/3184743

Korb, S. (2010). The neural correlates of the perception, production, and regulation of facial expressions. https://doi.org/10.13097/ARCHIVE-OUVERTE/UNIGE:14541

Korb, S., & Sander, D. (2009). The neural architecture of facial expressions. In D. Sander & K. R. Scherer (Eds.), *The Oxford companion to emotion and the affective sciences* (pp. 173–175). Oxford University Press.

Korb, S., With, S., Niedenthal, P., Kaiser, S., & Grandjean, D. (2014). The Perception and Mimicry of Facial Movements Predict Judgments of Smile Authenticity. *PLOS ONE*, *9*(6), e99194. https://doi.org/10.1371/journal.pone.0099194

Kraft, T. L., & Pressman, S. D. (2012). Grin and Bear It: The Influence of Manipulated Facial Expression on the Stress Response. *Psychological Science*, *23*(11), 1372–1378. https://doi.org/10.1177/0956797612445312

Kreibig, S. D. (2010). Autonomic nervous system activity in emotion: A review. *Biological Psychology*, *84*(3), 394–421. https://doi.org/10.1016/j.biopsycho.2010.03.010

Kroencke, L., Geukes, K., Utesch, T., Kuper, N., & Back, M. D. (2020). Neuroticism and emotional risk during the COVID-19 pandemic. *Journal of Research in Personality*, *89*, 104038. https://doi.org/10.1016/j.jrp.2020.104038

Kruger, T. H. C., & Wollmer, M. A. (2015). Depression – An emerging indication for botulinum toxin treatment. *Toxicon*, *107*, 154–157. https://doi.org/10.1016/j.toxicon.2015.09.035

Krumhuber, E. G., Tamarit, L., Roesch, E. B., & Scherer, K. R. (2012). FACSGen 2.0 animation software: Generating three-dimensional FACS-valid facial expressions for emotion research. *Emotion*, *12*, 351–363. https://doi.org/10.1037/a0026632

Kuehne, M., Polotzek, L., Haghikia, A., Zaehle, T., & Lobmaier, J. S. (2023). I spy with my little eye: The detection of changes in emotional faces and the influence of facial feedback in Parkinson disease. *European Journal of Neurology*, *30*(3), 622–630. https://doi.org/10.1111/ene.15647

Kuehne, M., Siwy, I., Zaehle, T., Heinze, H.-J., & Lobmaier, J. S. (2019). Out of Focus: Facial Feedback Manipulation Modulates Automatic Processing of Unattended Emotional Faces. *Journal of Cognitive Neuroscience*, *31*(11), 1631–1640. https://doi.org/10.1162/jocn_a_01445

Kuehne, M., Zaehle, T., & Lobmaier, J. S. (2021). Effects of posed smiling on memory for happy and sad facial expressions. *Scientific Reports*, *11*(1), Article 1. https://doi.org/10.1038/s41598-021-89828-7

Kumle, L., Võ, M. L.-H., & Draschkow, D. (2021). Estimating power in (generalized) linear mixed models: An open introduction and tutorial in R. *Behavior Research Methods*, *53*(6), 2528–2543. https://doi.org/10.3758/s13428-021-01546-0

Kurdi, B., Lozano, S., & Banaji, M. R. (2017). Introducing the Open Affective Standardized Image Set (OASIS). *Behavior Research Methods*, *49*(2), 457–470. https://doi.org/10.3758/s13428-016-0715-3

Kurimoto, T., Ueda, K., Mori, S., Sakamoto, M., Yamada-Nakanishi, Y., Matsumiya, W., & Nakamura, M. (2019). A study protocol for evaluating the efficacy and safety of skin electrical stimulation for Leber hereditary optic neuropathy: A single-arm, open-label, non-randomized prospective exploratory study. *Clinical Ophthalmology*, *Volume 13*, 897–904. https://doi.org/10.2147/OPTH.S204669

Kuznetsova, A., Brockhoff, P. B., & Christensen, R. H. B. (2017). lmerTest Package: Tests in Linear Mixed Effects Models. *Journal of Statistical Software*, *82*(1), Article 1. https://doi.org/10.18637/jss.v082.i13

Kwak, H. H., Park, H. D., Youn, K. H., Hu, K. S., Koh, K. S., Han, S. H., & Kim, H. J. (2004). Branching patterns of the facial nerve and its communication with the auriculotemporal nerve. *Surgical and Radiologic Anatomy*, *26*(6), 494–500. https://doi.org/10.1007/s00276-004-0259-6

L. Fredrickson, B., & Levenson, R. W. (1998). Positive Emotions Speed Recovery from the Cardiovascular Sequelae of Negative Emotions. *Cognition and Emotion*, *12*(2), 191–220. https://doi.org/10.1080/026999398379718

Lagerquist, O., & Collins, D. F. (2008). Stimulus pulse-width influences H-reflex recruitment but not Hmax/Mmax ratio. *Muscle & Nerve*, *37*(4), 483–489. https://doi.org/10.1002/mus.20957

Laird, J. D. (1974). Self-attribution of emotion: The effects of expressive behavior on the quality of emotional experience. *Journal of Personality and Social Psychology*, *29*(4), 475–486. https://doi.org/10.1037/h0036125

Lange, C. G. (1885). The mechanism of the emotions. *The Classical Psychologists*, 672–684.

Lapatki, B. G., Oostenveld, R., Van Dijk, J. P., Jonas, I. E., Zwarts, M. J., & Stegeman, D. F. (2006). Topographical Characteristics of Motor Units of the Lower Facial Musculature Revealed by Means of High-Density Surface EMG. *Journal of Neurophysiology*, *95*(1), 342–354. https://doi.org/10.1152/jn.00265.2005

Larsen, R. J., Kasimatis, M., & Frey, K. (1992). Facilitating the Furrowed Brow: An Unobtrusive Test of the Facial Feedback Hypothesis Applied to Unpleasant Affect. *Cognition and Emotion*, *6*(5), 321–338. https://doi.org/10.1080/02699939208409689

Laufer, Y., Ries, J. D., Leininger, P. M., & Alon, G. (2001). Quadriceps Femoris Muscle Torques and Fatigue Generated by Neuromuscular Electrical Stimulation With Three Different Waveforms. *Physical Therapy*, *81*(7), 1307–1316. https://doi.org/10.1093/ptj/81.7.1307

Lawrence, E. J., Shaw, P., Baker, D., Baron-Cohen, S., & David, A. S. (2004). Measuring empathy: Reliability and validity of the Empathy Quotient. *Psychological Medicine*, *34*(5), 911–920. https://doi.org/10.1017/S0033291703001624

Lenth, R. V. (2023). *emmeans: Estimated Marginal Means, aka Least-Squares Means* [Computer software]. https://CRAN.R-project.org/package=emmeans

Lewis, M. B. (2018). The interactions between botulinum-toxin-based facial treatments and embodied emotions. *Scientific Reports*, *8*(1), 14720. https://doi.org/10.1038/s41598-018-33119-1

Liao, K.-K., Chen, J.-T., Lai, K.-L., Lin, C.-Y., Liu, C.-Y., Kao, C.-D., Lin, Y.-Y., & Wu, Z.-A. (2007). Brainstem excitability is increased in subjects with palmomental reflex. *Journal of the Formosan Medical Association*, *106*(8), 601–607.

Littleton, H. L., Axsom, D., & Pury, C. L. S. (2005). Development of the body image concern inventory. *Behaviour Research and Therapy*, *43*(2), 229–241. https://doi.org/10.1016/j.brat.2003.12.006

Liu, Y., Huang, H., McGinnis-Deweese, M., Keil, A., & Ding, M. (2012). Neural Substrate of the Late Positive Potential in Emotional Processing. *The Journal of Neuroscience*, *32*(42), 14563–14572. https://doi.org/10.1523/JNEUROSCI.3109-12.2012

Livermore, A., Hummel, T., Pauli, E., & Kobal, G. (1993). Perception of olfactory and intranasal trigeminal stimuli following cutaneous electrical stimulation. *Experientia*, *49*(10), Article 10. https://doi.org/10.1007/BF01952594

Luck, S. J., & Kappenman, E. S. (2011). *The Oxford Handbook of Event-Related Potential Components*. Oxford University Press.

Lugo, A., Ferrer-Fuertes, A., Isabel Correa, L., Campolo, M., Casanova-Molla, J., & Valls-Sole, J. (2018). Clinical utility of contact heat evoked potentials (CHEPs) in a case of mentalis nerve lesion. *Clinical Neurophysiology Practice*, *3*, 74–77. https://doi.org/10.1016/j.cnp.2018.03.004

Lunghi, C., Lo Verde, L., & Alais, D. (2017). Touch Accelerates Visual Awareness. *I-Perception*, *8*(1), 2041669516686986. https://doi.org/10.1177/2041669516686986

Lynch, C. L., & Popovic, M. R. (2008). Functional Electrical Stimulation. *IEEE Control Systems Magazine*, *28*(2), 40–50. https://doi.org/10.1109/MCS.2007.914689

Macefield, V. G. (2005). Physiological characteristics of low-threshold mechanoreceptors in joints, muscle and skin in human subjects. *Clinical and Experimental Pharmacology and Physiology*, *32*(1–2), 135–144. https://doi.org/10.1111/j.1440-1681.2005.04143.x

Maffiuletti, N. A. (2010). Physiological and methodological considerations for the use of neuromuscular electrical stimulation. *European Journal of Applied Physiology*, *110*(2), 223–234. https://doi.org/10.1007/s00421-010-1502-y

Maillou, P., & Cadden, S. W. (2008). The effects of a maximal jaw clench on an inhibitory jaw reflex. *Journal of Oral Rehabilitation*, *35*(6), 415–423.

Maio, G. R., & Esses, V. M. (2001). The Need for Affect: Individual Differences in the Motivation to Approach or Avoid Emotions. *Journal of Personality*, *69*(4), 583–614. https://doi.org/10.1111/1467-6494.694156

Maisonobe, T., Tankéré, F., Lamas, G., Soudant, J., Bouche, P., Willer, J. C., & Fournier, E. (1998). Reflexes elicited from cutaneous and mucosal trigeminal afferents in normal human subjects. *Brain Research*, *810*(1–2), 220–228.

Makela, E., Ilves, M., Venesvirta, H., Lylykangas, J., Rantanen, V., Vehkaoja, A., Verho, J., Lekkala, J., Surakka, V., & Rautiainen, M. (2020). Effect of pulse waveforms on movement amplitudes and perceived discomfort in electric muscle stimulation in unresolved facial nerve palsy. *BIOMEDICAL PHYSICS & ENGINEERING EXPRESS*, *6*(3). https://doi.org/10.1088/2057-1976/ab7eea

Mäkelä, E., Venesvirta, H., Ilves, M., Lylykangas, J., Rantanen, V., Uusitalo, H., Verho, J., Vehkaoja, A., Lekkala, J., Surakka, V., & Rautiainen, M. (2021). Electrically Induced Blink for the Prevention of Ocular Symptoms and Blurred Vision in Patients With Acute Facial Nerve Palsy. *Ear, Nose & Throat Journal*, 014556132110485. https://doi.org/10.1177/01455613211048576

Mäkelä, E., Venesvirta, H., Ilves, M., Lylykangas, J., Rantanen, V., Ylä-Kotola, T., Suominen, S., Vehkaoja, A., Verho, J., Lekkala, J., Surakka, V., & Rautiainen, M. (2019). Facial muscle reanimation by transcutaneous electrical stimulation for peripheral facial nerve palsy. *Journal of Medical Engineering & Technology*, *43*(3), 155–164. https://doi.org/10.1080/03091902.2019.1637470

Manca, D., Munoz, E., Pastor, P., Valldeoriola, F., & Valls-Sole, J. (2001). Enhanced gain of blink reflex responses to ipsilateral supraorbital nerve afferent inputs in patients with facial nerve palsy. *Clinical Neurophysiology*, *112*(1), 153–156.

Mang, C. S., Lagerquist, O., & Collins, D. F. (2010). Changes in corticospinal excitability evoked by common peroneal nerve stimulation depend on stimulation frequency. *Experimental Brain Research*, *203*(1), 11–20. https://doi.org/10.1007/s00221-010-2202-x

Marcelli, E., Cavallari, P., Frigerio, A., Colletti, G., Biglioli, F., Fanti, R., Plicchi, G., & Cercenelli, L. (2013). A new gyro-based method for quantifying eyelid motion. *The International Journal of Artificial Organs*, *36*(3), 195–202.

Marchand, S., Bushnell, M. C., & Duncan, G. H. (1991). Modulation of Heat Pain Perception by High Frequency Transcutaneous Electrical Nerve Stimulation (TENS): *The Clinical Journal of Pain*, *7*(2), Article 2. https://doi.org/10.1097/00002508-199106000-00008

Marmolejo-Ramos, F., Murata, A., Sasaki, K., Yamada, Y., Ikeda, A., Hinojosa, J. A., Watanabe, K., Parzuchowski, M., Tirado, C., & Ospina, R. (2020). Your face and moves seem happier when I smile: Facial action influences the perception of emotional faces and biological motion stimuli. *Experimental Psychology*, *67*(1), 14–22. https://doi.org/10.1027/1618-3169/a000470

Marotta, N., Demeco, A., Inzitari, M. T., Caruso, M. G., & Ammendolia, A. (2020). Neuromuscular electrical stimulation and shortwave diathermy in unrecovered Bell palsy: A randomized controlled study. *Medicine*, *99*(8).

Martin, J., Rychlowska, M., Wood, A., & Niedenthal, P. (2017). Smiles as Multipurpose Social Signals. *Trends in Cognitive Sciences*, *21*(11), 864–877. https://doi.org/10.1016/j.tics.2017.08.007

Marur, T., Tuna, Y., & Demirci, S. (2014). Facial anatomy. *Clinics in Dermatology*, *32*(1), 14–23. https://doi.org/10.1016/j.clindermatol.2013.05.022

Mastryukova, V., Arnold, D., Güllmar, D., Guntinas-Lichius, O., & Volk, G. F. (2020). Can MRI quantify the volume changes of denervated facial muscles? *European Journal of Translational Myology*, *30*(1).

Matsumoto, H., & Ugawa, Y. (2017). Adverse events of tDCS and tACS: A review. *Clinical Neurophysiology Practice*, *2*, 19–25. https://doi.org/10.1016/j.cnp.2016.12.003

Matsuo, K., Osada, Y., & Ban, R. (2013). Electrical stimulation to the trigeminal proprioceptive fibres that innervate the mechanoreceptors in Müller's muscle induces involuntary reflex contraction of the frontalis muscles. *Journal of Plastic Surgery and Hand Surgery*, *47*(1), Article 1. https://doi.org/10.3109/2000656X.2012.718282

Maul, X. A., Borchard, N. A., Hwang, P. H., & Nayak, J. V. (2019). Microcurrent technology for rapid relief of sinus pain: A randomized, placebo-controlled, double-blinded clinical trial. *International Forum of Allergy & Rhinology*, *9*(4), Article 4. https://doi.org/10.1002/alr.22280

May, M., Hardin, W. B., Sullivan, J., & Wette, R. (1976). NATURAL HISTORY OF BELL??S PALSY: THE SALIVARY FLOW TEST AND OTHER PROGNOSTIC INDICATORS: *The Laryngoscope*, *86*(5), Article 5. https://doi.org/10.1288/00005537-197605000-00011

May, M., & Hawkins, C. D. (1972). Bell's palsy: Results of surgery; salivation test versus nerve excitability test as a basis of treatment. *The Laryngoscope*, *82*(7), 1337–1348.

McIntosh, D. N. (1996). Facial feedback hypotheses: Evidence, implications, and directions. *Motivation and Emotion*, *20*(2), 121–147. https://doi.org/10.1007/BF02253868

Mehling, W. E., Acree, M., Stewart, A., Silas, J., & Jones, A. (2018). The Multidimensional Assessment of Interoceptive Awareness, Version 2 (MAIA-2). *PLOS ONE*, *13*(12), e0208034. https://doi.org/10.1371/journal.pone.0208034

Mehling, W. E., Price, C., Daubenmier, J. J., Acree, M., Bartmess, E., & Stewart, A. (2012). The Multidimensional Assessment of Interoceptive Awareness (MAIA). *PLOS ONE*, *7*(11), e48230. https://doi.org/10.1371/journal.pone.0048230

Mellor, D., Fuller-Tyszkiewicz, M., McCabe, M. P., & Ricciardelli, L. A. (2010). Body Image and Self-Esteem Across Age and Gender: A Short-Term Longitudinal Study. *Sex Roles*, *63*(9), 672–681. https://doi.org/10.1007/s11199-010-9813-3

Melzack, R., & Wall, P. D. (1965). Pain Mechanisms: A New Theory. *Science*, *150*(3699), 971–979. https://doi.org/10.1126/science.150.3699.971

Mercante, B., Loi, N., Ginatempo, F., Biggio, M., Manca, A., Bisio, A., Enrico, P., Bove, M., & Deriu, F. (2020). Transcutaneous trigeminal nerve stimulation modulates the hand blink reflex. *Scientific Reports*, *10*(1), 21116.

Merlo, S. (2020). Surface electrical stimulation for persistent stuttering and concomitant orofacial disorders: A multiple case study. *Perceptual and Motor Skills*, *127*(4), 698–721.

Messinger, D. S., Fogel, A., & Dickson, K. L. (2001). All smiles are positive, but some smiles are more positive than others. *Developmental Psychology*, *37*(5), 642–653. https://doi.org/10.1037/0012-1649.37.5.642

Moineau, B., Myers, M., Ali, S. S., Popovic, M. R., & Hitzig, S. L. (2021). End-user and clinician perspectives on the viability of wearable functional electrical stimulation garments after stroke and spinal cord injury. *Disability and Rehabilitation: Assistive Technology*, *16*(3), 241–250. https://doi.org/10.1080/17483107.2019.1668974

Montero, J., Junyent, J., Calopa, M., Povedano, M., & Valls-Sole, J. (2007). Electrophysiological study of ephaptic axono-axonal responses in hemifacial spasm. *Muscle & Nerve*, *35*(2), 184–188.

Moors, A. (2009). Theories of emotion causation: A review. *Cognition & Emotion*, *23*(4), 625–662. https://doi.org/10.1080/02699930802645739

Morecraft, R. J., Louie, J. L., Herrick, J. L., & Stilwell-Morecraft, K. S. (2001). Cortical innervation of the facial nucleus in the non-human primate: A new interpretation of the effects of stroke and related subtotal brain trauma on the muscles of facial expression. *Brain*, *124*, 176–208.

Mori, K., & Mori, H. (2009). Another Test of the Passive Facial Feedback Hypothesis: When Your Face Smiles, You Feel Happy. *Perceptual and Motor Skills*, *109*(1), 76–78. https://doi.org/10.2466/pms.109.1.76-78

Mortimer, J. T., & Bhadra, N. (2018). Fundamentals of Electrical Stimulation. In *Neuromodulation* (pp. 71–82). Elsevier. https://doi.org/10.1016/B978-0-12-805353-9.00006-1

Mummolo, S., Nota, A., Tecco, S., Caruso, S., Marchetti, E., Marzo, G., & Cutilli, T. (2020). Ultra-low-frequency transcutaneous electric nerve stimulation (ULF-TENS) in subjects with craniofacial pain: A retrospective study. *CRANIO®*, *38*(6), Article 6. https://doi.org/10.1080/08869634.2018.1526849

Muñoz, E., Cervera, A., & Valls-Solé, J. (2003). Neurophysiological study of facial chorea in patients with Huntington's disease. *Clinical Neurophysiology*, *114*(7), 1246–1252.

Müri, R. M. (2016). Cortical control of facial expression. *Journal of Comparative Neurology*, *524*(8), 1578–1585. https://doi.org/10.1002/cne.23908

Murphy, G. J. (1990). Utilization of Transcutaneous Electrical Nerve Stimulation in Managing Craniofacial Pain. *The Clinical Journal of Pain*, *6*(1), 64.

Myckatyn, T. M. (2004). A Review of Facial Nerve Anatomy. *SEMINARS IN PLASTIC SURGERY*, *18*(1), 7.

Nag, S., Sharma, D., & Thakor, N. V. (2015). Electrical stimulation. In K. Iniewski & S. Carrara (Eds.), *Handbook of Bioelectronics: Directly Interfacing Electronics and Biological Systems* (pp. 365–378). Cambridge University Press. https://doi.org/10.1017/CBO9781139629539.036

Nakashima, K., & Takahashi, K. (1991). Exteroceptive Suppression of the Masseter and Temporalis Muscles and Parkinsonian Rigidity. *Psychiatry and Clinical Neurosciences*, *45*(4), 865–871. https://doi.org/10.1111/j.1440-1819.1991.tb00526.x

Natori, Y., Yoshizawa, H., Mizuno, H., & Hayashi, A. (2015). Preoperative transcutaneous electrical nerve stimulation for localizing superficial nerve paths. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *68*(12), Article 12. https://doi.org/10.1016/j.bjps.2015.08.018

Neal, D. T., & Chartrand, T. L. (2011). Embodied Emotion Perception Amplifying and Dampening Facial Feedback Modulates Emotion Perception Accuracy. *Social Psychological and Personality Science*, *2*(6), 673–678. https://doi.org/10.1177/1948550611406138

Neyroud, D., Gonzalez, M., Mueller, S., Agostino, D., Grosprêtre, S., Maffiuletti, N. A., Kayser, B., & Place, N. (2019). Neuromuscular adaptations to wide-pulse high-frequency neuromuscular electrical stimulation training. *European Journal of Applied Physiology*, *119*(5), 1105–1116. https://doi.org/10.1007/s00421-019-04100-1

Nguyen, J. D., & Duong, H. (2023). Anatomy, Head and Neck: Face. In *StatPearls*. StatPearls Publishing. http://www.ncbi.nlm.nih.gov/books/NBK551530/

Nicolini, Y., Manini, B., De Stefani, E., Coudé, G., Cardone, D., Barbot, A., Bertolini, C., Zannoni, C., Belluardo, M., Zangrandi, A., Bianchi, B., Merla, A., & Ferrari, P. F. (2019, April 8). *Autonomic Responses to Emotional Stimuli in Children Affected by Facial Palsy: The Case of Moebius Syndrome* [Research Article]. Neural Plasticity; Hindawi. https://doi.org/10.1155/2019/7253768

Niedenthal, P. M. (2007). Embodying emotion. *Science*, *316*, 1002–1005. psyh. https://doi.org/10.1126/science.1136930

Niedenthal, P. M., Mermillod, M., Maringer, M., & Hess, U. (2010). The Simulation of Smiles (SIMS) model: Embodied simulation and the meaning of facial expression. *Behavioral and Brain Sciences*, *33*(6), 417–433. https://doi.org/10.1017/S0140525X10000865

Nigam, P. K., & Nigam, A. (2010). BOTULINUM TOXIN. *Indian Journal of Dermatology*, *55*(1), 8–14. https://doi.org/10.4103/0019-5154.60343

Noah, T., Schul, Y., & Mayo, R. (2018). When both the original study and its failed replication are correct: Feeling observed eliminates the facial-feedback effect. *Journal of Personality and Social Psychology*, *114*(5), 657–664. https://doi.org/10.1037/pspa0000121

Nowak, D. A., Linder, S., & Topka, H. (2005). Diagnostic relevance of transcranial magnetic and electric stimulation of the facial nerve in the management of facial palsy. *Clinical Neurophysiology*, *116*(9), Article 9. https://doi.org/10.1016/j.clinph.2005.05.007

Núñez, S. C., Garcez, A. S., Suzuki, S. S., & Ribeiro, M. S. (2006). Management of Mouth Opening in Patients with Temporomandibular Disorders through Low-Level Laser

Therapy and Transcutaneous Electrical Neural Stimulation. *Photomedicine and Laser Surgery*, *24*(1), Article 1. https://doi.org/10.1089/pho.2006.24.45

Oberman, L. M., Winkielman, P., & Ramachandran, V. S. (2007). Face to face: Blocking facial mimicry can selectively impair recognition of emotional expressions. *Social Neuroscience*, *2*(3–4), 167–178. https://doi.org/10.1080/17470910701391943

O'Connor, D., Lennon, O., Minogue, C., & Caulfield, B. (2020). Design considerations for the development of neuromuscular electrical stimulation (NMES) exercise in cancer rehabilitation. *Disability and Rehabilitation*, *0*(0), 1–10. https://doi.org/10.1080/09638288.2020.1726510

Öge, A. E., Yazici, J., Boyaciyan, A., Tanyeri, S., Çlelik, M., Konyalioğlu, R., & Baslo, A. (1993). Magnetic stimulation in hemifacial spasm and post-facial palsy synkinesis: Facial Magnetic Stimulation. *Muscle & Nerve*, *16*(11), Article 11. https://doi.org/10.1002/mus.880161103

Ohira, H., & Hirao, N. (2015). Analysis of skin conductance response during evaluation of preferences for cosmetic products. *Frontiers in Psychology*, *6*, 103. https://doi.org/10.3389/fpsyg.2015.00103

O'Neil, R. (1981). Relief of chronic facial pain by transcutaneous electrical nerve stimulation. *British Journal of Oral Surgery*, *19*(2), Article 2. https://doi.org/10.1016/0007-117X(81)90035-4

Orhan, E. K., Yayla, V., Cebeci, Z., Baslo, M. B., Ovalı, T., & Öge, A. E. (2011). Excitability changes at brainstem and cortical levels in blind subjects. *Clinical Neurophysiology*, *122*(9), Article 9. https://doi.org/10.1016/j.clinph.2011.02.020

Paes, E. C., Teepen, H. J. L. J. M., Koop, W. A., & Kon, M. (2009). Perioral Wrinkles: Histologic Differences Between Men and Women. *Aesthetic Surgery Journal*, *29*(6), 467–472. https://doi.org/10.1016/j.asj.2009.08.018

Page, M. J., McKenzie, J. E., Bossuyt, P. M., Boutron, I., Hoffmann, T. C., Mulrow, C. D., Shamseer, L., Tetzlaff, J. M., Akl, E. A., Brennan, S. E., Chou, R., Glanville, J., Grimshaw, J. M., Hróbjartsson, A., Lalu, M. M., Li, T., Loder, E. W., Mayo-Wilson, E., McDonald, S., … Moher, D. (2021). The PRISMA 2020 statement: An updated guideline for reporting systematic reviews. *BMJ*, *372*, n71. https://doi.org/10.1136/bmj.n71

Palmeri, A., Restivo, D. A., & Casabona, A. (2000). Involvement of the noradrenergic system in modulating the blink reflex in humans. *Brain Research*, *867*(1–2), 210–216.

Papcke, C., Krueger, E., Olandoski, M., Nogueira-Neto, G. N., Nohama, P., & Scheeren, E. M. (2018). Investigation of the Relationship Between Electrical Stimulation Frequency and Muscle Frequency Response Under Submaximal Contractions. *Artificial Organs*, *42*(6), 655–663. https://doi.org/10.1111/aor.13083

Paracampo, R., Tidoni, E., Borgomaneri, S., di Pellegrino, G., & Avenanti, A. (2016). Sensorimotor Network Crucial for Inferring Amusement from Smiles. *Cerebral Cortex*, cercor;bhw294v2. https://doi.org/10.1093/cercor/bhw294

Paracampo, R., Tidoni, E., Borgomaneri, S., di Pellegrino, G., & Avenanti, A. (2017). Sensorimotor Network Crucial for Inferring Amusement from Smiles. *Cerebral Cortex*, *27*(11), 5116–5129. https://doi.org/10.1093/cercor/bhw294

Pavesi, G., Macaluso, G. M., Marchetti, P., Cattaneo, L., Tinchelli, S., De Laat, A., & Mancia, D. (2000). Trigemino-facial reflex inhibitory responses in some lower facial muscles. *Muscle & Nerve*, *23*(6), Article 6. https://doi.org/10.1002/(SICI)1097-4598(200006)23:6<939::AID-MUS15>3.0.CO;2-7

Peckham, P. H., & Knutson, J. S. (2005). Functional Electrical Stimulation for Neuromuscular Applications. *Annual Review of Biomedical Engineering*, *7*(1), 327–360. https://doi.org/10.1146/annurev.bioeng.6.040803.140103

Peirce, J., Gray, J. R., Simpson, S., MacAskill, M., Höchenberger, R., Sogo, H., Kastman, E., & Lindeløv, J. K. (2019). PsychoPy2: Experiments in behavior made easy. *Behavior Research Methods*, *51*(1), 195–203. https://doi.org/10.3758/s13428-018-01193-y

Pessa, J. E., Zadoo, V. P., Adrian, E. K., Jr, Yuan, C. H., Aydelotte, J., & Garza, J. R. (1998). Variability of the midfacial muscles: Analysis of 50 hemifacial cadaver dissections. *Plastic and Reconstructive Surgery*, *102*(6), 1888–1893.

Peters, M., Rhodes, G., & Simmons, L. W. (2007). Contributions of the face and body to overall attractiveness. *Animal Behaviour*, *73*(6), 937–942. https://doi.org/10.1016/j.anbehav.2006.07.012

Petrofsky, J. (2008). The effect of the subcutaneous fat on the transfer of current through skin and into muscle. *Medical Engineering & Physics*, *30*(9), 1168–1176. https://doi.org/10.1016/j.medengphy.2008.02.009

Pfeiffer, M., Duente, T., & Rohs, M. (2016). Let your body move: A prototyping toolkit for wearable force feedback with electrical muscle stimulation. *Proceedings of the 18th International Conference on Human-Computer Interaction with Mobile Devices and Services*, 418–427. https://doi.org/10.1145/2935334.2935348

Pilurzi, G., Ginatempo, F., Mercante, B., Cattaneo, L., Pavesi, G., Rothwell, J. C., & Deriu, F. (2020). Role of cutaneous and proprioceptive inputs in sensorimotor integration and plasticity occurring in the facial primary motor cortex. *The Journal of Physiology*, *598*(4), 839–851. https://doi.org/10.1113/JP278877

Pilurzi, G., Hasan, A., Saifee, T. A., Tolu, E., Rothwell, J. C., & Deriu, F. (2013). Intracortical circuits, sensorimotor integration and plasticity in human motor cortical projections to muscles of the lower face: Physiological properties and plasticity of facial motor cortex. *The Journal of Physiology*, *591*(7), 1889–1906. https://doi.org/10.1113/jphysiol.2012.245746

Pitcher, D., Garrido, L., Walsh, V., & Duchaine, B. C. (2008). Transcranial magnetic stimulation disrupts the perception and embodiment of facial expressions. *Journal of Neuroscience*, *28*(36), 8929–8933.

Pool, G. J., Schwegler, A. F., Theodore, B. R., & Fuchs, P. N. (2007). Role of gender norms and group identification on hypothetical and experimental pain tolerance. *Pain*, *129*(1), 122–129. https://doi.org/10.1016/j.pain.2006.10.008

Pressman, S. D., Acevedo, A. M., Hammond, K. V., & Kraft-Feil, T. L. (2021). Smile (or grimace) through the pain? The effects of experimentally manipulated facial expressions on needle-injection responses. *Emotion*, *21*(6), 1188–1203. https://doi.org/10.1037/emo0000913

Primbs, M. A., Pennington, C. R., Lakens, D., Silan, M. A. A., Lieck, D. S. N., Forscher, P. S., Buchanan, E. M., & Westwood, S. J. (2023). Are Small Effects the Indispensable Foundation for a Cumulative Psychological Science? A Reply to Götz et al. (2022). *Perspectives on Psychological Science*, *18*(2), 508–512. https://doi.org/10.1177/17456916221100420

Priya, B. S., Srinivasan, K. R., Lakshmanan, P., & Selvi, P. (2017). Facial Nerve Injury Following TMJ Surgery and its Management by Electrical Stimulation–A Case Study. *Biomedical and Pharmacology Journal*, *10*(4), 1855–1861.

Prutchi, D., & Norris, M. (2005). Design and Development of Medical Electronic Instrumentation: A Practical Perspective of the Design, Construction, and Test of Medical Devices. John Wiley & Sons.

Puls, W. C., Jarvis, J. C., Ruck, A., Lehmann, T., Guntinas-Lichius, O., & Volk, G. F. (2020). Surface electrical stimulation for facial paralysis is not harmful. *Muscle & Nerve*, *61*(3), 347–353. https://doi.org/10.1002/mus.26784

R Core Team. (2020). *R: A language and environment for statistical computing* [Computer software]. R Foundation for Statistical Computing. http://www.R-project.org

Racine, M., Tousignant-Laflamme, Y., Kloda, L. A., Dion, D., Dupuis, G., & Choinière, M. (2012). A systematic literature review of 10years of research on sex/gender and pain perception – Part 2: Do biopsychosocial factors alter pain sensitivity differently in women and men? *PAIN*, *153*(3), 619–635. https://doi.org/10.1016/j.pain.2011.11.026

Ramalho, B. L., Moly, J., Raffin, E., Bouet, R., Harquel, S., Farnè, A., & Reilly, K. T. (2022). Face-hand sensorimotor interactions revealed by afferent inhibition. *The European Journal of Neuroscience*, *55*(1), 189–200. https://doi.org/10.1111/ejn.15536

Ramírez-Maestre, C., Martínez, A. E. L., & Zarazaga, R. E. (2004). Personality Characteristics as Differential Variables of the Pain Experience. *Journal of Behavioral Medicine*, *27*(2), 147–165. https://doi.org/10.1023/B:JOBM.0000019849.21524.70

Rankin, M., & Borah, G. L. (2003). Perceived Functional Impact of Abnormal Facial Appearance. *Plastic and Reconstructive Surgery*, *111*(7), 2140–2146. https://doi.org/10.1097/01.PRS.0000060105.63335.0C

Rantanen, V., Vehkaoja, A., & Verho, J. (2018). *Stimulation Waveform Selection to Suppress Functional Electrical Stimulation Artifact from Surface EMG Signals* (H. Eskola, O. Vaisanen, J. Viik, & J. Hyttinen, Eds.; WOS:000449778900106; Vol. 65, pp. 422–425). https://doi.org/10.1007/978-981-10-5122-7_106

Rantanen, V., Vehkaoja, A., Verho, J., Veselý, P., Lylykangas, J., Ilves, M., Mäkelä, E., Rautiainen, M., Surakka, V., & Lekkala, J. (2016). Prosthetic Pacing Device for Unilateral Facial Paralysis. In E. Kyriacou, S. Christofides, & C. S. Pattichis (Eds.), *XIV Mediterranean Conference on Medical and Biological Engineering and Computing 2016* (pp. 653–658). Springer International Publishing. https://doi.org/10.1007/978-3-319-32703-7_126

Raphael, K. G., Janal, M. N., Sirois, D. A., & Svensson, P. (2013). Effect of Contingent Electrical Stimulation on Masticatory Muscle Activity and Pain in Patients with a Myofascial Temporomandibular Disorder and Sleep Bruxism. *Journal of Orofacial Pain*, *27*(1), Article 1. https://doi.org/10.11607/jop.1029

Raslan, A., Guntinas-Lichius, O., & Volk, G. F. (2020). Altered facial muscle innervation pattern in patients with postparetic facial synkinesis. *The Laryngoscope*, *130*(5). https://doi.org/10.1002/lary.28149

Reed, B. (1997). The Physiology of Neuromuscular Electrical Stimulation. *Pediatric Physical Therapy*, *9*(3), 96–102.

Revelle, W. (2017). *psych: Procedures for Psychological, Psychometric, and Personality Research*. Northwestern University. https://CRAN.R-project.org/package=psych

Rimpiläinen, I. (1994). Origin of the facial long latency responses elicited by magnetic stimulation. *Electroencephalography and Clinical Neurophysiology/Evoked Potentials Section*, *93*(2), Article 2. https://doi.org/10.1016/0168-5597(94)90075-2

Rinn, W. E. (1984). The neuropsychology of facial expression: A review of the neurological and psychological mechanisms for producing facial expressions. *Psychological Bulletin*, *95*(1), 52–77.

Rives Bogart, K., & Matsumoto, D. (2010). Facial mimicry is not necessary to recognize emotion: Facial expression recognition by people with Moebius syndrome. *Social Neuroscience*, *5*(2), 241–251. https://doi.org/10.1080/17470910903395692

Robinson, M. E., Gagnon, C. M., Riley, J. L., & Price, D. D. (2003). Altering gender role expectations: Effects on pain tolerance, pain threshold, and pain ratings. *The Journal of Pain*, *4*(5), 284–288. https://doi.org/10.1016/S1526-5900(03)00559-5

Rode, G., Vallar, G., Revol, P., Tilikete, C., Jacquin-Courtois, S., Rossetti, Y., & Farnè, A. (2012). Facial macrosomatognosia and pain in a case of Wallenberg's syndrome:

Selective effects of vestibular and transcutaneous stimulations. *Neuropsychologia*, *50*(2), Article 2. https://doi.org/10.1016/j.neuropsychologia.2011.11.018

Rodriguez, P. O., Setten, M., Maskin, L. P., Bonelli, I., Vidomlansky, S. R., Attie, S., Frosiani, S. L., Kozima, S., & Valentini, R. (2012). Muscle weakness in septic patients requiring mechanical ventilation: Protective effect of transcutaneous neuromuscular electrical stimulation. *Journal of Critical Care*, *27*(3), 319.e1-319.e8. https://doi.org/10.1016/j.jcrc.2011.04.010

Roesch, E. B., Tamarit, L., Reveret, L., Grandjean, D., Sander, D., & Scherer, K. R. (2011). FACSGen: A Tool to Synthesize Emotional Facial Expressions Through Systematic Manipulation of Facial Action Units. *Journal of Nonverbal Behavior*, *35*(1), 1–16. https://doi.org/10.1007/s10919-010-0095-9

Rösler, K. M., Magistris, M. R., Glocker, F. X., Kohler, A., Deuschl, G., & Hess, C. W. (1995). Electrophysiological characteristics of lesions in facial palsies of different etiologies. A study using electrical and magnetic stimulation techniques. *Electroencephalography and Clinical Neurophysiology/Electromyography and Motor Control*, *97*(6), Article 6. https://doi.org/10.1016/0924-980X(95)00134-7

Rossi, A., & Scarpini, C. (1992). Gating of trigemino-facial reflex from low-threshold trigeminal and extratrigeminal cutaneous fibres in humans. *Journal of Neurology, Neurosurgery & Psychiatry*, *55*(9), 774–780.

Rossi, B., Buonaguidi, R., Muratorio, A., & Tusini, G. (1979). Blink reflexes in posterior fossa lesions. *Journal of Neurology, Neurosurgery & Psychiatry*, *42*(5), 465–469.

Roth, P. M., & Thrash, W. J. (1986). Effect of transcutaneous electrical nerve stimulation for controlling pain associated with orthodontic tooth movement. *American Journal of Orthodontics and Dentofacial Orthopedics*, *90*(2), Article 2. https://doi.org/10.1016/0889-5406(86)90045-4

Ruckmick, C. A. (1936). The James-Lange-Sergi theory. In *The psychology of feeling and emotion.* (pp. 135–166). McGraw-Hill. https://doi.org/10.1037/10770-006

Rumsey, N., & Harcourt, D. (2004). Body image and disfigurement: Issues and interventions. *Body Image*, *1*(1), 83–97. https://doi.org/10.1016/S1740-1445(03)00005-6

Rutledge, L. L., & Hupka, R. B. (1985). The facial feedback hypothesis: Methodological concerns and new supporting evidence. *Motivation and Emotion, 9*(3), 219–240. https://doi.org/10.1007/BF00991829

Safi, M. (2020). Assessing Discomfort Levels During Facial Neuromuscular Electrical Stimulation Using Discomfort Level Scale: A Preliminary Study. *Indian Journal of Otolaryngology and Head & Neck Surgery*. https://doi.org/10.1007/s12070-020-02173-5

Safi, M. (2022). Assessing Discomfort Levels During Facial Neuromuscular Electrical Stimulation Using Discomfort Level Scale: A Preliminary Study. *Indian Journal of Otolaryngology and Head & Neck Surgery*, *74*(3), 5275–5279. https://doi.org/10.1007/s12070-020-02173-5

Safi, M. F., Wright-Harp, W., Lucker, J. R., & Payne, J. C. (2017). Effect of surface neuromuscular electrical stimulation on labial and lingual muscles in healthy volunteers. *International Journal of Rehabilitation Research. Internationale Zeitschrift Fur Rehabilitationsforschung. Revue Internationale de Recherches de Readaptation*, *40*(2), 119–126. https://doi.org/10.1097/MRR.0000000000000217

Safi, M. F., Wright-Harp, W., Lucker, J. R., Payne, J. C., & Harris, O. (2018). Effect of Neuromuscular Electrical Stimulation on Labial and Lingual Weakness: A Single-Case Preexperimental Study. *Topics in Geriatric Rehabilitation*, *34*(2), Article 2. https://doi.org/10.1097/TGR.0000000000000185

Salomon, R., Lim, M., Herbelin, B., Hesselmann, G., & Blanke, O. (2013). Posing for awareness: Proprioception modulates access to visual consciousness in a continuous flash suppression task. *Journal of Vision, 13*(7), 2–2. https://doi.org/10.1167/13.7.2

Samulowitz, A., Gremyr, I., Eriksson, E., & Hensing, G. (2018). "Brave Men" and "Emotional Women": A Theory-Guided Literature Review on Gender Bias in Health Care and Gendered Norms towards Patients with Chronic Pain. *Pain Research and Management, 2018*, e6358624. https://doi.org/10.1155/2018/6358624

Saylam, C., Ucerler, H., Orhan, M., Uckan, A., & Ozek, C. (2007). Localization of the Marginal Mandibular Branch of the Facial Nerve. *Journal of Craniofacial Surgery*, *18*(1), 137–142. https://doi.org/10.1097/01.scs.0000246732.69224.7e

Schiano Lomoriello, A., Caperna, G., Carta, A., De Stefani, E., Ferrari, P. F., & Sessa, P. (2023). Sensitivity to basic emotional expressions and the emotion perception space in the absence of facial mimicry: The case of individuals with congenital facial palsy. *Emotion*. https://doi.org/10.1037/emo0001275

Schiano Lomoriello, A., Maffei, A., Brigadoi, S., & Sessa, P. (2021). Altering sensorimotor simulation impacts early stages of facial expression processing depending on individual differences in alexithymic traits. *Brain and Cognition, 148*, 105678. https://doi.org/10.1016/j.bandc.2020.105678

Schmidt, K., Forkmann, K., Sinke, C., Gratz, M., Bitz, A., & Bingel, U. (2016). The differential effect of trigeminal vs. Peripheral pain stimulation on visual processing and memory encoding is influenced by pain-related fear. *NeuroImage, 134*, 386–395.

Schmolesky, M. T., Boelhouwer, A. J. W., & Blumenthal, T. D. (1996). The effect of acoustic pulse intensity upon the electrically elicited blink reflex at positive and negative stimulus onset asynchronies. *Biological Psychology*, *44*(2), 69–84.

Schoenen, J., Wang, W., & Gerard, P. (1994). Modulation of temporalis muscle exteroceptive suppression by limb stimuli in normal man. *Brain Research*, *657*(1–2), 214–220. https://doi.org/10.1016/0006-8993(94)90970-9

Schrooten, M. G., Vlaeyen, J. W., & Morley, S. (2012). Psychological interventions for chronic pain: Reviewed within the context of goal pursuit. *Pain Management*, *2*(2), 141–150. https://doi.org/10.2217/pmt.12.2

Schumann, N. P., Bongers, K., Scholle, H. C., & Guntinas-Lichius, O. (2021). Atlas of voluntary facial muscle activation: Visualization of surface electromyographic activities of facial muscles during mimic exercises. *PLoS ONE*, *16*(7), e0254932. https://doi.org/10.1371/journal.pone.0254932

Scott, W., Stevens, J., & Binder–Macleod, S. A. (2001). Human Skeletal Muscle Fiber Type Classifications. *Physical Therapy*, *81*(11), 1810–1816. https://doi.org/10.1093/ptj/81.11.1810

Seifi, M., Ebadifar, A., Kabiri, S., Badiee, M. R., Abdolazimi, Z., & Amdjadi, P. (2017). Comparative effectiveness of low level laser therapy and transcutaneous electric nerve stimulation on temporomandibular joint disorders. *Journal of Lasers in Medical Sciences*, *8*(Suppl 1), S27.

Seki, Y., Krain, L., Yamada, T., & Kimura, J. (1990). Transcranial Magnetic Stimulation of the Facial Nerve: Recording Technique and Estimation of the Stimulated Site. *Neurosurgery*, *26*(2), Article 2. https://doi.org/10.1227/00006123-199002000-00016

Sel, A., Calvo-Merino, B., Tuettenberg, S., & Forster, B. (2015). When you smile, the world smiles at you: ERP evidence for self-expression effects on face processing. *Social Cognitive and Affective Neuroscience*, *10*(10), 1316–1322. https://doi.org/10.1093/scan/nsv009

Sel, A., Forster, B., & Calvo-Merino, B. (2014). The Emotional Homunculus: ERP Evidence for Independent Somatosensory Responses during Facial Emotional Processing. *The Journal of Neuroscience*, *34*(9), 3263–3267. https://doi.org/10.1523/JNEUROSCI.0106-13.2014

Semin, G. R., & Cacioppo, J. T. (2008). Grounding Social Cognition: Synchronization, Entrainment, and Coordination. In G. R. Semin & E. R. Smith (Eds.), *Embodied grounding: Social, cognitive, affective, and neuroscientific approaches*. Cambridge University Press.

Sergerie, K., Chochol, C., & Armony, J. L. (2008). The role of the amygdala in emotional processing: A quantitative meta-analysis of functional neuroimaging studies. *Neuroscience & Biobehavioral Reviews*, *32*(4), 811–830. https://doi.org/10.1016/j.neubiorev.2007.12.002

SERGI, G. (1894). THE VARIETIES OF THE HUMAN SPECIES.

Serrao, M., Cortese, F., Andersen, O. K., Conte, C., Spaich, E. G., Fragiotta, G., Ranavolo, A., Coppola, G., Perrotta, A., & Pierelli, F. (2015). Modular organization of the head retraction responses elicited by electrical painful stimulation of the facial skin in humans. *Clinical Neurophysiology*, *126*(12), Article 12. https://doi.org/10.1016/j.clinph.2015.01.029

Serrao, M., Rossi, P., Parisi, L., Perrotta, A., Bartolo, M., Cardinali, P., Amabile, G., & Pierelli, F. (2003). Trigemino-cervical-spinal reflexes in humans. *Clinical Neurophysiology*, *114*(9), Article 9. https://doi.org/10.1016/S1388-2457(03)00132-9

Sessa, P., Schiano Lomoriello, A., Duma, G. M., Mento, G., De Stefani, E., & Ferrari, P. F. (2022). Degenerate pathway for processing smile and other emotional expressions in congenital facial palsy: An hdEEG investigation. *Philosophical Transactions of the*

*Royal Society B: Biological Sciences*, *377*(1863), 20210190. https://doi.org/10.1098/rstb.2021.0190

Shannon, R. V. (1992). A model of safe levels for electrical stimulation. *IEEE Transactions on Biomedical Engineering*, *39*(4), 424–426. https://doi.org/10.1109/10.126616

Shehu, H. A., Oxner, M., Browne, W. N., & Eisenbarth, H. (2023). Prediction of moment-by-moment heart rate and skin conductance changes in the context of varying emotional arousal. *Psychophysiology*, *n/a*(n/a), e14303. https://doi.org/10.1111/psyp.14303

Shimada, A., Castrillon, E. E., & Svensson, P. (2019). Revisited relationships between probable sleep bruxism and clinical muscle symptoms. *Journal of Dentistry*, *82*, 85–90. https://doi.org/10.1016/j.jdent.2019.01.013

Singh, P., & Singh, V. P. (2016). Mime therapy for Ramsay Hunt syndrome: A case study. *International Journal of Therapy and Rehabilitation*, *23*(3), Article 3. https://doi.org/10.12968/ijtr.2016.23.3.141

Slovic, P., Peters, E., Finucane, M. L., & MacGregor, D. G. (2005). Affect, risk, and decision making. *Health Psychology*, *24*(4, Suppl), S35–S40. https://doi.org/10.1037/0278-6133.24.4.S35

Sluka, K. A., & Walsh, D. (2003). Transcutaneous electrical nerve stimulation: Basic science mechanisms and clinical effectiveness. *The Journal of Pain*, *4*(3), 109–121. https://doi.org/10.1054/jpai.2003.434

Smith, G. V., Alon, G., Roys, S. R., & Gullapalli, R. P. (2003). Functional MRI determination of a dose-response relationship to lower extremity neuromuscular electrical stimulation in healthy subjects. *Experimental Brain Research*, *150*(1), 33–39. https://doi.org/10.1007/s00221-003-1405-9

Söderkvist, S., Ohlén, K., & Dimberg, U. (2017). How the Experience of Emotion is Modulated by Facial Feedback. *Journal of Nonverbal Behavior*, 1–23. https://doi.org/10.1007/s10919-017-0264-1

Sommerauer, L., Engelmann, S., Ruewe, M., Anker, A., Prantl, L., & Kehrer, A. (2021). Effects of electrostimulation therapy in facial nerve palsy. *Archives of Plastic Surgery*, *48*(03), Article 03. https://doi.org/10.5999/aps.2020.01025

Soussignan, R. (2002). Duchenne smile, emotional experience, and autonomic reactivity: A test of the facial feedback hypothesis. *Emotion*, *2*(1), 52–74. https://doi.org/10.1037/1528-3542.2.1.52

Stefani, E. D., Nicolini, Y., Belluardo, M., & Ferrari, P. F. (2019). Congenital facial palsy and emotion processing: The case of Moebius syndrome. *Genes, Brain and Behavior*, *18*(1), e12548. https://doi.org/10.1111/gbb.12548

Storbeck, F., Schlegelmilch, K., Streitberger, K.-J., Sommer, W., & Ploner, C. J. (2019). Delayed recognition of emotional facial expressions in Bell's palsy. *Cortex*, *120*, 524–531. https://doi.org/10.1016/j.cortex.2019.07.015

Strack, F. (2016). Reflection on the smiling registered replication report. *Perspectives on Psychological Science*, *11*(6), 929–930. https://doi.org/10.1177/1745691616674460

Strack, F., Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile: A nonobtrusive test of the facial feedback hypothesis. *Journal of Personality and Social Psychology*, *54*(5), 768–777. https://doi.org/10.1037/0022-3514.54.5.768

Sun, G., Abe, N., Sugiyama, Y., Nguyen, Q. V., Nozaki, K., Nakayama, Y., Takei, O., Hakozaki, Y., Abe, S., & Matsui, T. (2013). Development of an infection screening system for entry inspection at airport quarantine stations using ear temperature, heart and respiration rates. *Annual International Conference of the IEEE Engineering in*

*Medicine and Biology Society. IEEE Engineering in Medicine and Biology Society. Annual International Conference, 2013*, 6716–6719. https://doi.org/10.1109/EMBC.2013.6611097

Sundaram, P. K., Hegde, A. S., Chandramouli, B. A., & Das, B. S. (1999). Trigeminal evoked potentials in patients with symptomatic trigeminal neuralgia due to intracranial mass lesions. *Neurology India*, *47*(2), 94.

Suzuki, T., Shibukawa, Y., Kumai, T., & Shintani, M. (2004). Face Area Representation of Primary Somatosensory Cortex in Humans Identified by Whole-Head Magnetoencephalography. *The Japanese Journal of Physiology*, *54*(2), Article 2. https://doi.org/10.2170/jjphysiol.54.161

Tada, H., Torisu, T., Tanaka, M., Murata, H., De Laat, A., & Svensson, P. (2015). Experimental low-level jaw clenching inhibits temporal summation evoked by electrical stimulation in healthy human volunteers. *Archives of Oral Biology*, *60*(5), Article 5. https://doi.org/10.1016/j.archoralbio.2015.02.013

Tal, M., & Sharav, Y. (2005). Jaw Clenching Modulates Sensory Perception in High-But Not In Low-Hypnotizable Subjects. *Journal of Orofacial Pain*, *19*(1).

Tankéré, F., Maisonobe, T., Naccache, L., Lamas, G., Soudant, J., Danziger, N., Bouche, P., Fournier, E., & Willer, J. C. (2000). Further evidence for a central reorganisation of synaptic connectivity in patients with hypoglossal–facial anastomosis in man. *Brain Research*, *864*(1), 87–94.

Targan, R. S., Alon, G. A. D., & Kay, S. L. (2000). Effect of long-term electrical stimulation on motor recovery and improvement of clinical residuals in patients with unresolved facial nerve palsy. *Otolaryngology—Head and Neck Surgery*, *122*(2), 246–252.

Taylor, G. J., Ryan, D., & Bagby, M. (2010). Toward the Development of a New Self-Report Alexithymia Scale. *Psychotherapy and Psychosomatics*, *44*(4), 191–199. https://doi.org/10.1159/000287912

Tian, L., Nie, S., Lou, T., Chen, H., & Yuan, G. (2020). Clinical observation on acupoint massage plus Vitalstim electrical stimulation for deglutition disorder after stroke. *Journal of Acupuncture and Tuina Science*, *18*(6), 438.

Tian, X., Zheng, X., Ji, Y., Jiang, B., Wang, T., Xiong, S., & Wang, X. (2019). iBlink: A Wearable Device Facilitating Facial Paralysis Patients to Blink. *IEEE Transactions on Mobile Computing*, *18*(8), Article 8. https://doi.org/10.1109/TMC.2018.2868660

Topçu, Ç., Uysal, H., Özkan, Ö., Özkan, Ö., Polat, Ö., Bedeloğlu, M., Akgül, A., Döğer, E. N., Sever, R., & Çolak, Ö. H. (2018). Recovery of facial expressions using functional electrical stimulation after full-face transplantation. *Journal of NeuroEngineering and Rehabilitation*, *15*, 1–7.

Topka, H., & Hallett, M. (1992). Perioral reflexes in orofacial dyskinesia and spasmodic dysphonia. *Muscle & Nerve*, *15*(9), 1016–1022. https://doi.org/10.1002/mus.880150906

Tourangeau, R., & Ellsworth, P. C. (1979). The role of facial response in the experience of emotion. *Journal of Personality and Social Psychology*, *37*(9), 1519–1531. https://doi.org/10.1037/0022-3514.37.9.1519

Treacy, K. (1999). Awareness/relaxation training and transcutaneous electrical neural stimulation in the treatment of bruxism. *Journal of Oral Rehabilitation*, *26*(4), Article 4. https://doi.org/10.1046/j.1365-2842.1999.00381.x

Tuncay, F., Borman, P., Taser, B., Ünlü, I., & Samim, E. (2015). Role of electrical stimulation added to conventional therapy in patients with idiopathic facial (Bell) palsy. *American Journal of Physical Medicine & Rehabilitation*, *94*(3), 222–228.

Tversky, A., & Kahneman, D. (1992). Advances in Prospect Theory: Cumulative Representation of Uncertainty. 28.

Valls-Sole´, J., Cammarota, A., Alvarez, R., & Hallett, M. (1994). Orbicularis oculi responses to stimulation of nerve afferents from upper and lower limbs in normal humans. *Brain Research*, *650*(2), Article 2. https://doi.org/10.1016/0006-8993(94)91797-3

Vanden Bulcke, C., Van Damme, S., Durnez, W., & Crombez, G. (2013). The anticipation of pain at a specific location of the body prioritizes tactile stimuli at that location. *PAIN®*, *154*(8), 1464–1468. https://doi.org/10.1016/j.pain.2013.05.009

Vannuscorps, G., Andres, M., & Caramazza, A. (2020). Efficient recognition of facial expressions does not require motor simulation. *eLife*, *9*, e54687. https://doi.org/10.7554/eLife.54687

Vaz, M. A., & Frasson, V. B. (2018). Low-Frequency Pulsed Current Versus Kilohertz-Frequency Alternating Current: A Scoping Literature Review. *Archives of Physical Medicine and Rehabilitation*, *99*(4), 792–805. https://doi.org/10.1016/j.apmr.2017.12.001

Vivodtzev, I., Debigaré, R., Gagnon, P., Mainguy, V., Saey, D., Dubé, A., Paré, M.-È., Bélanger, M., & Maltais, F. (2012). Functional and Muscular Effects of Neuromuscular Electrical Stimulation in Patients With Severe COPD. *Chest*, *141*(3), 716–725. https://doi.org/10.1378/chest.11-0839

Wagenmakers, E.-J., Beek, T., Dijkhoff, L., Gronau, Q. F., Acosta, A., R. B. Adams, J., Albohn, D. N., Allard, E. S., Benning, S. D., Blouin-Hudon, E.-M., Bulnes, L. C., Caldwell, T. L., Calin-Jageman, R. J., Capaldi, C. A., Carfagno, N. S., Chasten, K. T., Cleeremans, A., Connell, L., DeCicco, J. M., … Zwaan, R. A. (2016). Registered Replication Report: Strack, Martin, & Stepper (1988). *Perspectives on Psychological Science*. https://doi.org/10.1177/1745691616674458

Waldeyer, A. (Ed.). (2011). Frontmatter: In *Teil 2 Kopf und Hals, Auge, Ohr, Gehirn, Arm, Brust* (p. I–XVI). De Gruyter. https://doi.org/doi:10.1515/9783111429847.fm

Waller, B. M., Cray, J. J., & Burrows, A. M. (2008). Selection for universal facial emotion. *Emotion*, *8*(3), 435–439. https://doi.org/10.1037/1528-3542.8.3.435

Waller, B. M., Julle-Daniere, E., & Micheletta, J. (2020). Measuring the evolution of facial 'expression' using multi-species FACS. *Neuroscience & Biobehavioral Reviews*, *113*, 1–11. https://doi.org/10.1016/j.neubiorev.2020.02.031

Waller, B. M., Vick, S.-J., Parr, L. A., Bard, K. A., Pasqualini, M. C. S., Gothard, K. M., & Fuglevand, A. J. (2006). Intramuscular electrical stimulation of facial muscles in humans and chimpanzees: Duchenne revisited and extended. *Emotion*, *6*(3), 367–382. https://doi.org/10.1037/1528-3542.6.3.367

Walls, R. M., Hockberger, R. S., & Gausche-Hill, M. (Eds.). (2018). *Rosen's emergency medicine: Concepts and clinical practice* (Ninth edition). Elsevier.

Wang, K., Svensson, P., & Arendt-Nielsen, L. (1999). Modulation of exteroceptive suppression periods in human jaw-closing muscles by local and remote experimental muscle pain. *Pain*, *82*(3), 253–262.

Warren, L. (2021). Smiling By Way of Zygomatic Electrical Stimulation: Investigating the Facial Feedback Hypothesis. *Psi Beta Research Journal*, 16–22. https://doi.org/10.54581/HSFS8439

Washburn, S., Catlin, R., Bethel, K., & Canlas, B. (2014). Patient-Perceived Differences Between Constant Current and Constant Voltage Spinal Cord Stimulation Systems. *Neuromodulation: Technology at the Neural Interface*, *17*(1), 28–36. https://doi.org/10.1111/ner.12085

Watson, D., Anna, L., & Tellegen, A. (1988). Development and Validation of Brief Measures of Positive and Negative Affect: The PANAS Scales. 8.

Watson, D., & Clark, L. A. (1994). *The PANAS-X: Manual for the Positive and Negative Affect Schedule - Expanded Form* [dataset]. University of Iowa. https://doi.org/10.17077/48vt-m4t2

Westerhof, W., & Bos, J. D. (1983). Trigeminal trophic syndrome: A successful treatment with transcutaneous electrical stimulation. *British Journal of Dermatology*, *108*(5), 601–604.

Willenbockel, V., Sadr, J., Fiset, D., Horne, G. O., Gosselin, F., & Tanaka, J. W. (2010). Controlling low-level image properties: The SHINE toolbox. *Behavior Research Methods*, *42*(3), 671–684. https://doi.org/10.3758/BRM.42.3.671

Wilson, C. M., & Ronan, S. L. (2010). Rehabilitation postfacial reanimation surgery after removal of acoustic neuroma: A case study. *Journal of Neurologic Physical Therapy*, *34*(1), 41–49.

Wilson-Pauwels, L. (Ed.). (2010). *Cranial nerves: Function and dysfunction* (3rd ed). People's Medical Pub. House.

Wingenbach, T. S. H., Brosnan, M., Pfaltz, M. C., Peyk, P., & Ashwin, C. (2020). Perception of Discrete Emotions in Others: Evidence for Distinct Facial Mimicry Patterns. *Scientific Reports*, *10*(1), Article 1. https://doi.org/10.1038/s41598-020-61563-5

Wood, A., Lupyan, G., Sherrin, S., & Niedenthal, P. (2016a). Altering sensorimotor feedback disrupts visual discrimination of facial expressions. *Psychonomic Bulletin & Review*, *23*(4), 1150–1156. https://doi.org/10.3758/s13423-015-0974-5

Wood, A., Rychlowska, M., Korb, S., & Niedenthal, P. (2016b). Fashioning the Face: Sensorimotor Simulation Contributes to Facial Expression Recognition. *Trends in Cognitive Sciences*, *20*(3), 227–240. https://doi.org/10.1016/j.tics.2015.12.010

Yamamoto, E., & Nishimura, H. (1987). Treatment of hemifacial spasm with transcutaneous electrical stimulation. *The Laryngoscope*, *97*(4), 458–460.

Yavlal, F., İnan, R., Gündüz, A., & Kızıltan, M. (2020). Synkinetic Spread and Hyperexcitability: Orbicularis Oris Recovery in Post-facial Synkinesis. *Turkish Journal Of Neurology*, *26*(4), Article 4. https://doi.org/10.4274/tnd.2020.68926

Yen-Chin, L., Feng, Y., Kunze, K., Shimizu, J., & Nakao, T. (2017). Eyewear to Make Me Smile: Can Electric Muscle Stimulation increase Happiness? *Proceedings of the Eleventh International Conference on Tangible, Embedded, and Embodied Interaction*, 579–582. https://doi.org/10.1145/3024969.3025097

Yıldız, N., Yıldız, S., Ertekin, C., Aydoğdu, I., & Uludag, B. (2004). Changes in the perioral muscle responses to cortical TMS induced by decrease of sensory input and electrical stimulation to lower facial region. *Clinical Neurophysiology*, *115*(10), 2343–2349.

Zariffa, J., Hitzig, S. L., & Popovic, M. R. (2014). Neuromodulation of Emotion Using Functional Electrical Stimulation Applied to Facial Muscles. *Neuromodulation: Technology at the Neural Interface*, *17*(1), Article 1. https://doi.org/10.1111/ner.12056

Zayan, K., Aggarwal, S., Felix, E., Levitt, R., Sarantopoulos, K., & Galor, A. (2020). Transcutaneous Electrical Nerve Stimulation for the Long-Term Treatment of Ocular Pain. *Neuromodulation: Technology at the Neural Interface*, *23*(6), Article 6. https://doi.org/10.1111/ner.13146

Zhang, Q., & Wu, S. (2021). Effects of Synchronized Neuromuscular Electrical Stimulation (NMES) on the Submental Muscles During Ingestion of a Specified Volume of Soft Food in Patients with Mild-to-Moderate Dysphagia Following Stroke. *Medical Science Monitor: International Medical Journal of Experimental and Clinical Research*, *27*, e928988. https://doi.org/10.12659/MSM.928988

Zhang, Y., Zhang, J., Wang, L., Wang, K., & Svensson, P. (2020). Effect of transcutaneous electrical nerve stimulation on jaw movement-evoked pain in patients with TMJ disc

displacement without reduction and healthy controls. *Acta Odontologica Scandinavica*, *78*(4), Article 4. https://doi.org/10.1080/00016357.2019.1707868