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FACIAL FEEDBACK AND AFFECTIVE DYSFUNCTION

The Impact of Facial Expression on Mental Health

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Common mental health disorders such as depression and anxiety impact individuals and communities worldwide, making these disorders a worthwhile focus of ongoing scientific research. The World Health Organization (2017) indicates that approximately 4.4% of the global population are experiencing clinical anxiety or depression at any one time and that depression is the single most significant contributor to global disability. In the United States, the National Institute of Mental Health (2022) indicates that depression is even more prevalent, affecting 8.4% of the current population, including 17% of young adults aged 18 to 25 years old. Recent findings from an Australian longitudinal study indicate that 86% of the population will likely experience sufficient psychological distress to develop a mental health disorder at some time in their lives (Caspi, 2020). Although many researchers have studied these widespread disorders, their pathophysiology is not fully understood. Researchers indicate that genetic influence may account for 30 to 40% of depression etiology. The remaining 60-70% is likely due to individual-specific environmental effects, including responses to childhood and current adversity and the development (or not) of coping skills for dealing with psychosocial stress (Hasler, 2010). While the genetic risk does seem high, examining the physiological changes an individual may experience during psychosocial stress is an opportunity for discovery. Facial expressions are an immediate physical reaction to emotional stimuli. The Facial Feedback Hypothesis (FFH) is an often overlooked, but well-supported, hypothesis suggesting that facial expressions not only reveal emotions but that "feedback" from facial expressions intensifies emotional experiences. Studies have shown that unsuccessful emotion regulation during emotional distress contributes to mental health disorders (Berking, 2014). Thus, during distress, intensified, negative emotions from facial feedback could adversely impact mental health if ineffectively regulated. Understanding more about the role of facial feedback in emotion and its potential function in intensifying psychosocial stress may bring a greater understanding of the pathophysiology of depression and other mental health disorders, as well as opportunities for new mental health treatments.

This literature review will discuss historical and current research on the FFH, including the implications of facial expression on mental and physical health, and available evidence examining the connection between facial expressions and regions of the brain involved in emotional processes. This literature review on FFH will be mostly chronological, assuming that research builds on prior research. However, it is not exhaustive, as many studies researched the FFH in the late 20th century. The last part of this review will include a few studies regarding the trigeminal nerve that examine its potential involvement in facial feedback and mental health.

History of Facial Feedback Hypothesis (FFH)

Charles Darwin and William James are credited for the concepts that led to FFH. Darwin claimed that enhancing or inhibiting an emotional expression would alter the intensity of the emotional experience (Darwin, 1872). James proposed an even stronger correlation and indicated that the face could have an *initiating* role in the experience of emotion (James, 1884), which instigated a debate on the subject that lasted decades. By the mid twentieth century, most psychologists believed that facial expression could only *modulate* an emotional experience (Allport, 1922; Gellhorn, 1964). However, some psychologists came to support an *initiating* role over time, as James had proposed (Strack et al., 1988; Levenson, Ekman, & Friesen, 1990; Soussignan, 2002).

The term facial feedback was coined in the 1960s, and in the 1970s, 80s, and 90s experimental studies of the FFH flourished, with most yielding data indicating facial feedback's role in emotion processes (McCanne & Anderson, 1987). During the 21st century, FFH studies have continued, many utilizing modern technologies such as electromyography (EMG), electroencephalography (EEG), positron emission tomography (PET), and functional magnetic resonance imaging (fMRI) to more objectively quantify facial expressions and neural activity, providing a basis for the hypothesized relationships.

Tourangeau and Ellsworth (1979) identified three potential explanations for the FFH: 1) the necessity hypothesis, which suggests that facial expression must be present for a subjective emotional experience; 2) the sufficiency hypothesis, which proposes a facial expression is sufficient to initiate an emotional experience; 3) the monotonicity hypothesis, that suggests that the intensity of facial expression will have a positive, monotonic (unchanging) correlation with the intensity of the subjective emotion. To test these hypotheses, Tourangeau and Ellsworth had 123 college students tighten specific facial muscles to create a facial expression typical for either fear, sadness, or a non-emotional grimace, while watching a two-minute film eliciting fear, sadness or no emotion. Subjects then reported their subjective fear and sadness. Results showed that the subject of the film affected the student's self-reported ratings of fear and sadness ($P < 0.05$ for each), while only a very slight correlation was found between manipulated facial expression and self-reported fear ($r = 0.01$) and sadness ($r = 0.02$). Tourangeau and Ellsworth's study results did not support the FFH; however, their study was later criticized by Izard (1981) for multiple flaws in the premise (e.g., ignoring the impact of covert facial expressions; possible differences of physiological responses in voluntary and involuntary facial expressions) and protocol (e.g., effort of holding a pose for two minutes; incongruence between sensory stimuli and face; insufficient diversity in self-report scales). Nevertheless, their suggested terms would help frame future FFH research, which included studying natural facial expressions during emotional states (Hess et al., 1992), studying emotions created by manipulated facial expressions (Strack et al., 1988; Levenson, Ekman, & Friesen, 1990; Soussignan, 2002), and suppressing or enhancing facial displays during emotionally arousing stimuli (McCanne & Anderson, 1987; Lee et al., 2012). The sufficiency and monotonicity-based FFH hypotheses have been researched more thoroughly and are generally supported (Stack et al., 1988; Soussignan, 2002; Lewis, 2012), while the necessity hypothesis has been less researched and accepted (Fernández-Dols & Ruiz-Belda, 1995). Additional FFH research has examined discrete emotions (e.g., anger, fear, happiness) versus dimensional (e.g., valence and arousal) (Adelmann & Zajonc, 1989; Soussignan, 2004) and the subject's awareness of facial manipulation (Strack, 1988; Larsen et al., 1992; Soussignan, 2002).

Methods

A search for research articles was conducted in the University of Utah online database at www.lib.utah.edu with search terms such as “facial feedback and emotion,” “facial feedback and depression,” “facial expression and neural connections,” and “neural processes of facial expression.” Trigeminal nerve studies were found similarly with keyword searches such as “trigeminal nerve and depression” or “trigeminal nerve and mental health.” Additional research articles on these subjects were found through Google Scholar and the citations and reference lists of discovered articles. Fifty-one articles were read and analyzed for facial feedback, facial expression, and mental, physical, and neural implications. Nineteen studies were selected that added a new dimension and appeared to build upon prior knowledge of FFH, or neural processes involved with facial expressions.

Autonomic Nervous System Activity Distinguishes among Emotions

Paul Ekman and Wallace Friesen (1978) developed the Facial Activation Coding System (FACS) to assist researchers in more accurately identifying expressed emotions (and their strength) by live subjects or subjects in photographs and videos. They spent nearly a year categorizing specific facial muscles used in every conceivable facial expression and identified 46 action units to create those expressions. The FAC, created by Ekman and Friesen, was manualized for researchers and has been a useful tool in past and current FFH studies.

While Ekman and Friesen worked to create the FAC, they both experienced strong physical sensations contracting their facial muscles into facial expressions considered to be universal. This experience led them to develop the theory that “voluntary production of emotional facial configurations would produce emotion-specific patterns of autonomic activity” (Levenson et al. 1990). A few years later, Ekman, Levenson, and Friesen (1983) studied the autonomic responses of six universal emotions: surprise, disgust, sadness, anger, fear, and happiness. Sixteen subjects’ (12 actors and 4 researchers) created the six emotions with two tasks: 1) voluntarily creating and holding (for 10 seconds) a facial expression from instructions to contract specific muscles—resulting in a prototypical emotional expression; 2) creating a specific emotion by reliving a personal experience relating to the emotion. The subjects’ heart rate, skin temperatures over the left and right hand, skin conductance and forearm muscle tension were measured during the tasks. Ekman, Levenson, and Friesens’ hypothesis that there are differences in autonomic responses between the six emotions was supported (Emotion main effect, $F [25, 317] = 2.51$, $P < 0.001$). A significant increase in heart rate was found for anger, fear, and sadness ($P = 0.05$), and anger alone showed a significant difference in skin temperature ($P < 0.05$) (Figure 1). Additionally, there were differences between the autonomic responses of emotions created by facial actions and those triggered by reliving an emotional experience ($F [25, 62] = 2$, $P = 0.014$). The autonomic responses created by facial expressions were stronger than those created by relived experiences, supporting the *sufficiency* hypothesis of the FFH.

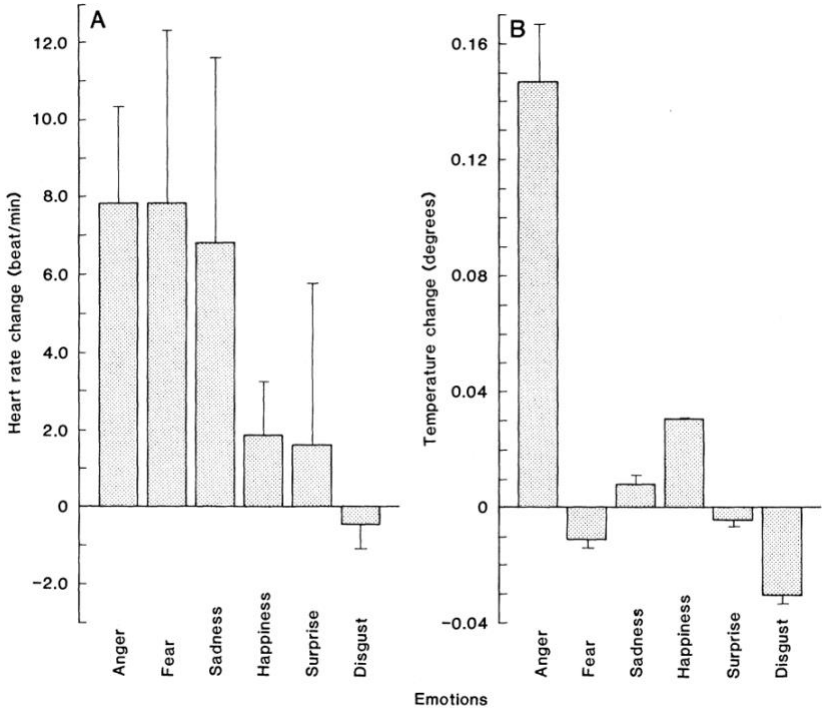

Figure 1. Heart rate and skin temperature for the six emotions measured. Charts from Ekman et al. (1983) study used with permission.

Inhibited or Facilitated Smiles

Strack, Martin, and Stepper's (1988) FFH research was one of the first to successfully blind the subjects to the study's purpose, increasing the confidence of the results. Their study of manipulated facial expressions supported the *sufficiency* hypothesis that facial feedback could initiate emotion. Ninety-two study subjects were told a cover story regarding the necessity of injured or disabled people holding a pen in a non-standard way. Subjects then held the pen with lips only (inhibiting smile), with teeth only (facilitating smile), or with their non-dominant hand—as they performed simple tasks, including rating the humor of cartoons (Figure 2). Subjects that viewed the cartoons with the pen-facilitated smile (teeth only) rated the cartoons significantly funnier than those with the pen-inhibited smile (lips only) or with the non-dominant hand ($t(89) = 1.85$, $p = 0.03$). Other studies have replicated and confirmed these results, which contributed to the general acceptance of FFH in psychology (Soussignan, 2002).

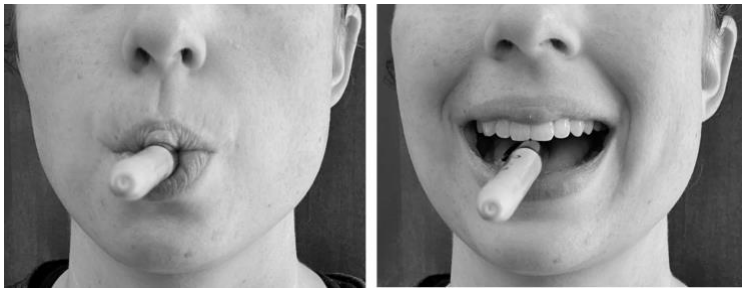

Figure 2. The model on the left shows how the pen was held between the lips, inhibiting smile muscles. On right, the model holds the pen between the teeth, facilitating smile muscles. (Image created by the author following methods of the Strack et al. 1988 article.)

Voluntary Facial Actions Initiate Emotion-Specific Autonomic Nervous System Activity

Levenson, Ekman, and Friesen (1990) sought to answer questions derived from their 1983 study of autonomic responses of emotion. Study subjects' heart rate, skin conductance, finger temperature, and forearm muscle movement were measured, and autonomic changes from baseline were recorded in three studies of facial manipulation from muscle-movement instructions (without naming the emotion portrayed). This study combined data from three varied groups: the data from the researchers' 1983 study of 12 actors and four face researchers was used for the first study, 103 college students for the second, and 119 volunteers recruited through the newspaper for a third. For experiments one and three, subjects had a mirror to view their facial expression. For experiment two, there was no mirror. Subjects were asked if they felt a "feeling" (groups one and three) or an "emotion" (group two) after each facial movement.

Results indicated that a significant number of study subjects experienced the target emotion from their facial expression: 26% of subjects from experiment one ($z = 2.46$, $p = 0.007$), and 27% from experiment three ($z = 3.69$, $p < 0.001$). Surprisingly, experiment two, which did not include mirrors and asked if they felt an "emotion" instead of "feeling," had even higher (78.1%) target emotion results in subjects ($z = 9.59$, $p < 0.001$).

The subjects were grouped together for tracking autonomic changes. Significant autonomic differences were found in heart rate ($F [5, 240] = 11.13$. $p < 0.001$) and skin conductance ($F [5, 240] = 3.16$. $p = 0.02$). Skin temperature approached significance ($F [5, 240] = 1.97$. $p = 0.09$). Forearm muscle activity was not significant [5, 240] = 0.42. (Figure 3).

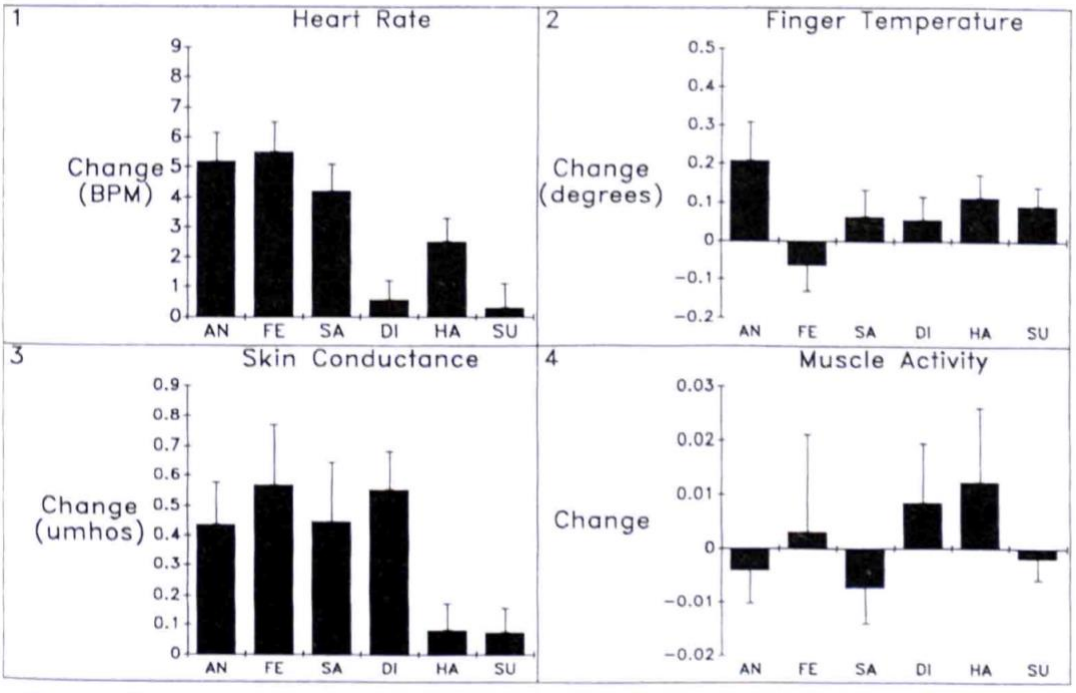

Figure 3. Autonomic changes from baseline with standard deviations for the six facial expression configurations that most resemble universal emotional expressions. AN = Anger, FE = Fear, SA = Sadness, DI = disgust, HA = Happiness, SU = Surprise. (Charts from Levanson et al. 1990 article used with permission.)

Levenson, Ekman and Friesen also found that study subjects that most closely replicated target facial expressions based on FACS, experienced even stronger autonomic response than the group response: heart rate ($F [5, 240] = 27.42$. $p < 0.001$), skin conductance ($F [5, 240] = 18.21$. $p = < 0.001$). Skin temperature was also higher ($F [5, 240] = 3.44$. $p = 0.06$). The stronger autonomic response from those that closely replicated facial expressions supports the monotonicity hypothesis, suggesting that more intense facial expressions result in a more intense emotional experience.

Additionally, no gender differences were discovered in the results, and all populations studied showed significance. The subjects in experiment three also rated the difficulty of their task, and the researchers indicated that there was no correlation between task difficulty and autonomic results. A fourth experiment asked subjects to read the instructions given to the previous subjects on how to move their facial muscles (without making the facial expressions) and guess the emotion the facial movement might be expressing. A significant proportion correctly guessed the target emotions in all areas except fear (anger = 39.5%, disgust = 47.4%, fear = 2.6%, happiness = 61.5%, sadness = 66.7%, surprise 76.9%; $p < 0.001$), so there is a possibility that these results were impacted by the subjects' ability to identify the target emotion from the instructions or from producing the facial expression.

Duchenne (Genuine) Smile, Emotional Experience, and Autonomic Reactivity

Robert Soussignan (2002) noted several limitations in the Strack et al. (1988) cartoon humor and smile study which he sought to overcome with his replication that included several alterations: 1) The 96 subjects, divided randomly between four groups, held a pencil instead of a pen in their mouths during testing. 2) The pleasantness or unpleasantness of the pen-holding positions may have impacted the humor ratings in the Strack study, so Soussignan added a self-report survey to assess this variable. 3) Research assistants demonstrated the correct pencil holding technique for each group, and the subjects were videotaped to verify that they had the correct facial expression and duration. 4) Unlike the control group for the Strack et al. study, Soussignan's control group (CG) did not hold the pencil with their hand but between their teeth without touching the pencil with their lips. This method did not produce a smile or negative (angry or sad) expression. 5) The facilitated smile from the Strack et al. study did not utilize the orbicularis oculi (muscle surrounding the eye) that is contracted when the cheek is lifted during the "Duchenne" (genuine) smile. Because it had been hypothesized that the Duchenne smile would produce more significant facial feedback effects than the standard smile (Levenson et al., 1990), Soussignan included two smile groups—a non-Duchenne smile group (n-DSG) and a Duchenne smile group (DSG). Soussignan also noted that the smile inhibiting condition of the Strack et al. study contracted the orbicularis oris muscles (surrounding the mouth), which is used in angry expressions, which may have negatively impacted ratings. Soussignan utilized this same method for his study's Lip-Pressing Group (LPG).

Each group in Soussignan's study performed two tasks while holding their pencils in their assigned position: 1) circled vowels on a worksheet, 2) viewed eight 10 second silent film clips that previous university students indicated would induce affective reactions. The subjects were told the study would assess whether the object in their mouth affected their perception or attention abilities and induced a pleasant or unpleasant feeling. Additionally, autonomic monitoring, including body temperature, heart rate, skin conductance, and respiratory rate, would be examined. Results indicated that task pleasantness or difficulty between groups were not

significant. However, the main effect for facial configuration was significant (F [3, 62] = 4.33, p = .008; 2 = 0.173, effect size = 0.46). Post-hoc comparisons showed that the Duchenne Smiling Group (DSG) reacted more positively to the videos than the other groups: DSG vs. CG: p < .01; DSG vs. LPG: p < .01; DSG vs. n-DSG: p < .05, suggesting the Duchenne (genuine) smile, utilizing orbicularis oculi muscles, impacts mood more positively than a basic smile without eye muscle involvement. No significant differences were seen between the four groups in any autonomic responses, suggesting it was muscular movement and not effort that created the differences.

Self-Reported Emotion and Facial Expression

A study by Larsen et al. (2003) examined the correlations between self-reported affect and zygomaticus major (smile) and corrugator supercilii (frown) muscle movement. Positive and negative reactions to emotionally arousing pictures, words, and sounds were collected from 68 women. First emotional reactions were assessed with EMG facial muscle measurements, then after a recovery period with self-reported positive and negative affective reactions to the same stimuli. Results revealed correlations between EMG uV measurements of zygomaticus and corrugator muscle movement and self-reported affect from the stimuli. The picture task showed the most robust linear response of all the stimuli with a significant linear correlation between corrugator supercilii activity and self-reported affect (r (66) = -.94, p<.001). Zygomaticus major activity was also significantly correlated, although it was not as strong as the corrugator supercilii (r (66)=.52, p <.001) (Figure 4).

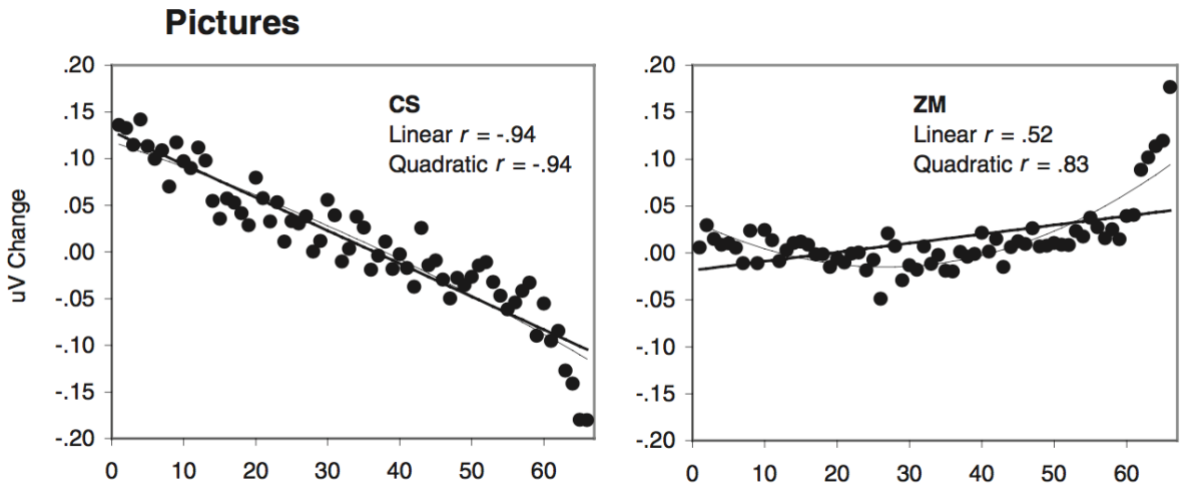

Figure 4. Linear correlation of participants' subjective valence judgments (X) with EMG facial muscular response (Y) in the picture task. Corrugator supercilii (CS) activity is shown on left, and zygomaticus major (ZM) activity is shown on right (Charts from Larsen et al. 2003 article used with permission).

Botulinum Toxin Injections Modulated Frowns and Limbic Response

Hennenlotter et al. (2008) noted that many studies of facial mimicry support the FFH and suggest neural connections between facial musculature and limbic regions of the brain, such as the amygdala (Carr et al., 2003; Wild et al., 2003; Lee et al., 2006). The amygdala is a critical component of emotional processing and is significantly involved in processing negative emotions (Hamann et al., 2002). It is the most connected structure in the forebrain and contains

receptors for many hormones and neurotransmitters involved in emotion, such as dopamine, serotonin, and norepinephrine (Gazinga, 2019).

Hennenlotter et al. investigated the FFH by examining neural correlates of facial mimicry with fMRI after botulinum toxin (BTX) treatment immobilized facial muscles used in emotional expression. Thirty-eight healthy study subjects receiving BTX in the corrugator supercilii muscle for frown line treatment were divided into two separate groups: before BTX (control group; n = 19) and after BTX (BTX group; n = 19). All subjects observed images of angry, neutral, and sad facial expressions and also replicated the facial expressions (Figure 5) while fMRI imaging recorded their bilateral amygdala response. The subjects' brow lowering strength was measured with the FAC (Ekman & Friesen, 1978).

In both the control group and the BTX groups, researchers found bilateral amygdala activation during angry and sad facial mimicry (compared to baseline) and no amygdala activation during the observation of facial expressions. However, the BTX group showed reduced amygdala activation in the left amygdala during imitation of angry expressions ($p < 0.05$) but not during sad facial expressions. The left amygdala also showed a significant linear correlation between brow lowering intensity in fMRI images during angry facial expressions of the control group ($r = 0.58$, $P < 0.05$), supporting the monotonicity hypothesis of FFH (Figure 6).

Although BTX treatment did not attenuate amygdala response during sad facial expressions, the BTX group did show significantly reduced activation of other brain regions during sad expressions, including the left lateral orbitofrontal cortex ($p < 0.005$, uncorrected), which is known to affect subjective emotional experience (Rolls, 2019).

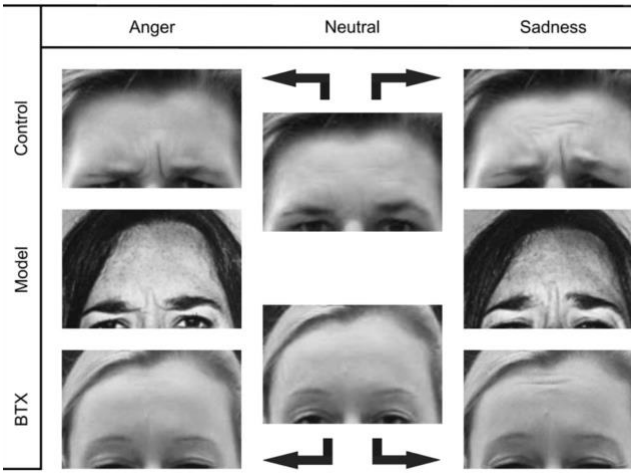

Figure 5. This chart shows BTX effect on corrugator muscles during facial mimicry of angry, neutral, and sad expressions. (Image from Hennenlotter et al. 2008 article used with permission).

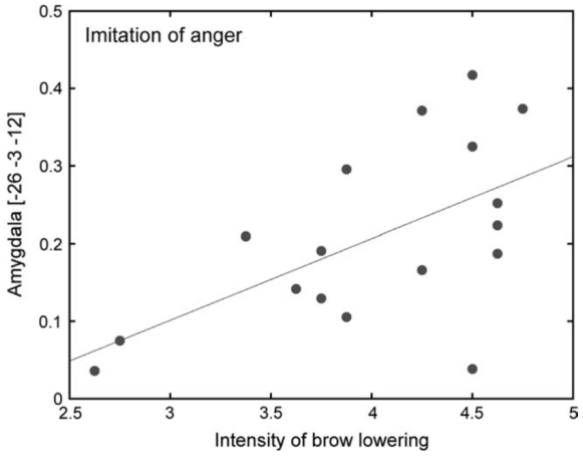

Figure 6. Left amygdala response correlates with brow lowering intensity during imitation of angry facial expressions in control group (Image from Hennenlotter et al. 2008 article used with permission).

Hennelotter et al. were also interested in the coupling of the hypothalamus/brain stem and amygdala regions involved in autonomic arousal. fMRI results indicated reduced coupling in the BTX group between the left amygdala and the dorsolateral pons in the brain stem. The amygdala sends projections to three nuclei in the pontine: periaqueductal gray (PAG), the reticular

formation, and the parabrachial nucleus (LeDoux, 2000). The PAG is of particular interest, as the more recent development of 7-Tesla powered fMRI machines helped discover that the PAG is an essential center of emotion processing (Gazinga et al. 2019).

Cognitive Reappraisal and Negative Affect

A study by Ray and Ochsner (2010) examined measured facial corrugator (frown) movement with EMG concurrently with self-reported affect. They examined the use of cognitive reappraisal to regulate affective response to positive and neutral-valence images. Reappraisal is an essential skill in self-regulation and is the foundation for cognitive therapy (Lee et al., 2012). Here, 53 women were taught reappraisal strategies and instructed to either increase, decrease, or be aware of their emotional response as they observed negative and neutral images. Instructions to increase the subjects' emotional response led to significant self-reports of increased negative affect, while instructions to decrease emotional response led to significant decreases in self-reported affect for both negative images (F [1.44, 75.05] = 275.95, p<.001) and neutral images (F [1.15, 48.12] = 198.99, p <.001). The subjects produced larger corrugator (frown) EMG movements from instructions to increase their negative emotional response (M = 0.21 ± 0.32) than from the instructions to be aware of their response (M = 0.08 ± 0.21; t [71.59] = 2.95, p <.014). Instructions to decrease their emotional response instigated smaller corrugator EMG magnitudes (M=0.09 ± 0.23) than the cue to be aware of their response (t [71.59] =5.93, p <.001). In summary, Ray and Ochsner's results showed simultaneous matched effects of self-reported emotional affect and facial-corrugator muscle activity during subjects' reappraisal, demonstrating that cognitive reappraisal effectively regulates undesired emotional responses to negative stimuli and can also create a negative response to neutral stimuli.

Facial Expression Measurements Predict fMRI Measurements of Amygdala

Another study on the reappraisal of negative stimulus was conducted by Lee et al. (2012). It used two trials to examine the regulation ability of emotion and the neural networks utilized in emotion regulation. Previous researchers had identified that the amygdala detects the significance of emotional situations and generates bio-behavior responses accordingly (Phelps and LeDoux, 2005), the prefrontal cortex (PFC) provides top-down regulation, including inhibiting or maintaining emotional responses (Miller and Cohen, 2001), and a reciprocal PFC-amygdala relationship occurs while subjects reappraise negative emotion (Banks et al., 2007). Lee et al. noted that although these brain regions' activity was pretty reliable, differences between individuals' neural responses still existed. Consequently, Lee et al. examined within-subject neural processes of emotion regulation with EMG—which reliably measures emotional responses, followed by fMRI of the same subjects and tasks.

Fifty-six male participants were shown emotionally arousing pictures and instructed to either enhance, suppress, or maintain their emotional responses. In session one, EMG measured the magnitude of the participants' emotional response to the images by measuring the participants' corrugator activity during emotion regulation. In session two, fMRI was used to identify the participants' neural processes during emotion regulation. Results showed that emotion regulation skills indicated by EMG corrugator measurements of participants from session one predicted amygdala-prefrontal-functional connectivity in fMRI amygdala measurements in session two (r = 0.39, p = 0.003). Although this study did not directly examine

FFH, the correlation of facial expression with amygdala-PFC connectivity supports facial expression and neural connection.

Eyebrow Placement Implicates Facial Feedback Correlation with Emotion

Three experiments by Michael Lewis (2012) explored and supported the facial feedback sufficiency hypothesis. In Lewis' first experiment, 54 random subjects were told the research regarded concentration methods and were instructed to raise their eyebrows high, lower their eyebrows, or keep them in the middle while taking the Irritability-Depression-Anxiety (IDA) questionnaire. Analysis of the eyebrows-down placement scores showed significance for depression (F [2, 51] = 5.443; p<.01), and anxiety (F [2, 51] =18.731; p<.01), but not irritability (F [2, 51] = 2.759; p <.073) (Figure 7). Lewis suggested that these findings support the idea that BTX treatments could reduce depression by suppressing frowning capability.

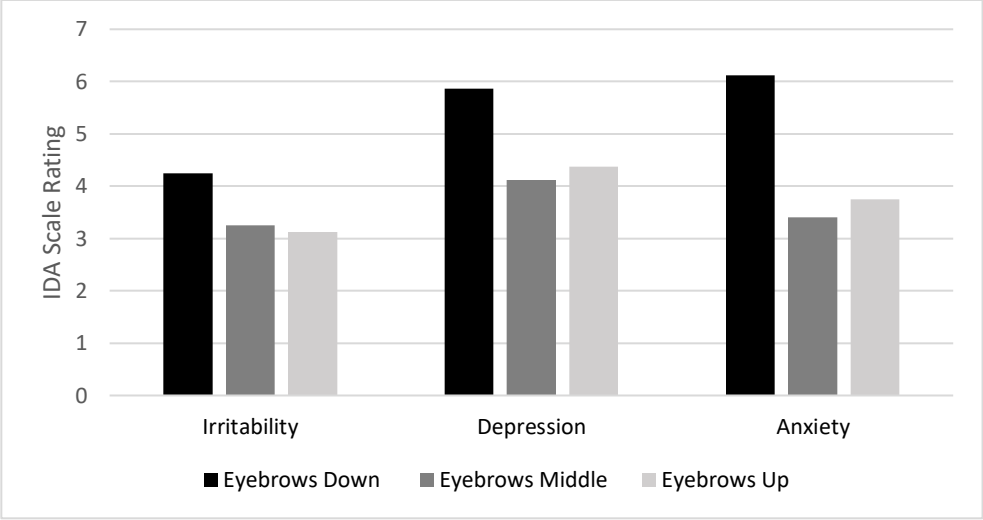

Figure 7. The mean ratings of the IDA questionnaire for the three facial manipulations in experiment one show the effect of eyebrows down on mood. (Chart created with data from the Lewis 2012 article.)

The cover story from experiment one was used in a second experiment. The facial feedback influence of surprise or disbelief was explored as 24 subjects either raised their eyebrows as high as possible, lowered their eyebrows as low as possible, or held them constant while rating the plausibility of ten "facts." Manipulation of eyebrows proved to impact the surprise or believability of the facts (F [2, 46] = 5.832; p<.01). The third experiment examined whether facial expressions of disgust would impact subjects' evaluation of odors. Thirty-three subjects were told that researchers were examining how facial muscle activity moved smells to different parts of the nasal cavity. Subjects then forced their noses as high as possible, as low as possible (by lowering the lower lip), or by keeping the nose relaxed as they smelled boxes of mostly unpleasant odors, such as "urine," "farmyard," and "vomit." Manipulation of the nose impacted the pleasantness or unpleasantness ratings of the smells (F [2, 64] = 5.343; p = .007).

The overall results from the three experiments showed that 1) the participant's mood was negatively impacted when someone lowered their eyebrows (p=.01), 2) facts seemed more surprising when eyebrows were raised (p=.012), and 3) wrinkling noses made odors seem more unpleasant (p=.007).

Cardiovascular Responses to Smiling

Facial feedback may also affect other autonomic processes besides emotion. In a study by Kraft and Pressman (2012), the impact of facial expression on cardiovascular health during a stress test was examined. One hundred seventy participants divided randomly into three groups held two chopsticks in their mouth in three different ways to 1) activate the zygomaticus major muscle (standard smile group), 2) activate the zygomaticus major and orbicularis oculi (eye muscles) ("Duchenne," genuine smile group), or 3) not activate smile muscles (neutral group) as they took a stress test (Figure 8). The subjects were told a cover story that the research involved multi-tasking to help prevent awareness of smiling. The stress test consisted of two tasks: tracing a mirror image of a star eight times while research assistants criticized mistakes, then submerging their hands in ice water for one minute. The chopsticks were removed after the stress test, and the heart rates were monitored during recovery. Additionally, half the smiling participants were informed they were smiling during the stress test, and the other half were not informed that they were smiling. Measurements also assessed whether knowledge of smiling influenced heart rate.

Figure 8. Example of photographs shown to participants to help them form the appropriate expression—Neutral group (left), standard smile group (middle), and the "genuine" smile group (right). (Image from Kraft & Pressman 2012 article used with permission.)

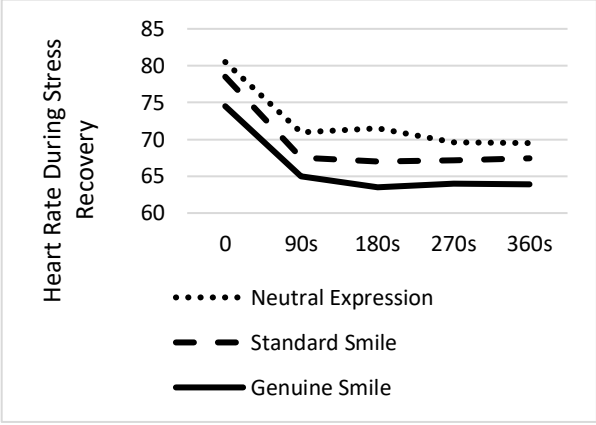

Figure 9. Heart rate during stress recovery of neutral group, standard-smile group, and "genuine" smile group conditions. (Chart created from data from Kraft & Pressman 2012 article).

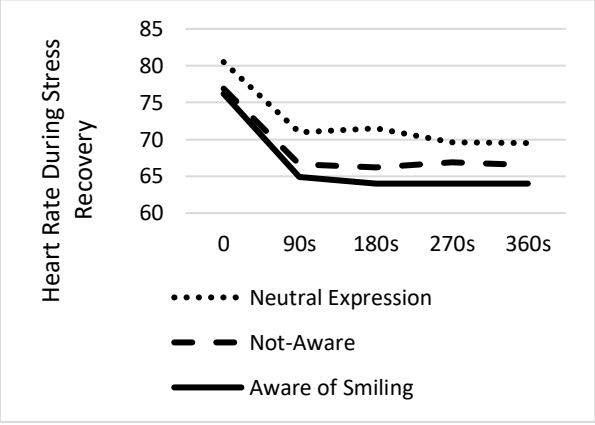

Figure 10. Heart rate during stress recovery of neutral group, not-aware-smile group, and aware-smile group conditions. (Chart created from data from Kraft & Pressman 2012 article).

Both the standard smile and "Duchenne," genuine smile groups had significantly lower heart rates during stress recovery than the neutral group ($M_{standard\text{-}smile}$ = 68.19 bpm vs. $M_{neutral}$ =

71.45 bpm; F [1,117] = 3.95, p = .05), with a slight advantage for the "Duchenne," genuine smile group ($M_{Duchenne}$ = 66.40 bpm vs. $M_{neutral}$ = 71.69 bpm; F [1,74] = 6.71, $p < .05$). (Figure 9.)

Awareness of smiling may also assist with stress reduction, as aware smilers showed a better response than the neutral group (M_{aware} = 66.60 bpm vs. $M_{neutral}$ = 71.29 bpm), F (1,72) = 5.40, $p < .05$ (Figure 10). Overall, findings show physiological benefits (e.g., better heart rate recovery from stress) from maintaining positive facial expressions during stress.

Conditioned Emotional Stroop Test

Blanchette and Richards (2013) were not testing facial feedback in this study. However, they used EMG measurement of facial expressions to examine attentional bias toward threat with an emotional Stroop test of conditioned stimuli. After taking the State-Trait Anxiety Inventory (STAI) test, the 44 subjects were divided equally into low and high-trait anxious groups. Scores ranged from 21 to 62 (M=41.1, SD = 9.3). In a Stroop test, subjects' response time is measured in a task requiring the subjects to filter out incongruent information. A standard Stroop test is for subjects to state the font color of color names, and often the font color is incongruent with the name. For this emotional Stroop test, negative and neutral images were paired with neutral non-words (e.g., lostal, sturl, priducy). Affective response to the images was measured with EMG, and the physiological response was measured with skin conductance responses (SCR). The subjects were then shown the images with the paired non-word written in an incongruent colored font, and subjects pressed a key on the keyboard that represented the color of the word. Stroop test reaction times were compared between the low anxiety and high anxiety groups.

EMG measurements during conditioning showed a significant interaction between groups, image valence, and the time the subjects viewed the image (F [3, 123] = 2.9, $p < .05$). A significant difference was also found in the corrugator activity of the high-trait anxious and the low-trait-anxious group during the conditioning of non-words to negative and neutral images (Figures 11 and 12). The difference between the EMG measurements of negative and neutral image conditioning increased significantly over time in the High Anxious Group (F [3, 57] = 4.4, $p < .01$) (Figure 12). Additionally, the high-trait anxious group's response times for the Stroop test were significantly slower than for the low-trait anxious group (r .31, p = .05).

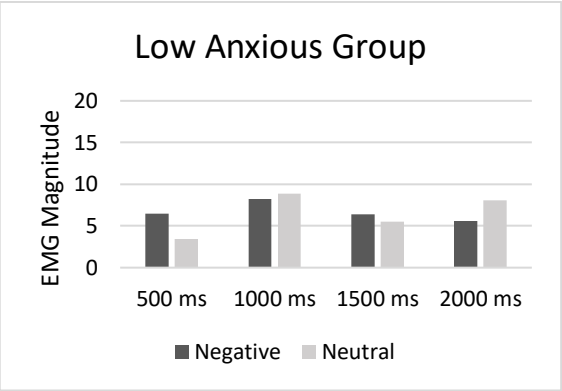

Figure 11. Low-anxious group EMG corrugator activity measurements during conditioning of neutral, non-words with negative and neutral images. (Charts created with data from Blanchette & Richards 2013 article.)

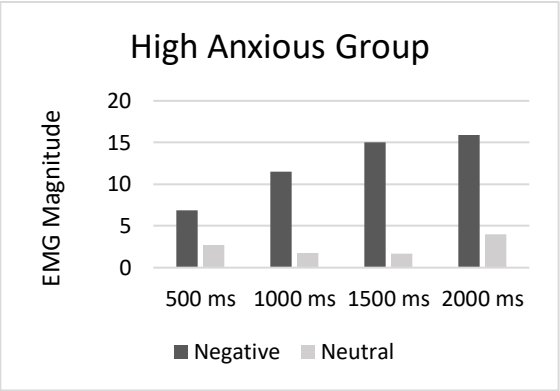

Figure 12. High-anxious group EMG corrugator activity measurements during conditioning of neutral, non-words with negative and neutral images. (Chart created with data from Blanchette & Richards 2013 article.)

These results show that corrugator facial movement is more significant in high-trait anxious individuals than low-trait anxious individuals while observing negative valence images. Blanchette and Richards suggested that these findings endorse the premise that high-trait anxious individuals show attentional bias toward threat.

Corrugator (Frowning) Activity Simultaneous EMG and fMRI

Heller et al. (2014) examined correlations between facial expressions and neural activity with a novel method of combining EMG facial measurement and fMRI concurrently. Twenty-six subjects' emotional responses were assessed with both EMG and fMRI while subjects viewed negative and neutral images. Results showed that trial-by-trial increases in corrugator-EMG responses to negative pictures correlated with more significant amygdala activity in fMRI images ($t\ [25] = 2.62$, $p = .01$). In addition, a simultaneous decrease in ventromedial PFC activity was found that correlated with increased amygdala and corrugator activity. As indicated in the Lee et al. 2012 study, the PFC is involved in top-down emotion regulation, while the amygdala is more stimuli-driven (bottom-up). Increased top-down regulation appears to help regulate emotional reactions in the amygdala. Heller et al. suggested their study indicates a reciprocal relationship in encoding emotional valence between brain regions and facial expressions ($p < 0.05$).

Heller et al. suggest that the corrugator EMG measurement and the time course for the fMRI scan session show a significant valence effect across the first 4 seconds of image presentation ($t\ [27] = 2.21$, $p = .04$), as there is a significant difference between negative valence and neutral valence effects at 2 and 3 seconds ($t\ [27] = 2.64$, $p = .01$). Image presentation time is indicated by the green bar (Figure 13).

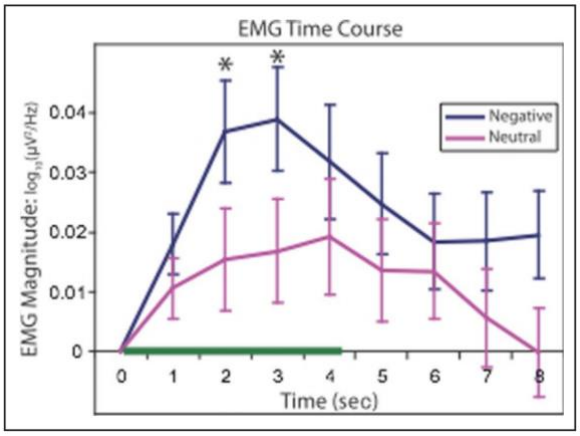

Figure 13. Corrugator EMG measurement and time course for fMRI scan session (Image from Heller et al. 2014 article used by permission)

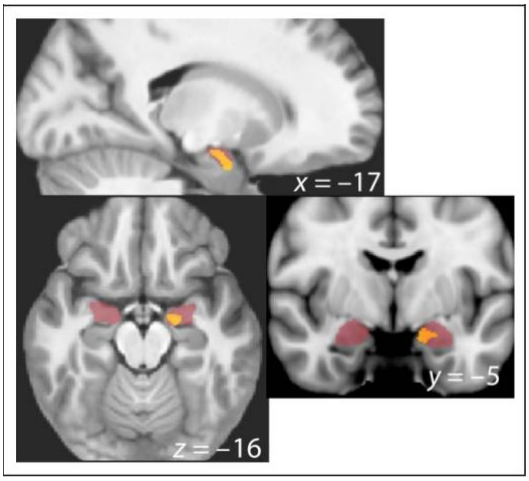

Figure 14. Activity within the amygdala region during image presentation (Image from Heller et al. 2014 article used by permission)

Significant activity within the amygdala region was found during image presentation correlation with corrugator EMG magnitude. The amygdala is shown in pink, and the orange portion is the significant cluster within the amygdala (Figure 14). Greater corrugator EMG response to negative stimuli predicted greater amygdala activity ($t\ [25] = 2.62$ $p = .01$).

Strack Study Replications

Wagenmaker et al. (2016) challenged the validity of FFH with an international, seventeen-trial replication of the Strack et al. (1988) study where subjects held pens in their mouths to facilitate or inhibit smiles while rating the humor of cartoons. Wagenmaker's replication did not have the same results as the Strack study. Only nine of the 17 trials in the Wagenmaker's study showed the facial feedback effect. However, the Wagenmaker study was criticized because it filmed the participants, and the Strack study did not. Noah et al. (2018) determined to test Wagenmaker's results with a revised replication. The Noah study was split into two groups, 100 subjects followed Strack's original protocol and a second group of 100 subjects added the video recording of the participants as Wagenmaker's had done. Noah's results supported Strack's original findings as study subjects who performed the task without a camera reported more amusement than those who performed tasks with the camera, (M_{teeth} = 5.75, SD 1.35, M_{lips} = 4.92, *SD* 1.46), (*t* [162] 2.48, $p < .01$). Noah et al. suggested that the significant differences between the two groups suggests that filming participants might alter outcomes. However, Soussignan's (2002) study also filmed participants and their results still showed the facial feedback effect. It is possible that other variables, or alterations from the original protocol, confounded the eight trials that did not show the facial feedback effect in the Wagenmaker study.

Mental Health Implications from Botox Treatment

Earlier research showed that BTX used as a cosmetic treatment reduced depression symptoms (Sommer et al., 2003). Li et al. (2021) discussed several theories about the physiological mechanisms of this reduction: 1) facial feedback, which claims that BTX denervation of frown musculature reduces the negative facial feedback patients experience, enhancing their mood; 2) social feedback, which claims that people will have more positive social interactions when they are unable to show angry or sad facial expressions, improving their mood; 3) brain changes from BTX, including upregulation of brain-derived neurotrophic factor (BDNF), increased monoamines, insula cortex modification, and reduced neuroinflammation which may improve mood directly. Improved self-esteem is a possible fourth theory, as research by De Aquino et al. (2013) showed a significant improvement in patients' self-esteem after BTX treatment, and low self-esteem has been shown to contribute to psychological disorders (Singh et al., 2015).

Michael Lewis (2018) indicated that the most commonly accepted reason for depression reduction from BTX is the Facial Feedback effect. He also suggested that BTX treatment for crow's feet (laughter lines) would impair genuine smiles (using both mouth and eyes), which may then negatively impact mood, as genuine smiles have shown to improve mood above standard smiles (Soussignan, 2002). Additionally, studies have shown that impaired mimicking of facial expressions inhibits emotion recognition (Oberman et al., 2007), suggesting that facial feedback also helps humans identify other people's emotions which is helpful in social interactions. Lewis (2018) explored the effect of BTX treatments on several mental health parameters, including anxiety, depression, and facial-emotion recognition. Twenty-four BTX patients and 12 control subjects, all-female, took several surveys, including the Hospital Anxiety and Depression Scale (HADS) and the Facial Emotion Recognition (FER) test. Half the BTX patients took the tests before BTX treatment, and half took them after.

Results indicated that the HADS questionnaire given to each subject showed a significant decrease in negative mood after BTX treatment for frown lines only (center bars on Figure 15), (t [12] = 3.285, p = 0.007, d = 1.897). The non-BTX group and the group who received BTX treatment for both frown lines and crow's feet did not experience a similar benefit (right bars on Figure 15). Patients who received BTX treatment experienced significantly reduced emotion recognition ability (t [10] = 2.543, p = 0.029, d = 1.608) (Figure 16).

Lewis' study results indicated that inhibiting the corrugator muscle movement involved in frowning was directly related to improved mood in study subjects. Additionally, the study shows that the positive benefits from frown line immobilization were annulled for the subjects who received treatments that immobilized the orbicularis oculi (eye) muscles, thus preventing "genuine" (using mouth and eyes) smiles. This study supports the hypothesis that facial expression has a significant impact on affect and suggests the involvement of facial expression in mental health disorders.

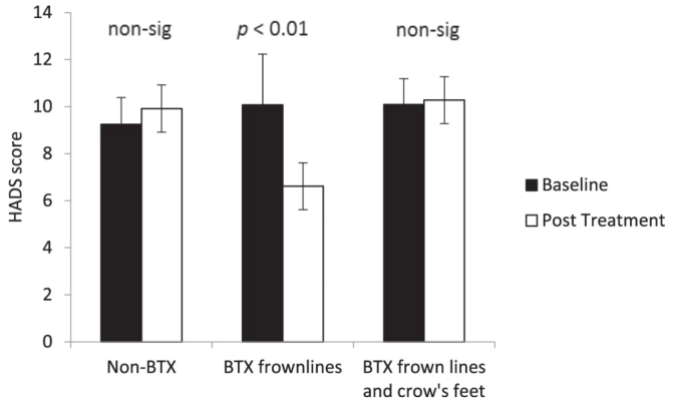

Figure 15. Baseline and post-treatment scores for the Hospital Anxiety and Depression Scale (HADS) of non-BTX patients, BTX frownline patients, and BTX frownline and crow's feet patients (Images from Lewis 2018 article are open access).

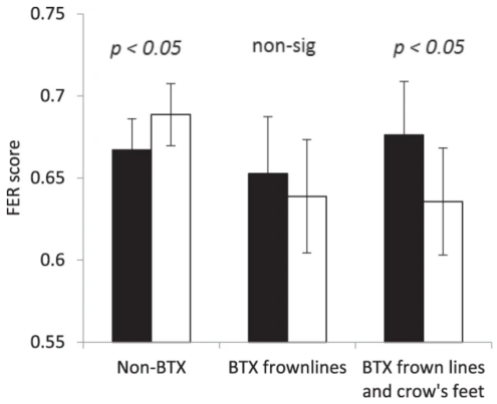

Figure 16. Baseline and post-treatment Facial Emotion Recognition scores of non-BTX patients, BTX frownline patients, and BTX frownline and crow's feet patients (Images from Lewis 2018 article are open access).

Facial Feedback Meta-Analysis & Effect Sizes

Coles et al. (2019a) evaluated the cumulative evidence for the FFH with a meta-analysis of 286 effect sizes from 138 studies that manipulated facial feedback and collected emotion self-reports. The authors indicated that the combined effect sizes from all the studies were small (d = .20) but varied widely. The authors identified potential moderators and determined that several likely significantly impacted the study's effect sizes. Larger effect sizes were found for studies that did not include emotional stimuli but relied on manipulated facial muscles (d = .32). These results suggest that facial musculature movement might have a greater impact than some emotionally arousing stimuli alone. In addition, facial feedback effect sizes varied depending on the type of stimuli (Figure 17). Some stimuli had lower effect sizes (pictures, d =.16, films, d = .13, social contexts, d =-.14), and some had much larger effect sizes, (stories, d = .41, emotional audio, d = .72, imagined scenarios (d = 1.28). The authors conclude that facial feedback can both modulate and initiate emotional experiences and that the effect size varies greatly based on the type of emotional stimuli introduced.

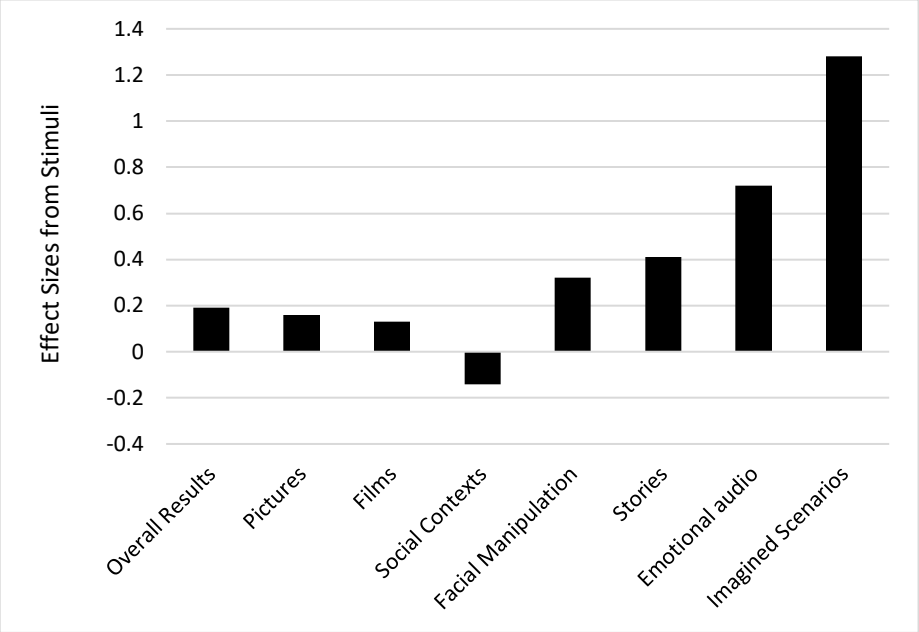

Figure 17. Facial feedback effect sizes by type of stimuli (Chart created with data from Coles et al. 2019a article).

Meta-Analysis on BTX as Depression Treatment

Another meta-analysis of seven studies by Coles (Coles et al, 2019b) focused on depression reduction of subjects who received glabellar-region botulinum toxin injections (GBTX). Coles et al. selected studies 1) in which the sample was clinically depressed, 2) BTX was injected into the glabellar region for reasons unrelated to FDA approved clinical uses, 3) and depression levels were measured. Studies utilizing placebo versus GBTX groups indicated that six weeks after treatment, GBTX groups were significantly less depressed compared to placebo groups (d = 0.83, 95% CI [0.52, 1.14], z = 5.27, $p < .001$; $\tau 2 = 0$). Within-subject studies that compared pretreatment depression levels with six-week after treatment levels showed an even more significant result (d = 1.57, 95% CI [1.09, 2.05], z = 6.43, $p < .001$; $\tau 2 = 0.12$). The overall effect size of all GBTX treatment studies combined was found to be d = 1.28, 95% CI [0.73, 1.82], z = 4.61, $p < .001$; $\tau 2 = 0.44$ (Figure 18).

Coles et al. were apprehensive about these treatment successes because the researchers had estimated that effectiveness for GBTX would be between d = 0.17 and d=0.42. The lower estimate was from facial feedback lab experiments' effect sizes (Coles et al. 2019a), and the higher estimate is the largest effect size of FDA-approved anti-depressant medications. The average effect size of FDA-approved anti-depressants is d = 0.31 (Turner et al., 2008).

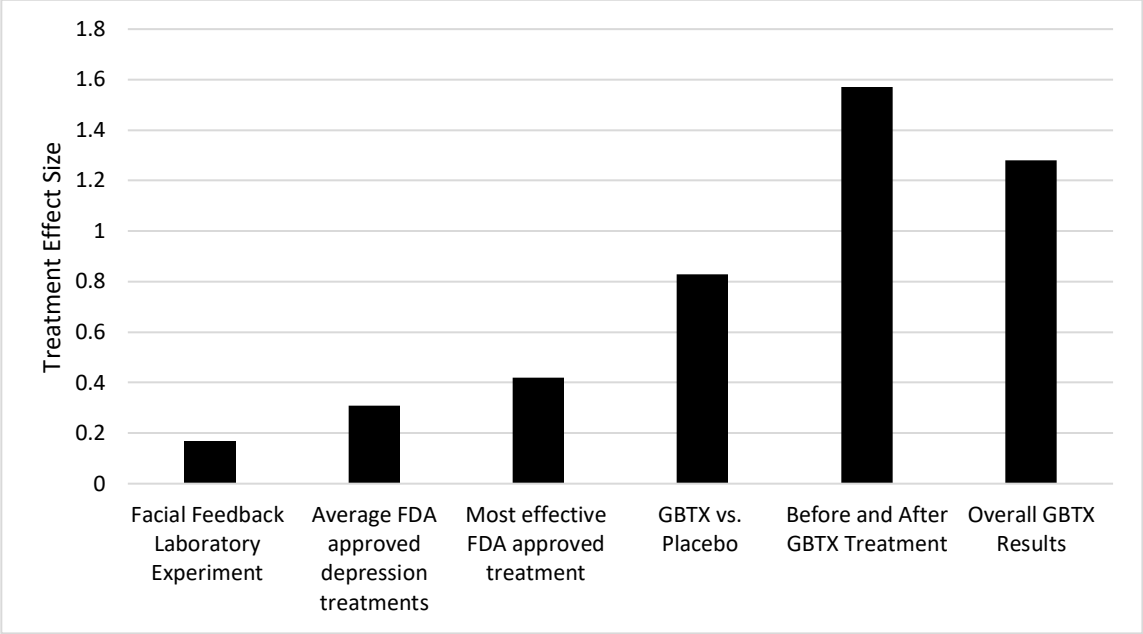

Figure 18. Meta-analysis of BTX depression treatment effect sizes by study type (Chart created with data from Coles et al. 2019b article.)

Coles et al. examined the unexpected outcomes using statistical evaluation procedures, including symmetry, trim-and-fill, and weight-function modeling, the last suggesting significant bias in the studies, $\chi 2(1) = 5.17$, $p = .02$. They concluded that confidence in GBTX as depression therapy is "premature" due to problems found in some of the studies: 1) not all trial outcomes were reported, and requests for missing data were ignored; 2) it is almost impossible to blind GBTX recipients as to whether they were given BTX treatment or a placebo as the subjects will likely recognize whether they have facial muscle immobilization or not; 3) 96% of researchers had a conflict of interest in this study, either as a patent owner, an employee of the manufacturer, or consultant to the manufacturer.

Despite these concerns, Coles et al. determined that further research is essential in this area because of its enormous yet inexpensive clinical potential with minimal side effects. It is a possible alternative therapy for treatment-resistant depressed patients. The authors also noted that understanding the disruption of emotional processing is vital for cosmetic BTX consumers and psychiatric patients. Additionally, they recognized that thorough research into the effects of BTX depression treatment might help resolve debates in the facial feedback literature regarding the role of efferent versus afferent muscular feedback.

Afferent Neural Communication from the Face to the Brain

The trigeminal nerve is a possible conduit for afferent facial-feedback signals transmitting emotional triggers. It is already known that trigeminal afferent-neural pathways innervate facial sensation and that the trigeminal nerve's branches reach regions in the brain involved in emotional processes. Researchers have noted that many anastomoses (unexpected connection points) exist between the facial nerve and the trigeminal nerve (Baumel, 1974). A study of 17 cadavers by Odobescu and Gilardino (2012) sought to understand the frequency and significance of anastomoses between the temporal branch of the facial nerve and the

zygomaticotemporal branch of the trigeminal nerve. They observed a consistent connection between one or two branches in the zygomaticotemporal region of 14 of 17 dissected cadaveric half faces (Figure 19). Histochemical analysis suggests that these connections contain myelinated fibers, which could be proprioceptive (body awareness) or motor fibers. Twentieth century FFH researchers indicated that facial proprioception might be an integral part of the Facial Feedback mechanism (Gellhorn, 1964; Izard, 1977), relying on afferent neural communication, such as the trigeminal nerve.

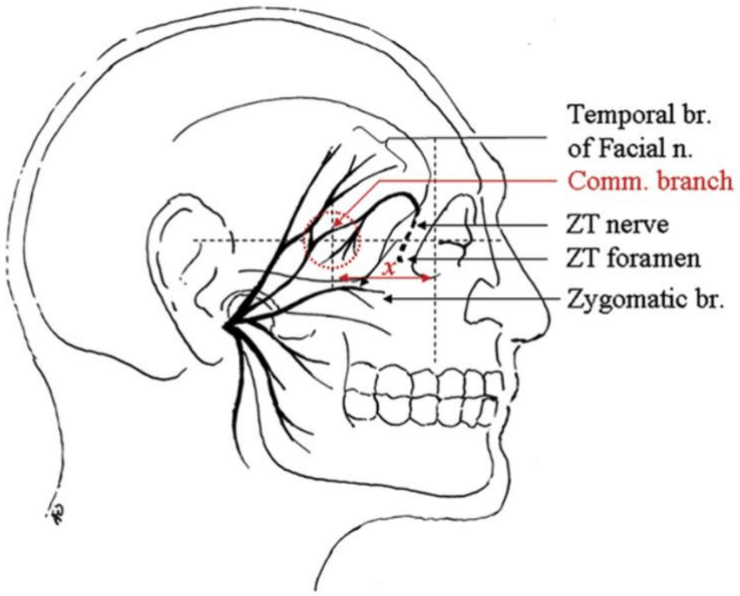

Figure 19. Location of the facial-zygomaticotemporal branch of the trigeminal nerve where it intersects with the temporal branch of the facial nerve. The red circle identifies a 1 cm diameter area centered at 36 mm lateral to the lateral canthus (outside point of the eye) where the communicating branches were usually found in the cadavers (Image from Odobescu & Gilardino 2012 article used by permission).

Trigeminal Nerve Stimulation for Treatment-resistant Depression

A review by Cook et al. (2014) describes recent studies of three treatment-resistant depression interventions, including external trigeminal nerve stimulation (eTNS). Stimulation of the trigeminal nerve was chosen as a possible therapy for treatment-resistant depression as it poses no risk for cardiac disruption and is also less invasive than stimulating the vagus nerve. The Trigeminal nerve is the largest cranial nerve, providing an excellent pathway to the central nervous system. It communicates directly to regions of the brain implicated in emotion and arousal, such as the nucleus of the tractus solitarius, which is involved in the modulation of emotional memories (Kerfoot, 2008), the locus coeruleus, which is a crucial mediator in emotion and stress-induced anxiety (Gong, 2021), the raphe nuclei, which hosts serotonergic neurons critical to the central nervous system (Tian, 2017), the medullary reticular activation system which is involved in general arousal (Martin, 2011), and thalamic structures, involved in the assessment of complex emotional stimuli (Frank, 2014), and then to sensory, limbic, and other cortical and subcortical regions.

An eight-week pilot study of eTNS at UCLA included 11 adults with treatment-resistant major depressive disorder (MDD). Study subjects applied nerve stimulating electrodes on their

forehead (over the V1 - ophthalmic branch of the trigeminal nerve) for approximately eight hours of stimulation each night for eight weeks. All subjects experienced a significant reduction in depression severity. Scores from the 28 item Hamilton Depression Rating Scale (HDRS-28) decreased from 28.0 (*SD* = 6.9) to 14.4 (*SD* = 6.5) (2-tail paired t [10] = 5.95, *p* = 0.00014, Cohen's d = 1.8), (Figure 19). Individual decreases ranged between 17% – 64%, an average of 51%, and four of the 11 subjects (36%) had remittance by the end of the trial (Schrader et al., 2011).

In a second study, 12 adults who had both treatment-resistant MDD and post-traumatic stress disorder (PTSD) were treated in the same method and experienced a similar symptom reduction. PTSD Patient Checklist (PCL) scores showed significant decreases from the start of the study to week eight (*p* = 0.003) (Figure 20). The median decrease was 15 points. Depression scores also showed a significant reduction, with both the 17-item Hamilton Depression Rating Scale (HDRS-17) and Quick Inventory of Depressive Symptomatology (QIDS-C) indicating the same significance for the changes (p< 0.001). Large Cohen d effect sizes were established for all symptom changes (d=1.5 for PCL, d=2.1 for HDRS-17, d=1.8 for QIDS-C) (Cook et al., 2016).

Forty-two subjects with drug-resistant epilepsy (DRE) were tested using a similar eTNS treatment in a third trial. This trial included a control group who received a sham treatment of 2 Hz TNS stimulation, while the treatment group received the therapeutic dose of 120 Hz. The subjects took depression inventories as part of the study, and the Beck Depression Inventory (BDI) scores of the treatment group showed over twice the improvement of the sham treatment group (*p* < 0.02) (DiGiorgio et al., 2013). While eTNS depression treatment shows great potential, it is still in clinical trials.

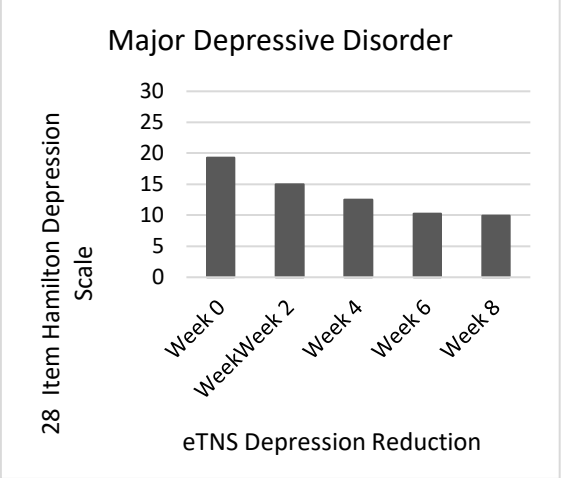

Figure 19. Effects of eTNS on depression severity on subjects with treatment-resistant Major Depressive Disorder with comorbid PTSD. (Chart created with data from Cook et al. 2014 article.)

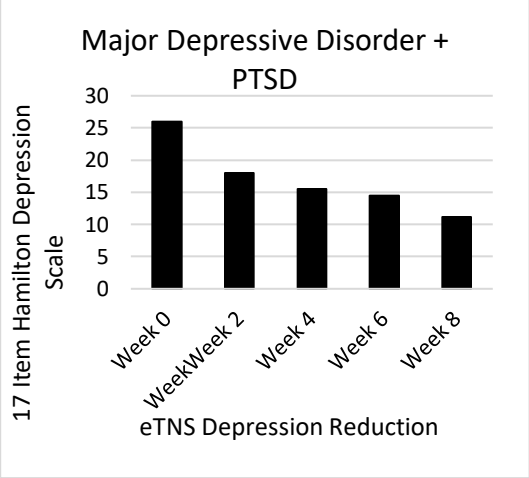

Figure 20. Effects of eTNS on depression severity on subjects with treatment-resistant Major Depressive Disorder comorbid with PTSD. (Chart created with data from Cook et al. 2014 article.)

Connections Between Facial and Trigeminal Nerves

Although the neuroanatomy and neurology of facial muscles are reasonably well understood in the medical world, facial muscle proprioception is less understood because facial muscles lack evident proprioception nerves. Cobo et al. (2017) suggested that the trigeminal nerve is likely responsible for a large percent of facial proprioception. They reviewed several

recent cadaver studies that examined facial and trigeminal nerves and facial muscle connections to verify this assumption and concluded that the trigeminal nerve's connections with the facial nerves must innervate facial muscle proprioception.

Discussion

This literature review has discussed historical and current research on the FFH, the implications of facial expression on mental and physical health, and neurological evidence showing connections between facial musculature and regions of the brain involved in emotion processing. Although two studies did not support the FFH (Tourangeau & Ellsworth,1979; Wagenmaker et al., 2016), both were criticized by other researchers for questionable methods (Izard, 1981) and incorrect replication protocol (Noah, 2018). Numerous other studies show significant correlations between facial expression and emotion, with some supporting the sufficiency hypothesis suggesting facial expressions alone can initiate an emotional experience (Strack et al., 1988; Soussignan, 2002; Lewis, 2012). The Coles, Larsen, and Lench (2019a) meta-analysis of facial feedback studies indicated that the average effect size varies considerably. However, facial-feedback studies of "imagined scenarios" show the literature's largest and most meaningful overall effect size (d=1.28). "Imagined scenarios" are similar to the exaggerated cognition appraisals of emotional distress that contribute to mental health challenges; notably, these are also the target of some well-established cognitive therapy techniques (Burns, 2020). Evidence of neural activity between facial expressions and emotional processing has also been found in several studies reviewed (Hennenlotter, 2008; Lee et al., 2012; Heller et al., 2014). In conclusion, the overall cumulative results from the studies reviewed here provide a robust endorsement of the role of facial feedback in human emotional processes and suggests that researchers should identify its possible role in mental health disorders.

Research on the role of facial feedback in mental health disorders could begin by studying temporomandibular disorders (TMD), which researchers have already identified as frequently associated with mental health disorders (Fredricson et al., 2022; Al-Khotani et al., 2021; Namvar et al., 2021; Mottaghi & Zamani, 2014). Stress is a known initiator of TMD (Namvar et al., 2021) and mental health challenges (Schneiderman, N., 2005). TMD and mental health disorders may be bidirectional, creating and maintaining a cycle of distress. Future studies could study the temporalis and masseter muscles with EMG of individuals diagnosed with TMD to look for exaggerated muscular responses during emotional tasks. Exaggerated facial muscle responses during distress could instigate exaggerated facial feedback and contribute to mental health disorders. Additional studies could survey mental health patients for unrecognized TMD symptoms. Further studies could examine mental health patients more extensively with dental X-rays, CT scans, or MRIs to determine if they have undiagnosed TMD. Diagnosing mental health patients with comorbid TMD may facilitate a more rapid mental health recovery as TMD treatments are combined with psychological treatments.

Additional FFH-mental health studies could examine distinctions in facial musculature between those with and without mental health challenges. Based on prior studies, promising muscles of interest might include the corrugator, orbicularis oculi, and zygomaticus muscles. The corrugator and orbicularis oculi have been shown to be mediators of mood in BTX studies (Lewis, 2018), while the zygomaticus minor muscle is involved in both grimacing and smiling (Sendic, 2022) so should be an important muscle for research. Matusmoto and Ekman (2008) indicate that facial muscles are the only muscles in the body that attach on one side to bones and

the other side to skin. Additionally, some facial muscles, such as the orbicularis oculi (around the eyes) and orbicularis oris (around the mouth), do not attach to bones at all. Researchers could examine if these unique characteristics put these muscles at risk for strain during distress, which might alter facial feedback responses (e.g., intensity, timing) and contribute to mental health challenges.

Additional facial feedback research could focus on understanding the facial and trigeminal nerves' possible roles in mental health disorders. Focuses could be on the trigeminal and facial nerves' anastomoses and understanding if facial feedback processes differ from proprioception. Identifying neural pathways from temporalis, masseter, corrugator, orbicularis oculi, and zygomaticus muscles (major and minor) to anastomoses and brain regions responsible for neurotransmission of monoamines involved in mental health disorders may lead to a better understanding of these processes. Recognition of the emotional pathways in the facial and trigeminal nerves would also help researchers understand and improve eTNS and BTX therapies for depression. Phase III trials of BTX as a depression treatment that controls for improved self-esteem (and without conflict of interest) would clarify its role in depression reduction, and trials of eTNS therapy with a larger subject population may prove enlightening.

Examining the contributions of facial feedback in existing mental health treatments would also be beneficial to those struggling with mental health disorders. Cognitive Behavioral Therapy (CBT), mindfulness, and meditation therapies involve modifying cognitions (which move facial musculature) or purposeful relaxation (which includes facial muscles.) Researchers could study facial movement with EMG during CBT, mindfulness, and meditation along with subjects' mood scores to determine correlations between facial movement and mood improvement. Future research could also assess mood implications of depressed and anxious patients' awareness and alterations of facial reactions during stress.

Clarifying and acknowledging the significance of facial feedback in emotional processes would help psychologists, psychiatrists, neurologists, and other mental health researchers also determine its role in mental health disorders. Understanding the role of facial musculature in mental health disorders could provide significant insight into the development and treatment of common mental health disorders, such as depression and anxiety.

References

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

Al-Khotani, A., Meisha, D. E., Al Sayegh, S., Hedenberg-Magnusson, B., Ernberg, M., & Christidis, N. (2021). The Association Between Psychological Symptoms and Self-Reported Temporomandibular Disorders Pain Symptoms in Children and Adolescents. *Frontiers in Oral Health, 2,* 675709–675709. https://doi.org/10.3389/froh.2021.675709

Allport, F. H. (1922). A physiological-genetic theory of feeling and emotion. *Psychological Review, 29,* 132–139. http://dx.doi.org/10.1037/h0075652

Banks, S. J., Eddy, K. T., Angstadt, M., Nathan, P. J., & Phan, K. L. (2007). Amygdala-frontal connectivity during emotion regulation. *Social cognitive and affective neuroscience*, *2*(4), 303–312. https://doi.org/10.1093/scan/nsm029

Blanchette, I., & Richards, A. (2013). Is emotional stroop interference linked to affective responses? Evidence from skin conductance and facial electromyography. *Emotion, 13*(1), 129–138. https://doi.org/10.1037/a0029520

Baumel, J.J. (1974). Trigeminal-facial nerve communications: Their function in facial muscle innervation and reinnervation. Archives of Otolaryngology (1960), 99(1), 34–44. https://doi.org/10.1001/archotol.1974.00780030038007

Berking, M., Wirtz, C. M., Svaldi, J., & Hofmann, S. G. (2014). Emotion regulation predicts symptoms of depression over five years. *Behaviour Research and Therapy*, *57*, 13–20. https://doi.org/10.1016/j.brat.2014.03.003

Burns, D. (2020). *Feeling great: The revolutionary new treatment for depression and anxiety*, PESI Publishing and Media.

Carr, L., Iacoboni, M., Dubeau, M-C., Mazziotta, J. C., & Lenzi, G. L. (2003). Neural mechanisms of empathy in humans: A relay from neural systems for imitation to limbic areas. *Proceedings of the National Academy of Sciences - PNAS, 100*(9), 5497–5502. https://doi.org/10.1073/pnas.0935845100

Caspi, A., Houts, R. M., Ambler, A., Danese, A., Elliott, M. L., Hariri, A., Harrington, H., Hogan, S., Poulton, R., Ramrakha, S., Rasmussen, L. J. H., Reuben, A., Richmond-Rakerd, L., Sugden, K., Wertz, J., Williams, B. S., & Moffitt, T. E. (2020). Longitudinal assessment of mental health disorders and comorbidities across 4 decades among participants in the Dunedin birth cohort study. JAMA Network Open, 3(4), e203221–e203221. https://doi.org/10.1001/jamanetworkopen.2020.3221

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

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

Cook, Abrams, M., & Leuchter, A. F. (2016). Trigeminal nerve stimulation for comorbid posttraumatic stress disorder and major depressive disorder. *Neuromodulation, 19*(3), 299–305. https://doi.org/10.1111/ner.12399

Cook, I. A., Espinoza, R., & Leuchter, A. F. (2014). Neuromodulation for depression: invasive and noninvasive (deep brain stimulation, transcranial magnetic stimulation, trigeminal nerve stimulation). *Neurosurgery Clinics of North America, 25*(1), 103–116. https://doi.org/10.1016/j.nec.2013.10.002

Darwin, C. (1872). *The expression of the emotions in man and animals*. London, UK: William Clowes and Sons.

De Aquino, M.S., Haddad, A., & Ferreira, L. M. (2013). Assessment of Quality of Life in Patients Who Underwent Minimally Invasive Cosmetic Procedures. Aesthetic Plastic Surgery, 37(3), 497–503. https://doi.org/10.1007/s00266-012-9992-0

DeGiorgio, C.M., Soss, J., Cook, I. A., Markovic, D., Gornbein, J., Murray, D., Oviedo, S., Gordon, S., Corralle-Leyva, G., Kealey, C. P., & Heck, C. N. (2013). Randomized controlled trial of trigeminal nerve stimulation for drug-resistant epilepsy. *Neurology, 80*(9), 786–791. https://doi.org/10.1212/WNL.0b013e318285c11a

Ekman, P., Friesen W.V. (1978). *Facial action coding system: A technique for the measurement of facial movement*. Palo Alto: Consulting Psychologists Press.

Ekman, P., Levenson, R. W., & Friesen, W. V. (1983). Autonomic Nervous System Activity Distinguishes among Emotions. *Science, 221*(4616), 1208–1210. https://doi.org/10.1126/science.6612338

Fernández-Dols, J. M., & Ruiz-Belda, M. A. (1995). Are smiles a sign of happiness? Gold medal winners at the Olympic Games. *Journal of Personality and Social Psychology, 69,* 1113–1119. https://doi.org/10.1037/0022-3514.69.6.1113

Frank, D.W., & Sabatinelli, D. (2014). Human thalamic and amygdala modulation in emotional scene perception. *Brain Research*, 1587, 69–76. https://doi.org/10.1016/j.brainres.2014.08.061

Fredricson, A.S., Weiner, C. K., Adami, J., Rosen, A., Lund, B., Hedenberg-Magnusson, B., Fredriksson, L., & Naimi-Akbar, A. (2022). The Role of Mental Health and Behavioral

Disorders in the Development of Temporomandibular Disorder: A SWEREG-TMD Nationwide Case-Control Study. *Journal of Pain Research, 15*, 2641–2655. https://doi.org/10.2147/JPR.S381333

Gazinga, M., Ivry, R., Mangun, G., (2019). *Cognitive Neuroscience: The biology of the mind.* (4th ed.) W.W. Norton.

Gellhorn, E. (1964). Motion and emotion: The role of proprioception in the physiology and pathology of the emotions. *Psychological Review, 71*, 457–472. http://dx.doi.org/10.1037/h0039834

Gong, L., Shi, M., Wang, J., Xu, R., Yu, S., Liu, D., Ding, X., Zhang, B., Zhang, X., & Xi, C. (2021). The abnormal functional connectivity in the locus coeruleus-norepinephrine system associated with anxiety symptom in chronic insomnia disorder. *Frontiers in Neuroscience, 15*, 678465–678465. https://doi.org/10.3389/fnins.2021.678465

Hamann, S.B., Ely, T. D., Hoffman, J. M., & Kilts, C. D. (2002). Ecstasy and Agony: Activation of the Human Amygdala in Positive and Negative Emotion. *Psychological Science, 13*(2), 135–141. https://doi.org/10.1111/1467-9280.00425

Hasler, G. (2010). Pathophysiology of depression: Do we have any solid evidence of interest to clinicians? World Psychiatry, 9(3), 155–161. https://doi.org/10.1002/j.2051-5545.2010.tb00298.x

Heller, A. S., Lapate, R. C., Mayer, K. E., & Davidson, R. J. (2014). The face of negative affect: Trial-by-trial corrugator responses to negative pictures are positively associated with amygdala and negatively associated with ventromedial prefrontal cortex activity. *Journal of Cognitive Neuroscience*, *26*(9), 2102–2110. https://doi.org/10.1162/jocn_a_00622

Hennenlotter, A., Dresel, C., Castrop, F., Ceballos-Baumann, A. O., Wohlschläger, A. M., & Haslinger, B. (2008). 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., Kappas, A., McHugo, G. J., Lanzetta, J. T., & Kleck, R. E. (1992). The facilitative effect of facial expression on the self-generation of emotion. *International Journal of Psychophysiology, 12*(3), 251–265. https://doi.org/10.1016/0167-8760(92)90064-I

Izard, C. E. (1981). Differential emotions theory and the facial feedback hypothesis of emotion activation: Comments on Tourangeau and Ellsworth's "The role of facial response in the experience of emotion." Journal of Personality and Social Psychology, 40(2), 350–354. https://doi.org/10.1037/0022-3514.40.2.350

Izard, C. E. (1977). *Human Emotions*. Plenum Publishing Corp.

James, W. (1884). What is an emotion? *Mind, 9,* 188–205. http://dx.doI.org/10.1093/mInd/os-IX.34.188

Kerfoot, E.C., Chattillion, E. A., & Williams, C. L. (2008). Functional interactions between the nucleus tractus solitarius (NTS) and nucleus accumbens shell in modulating memory for arousing experiences. *Neurobiology of Learning and Memory, 89*(1), 47–60. https://doi.org/10.1016/j.nlm.2007.09.005

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

Larsen, J.T., Norris, C. J., & Cacioppo, J. T. (2003). Effects of positive and negative affect on electromyographic activity over zygomaticus major and corrugator supercilii. *Psychophysiology, 40*(5), 776–785. https://doi.org/10.1111/1469-8986.00078

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,* 321–338. https://doi.org/10.1080/02699939208409689

Ledoux, J.E. (2000). Emotion circuits in the brain. *Annual Review of Neuroscience, 23*(1), 155–184. https://doi.org/10.1146/annurev.neuro.23.1.155

Lee, H., Heller, A. S., van Reekum, C. M., Nelson, B., & Davidson, R. J. (2012). Amygdala–prefrontal coupling underlies individual differences in emotion regulation. *NeuroImage, 62*(3), 1575–1581. https://doi.org/10.1016/j.neuroimage.2012.05.044

Lee T., Josephs, O., Dolan, R. J., & Critchley, H. D. (2006). Imitating expressions: emotion-specific neural substrates in facial mimicry. *Social Cognitive and Affective Neuroscience, 1*(2), 122–135. https://doi.org/10.1093/scan/nsl012

Levenson, R.W., Ekman, P., & Friesen, W. V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology, 27*, 363–384. https://doi.org/10.1111/j.1469-8986.1990.tb02330.x

Lewis, M.B. (2012). Exploring the positive and negative implications of facial feedback. *Emotion*, *12*(4), 852–859. https://doi.org/10.1037/a0029275

Lewis, M.B. (2018). The interactions between botulinum-toxin-based facial treatments and embodied emotions. *Scientific Reports*, *8*(1), 1-9. https://doi.org/10.1038/s41598-018-33119-1

Li, Y., Liu, T., & Luo, W. (2021). Botulinum neurotoxin therapy for depression: Therapeutic mechanisms and future perspective. *Frontiers in Psychiatry*, *12*, 584416–584416. https://doi.org/10.3389/fpsyt.2021.584416

Martin, E.M., Devidze, N., Shelley, D., Westberg, L., Fontaine, C., & Pfaff, D. (2011). Molecular and neuroanatomical characterization of single neurons in the mouse medullary gigantocellular reticular nucleus. *Journal of Comparative Neurology* (1911), 519(13), 2574–2593. https://doi.org/10.1002/cne.22639

Matusmoto, D., Ekman, P. (2008, May 14). Facial expression analysis. *Scholarpedia*, *http://www.scholarpedia.org/article/Facial_expression_analysis*

Miller, E.K., & Cohen, J. D. (2001). An integrative theory of prefrontal cortex function. *Annual Review of Neuroscience, 24*(1), 167–202. https://doi.org/10.1146/annurev.neuro.24.1.167

McCanne, T., & Anderson, J. A. (1987). Emotional Responding Following Experimental Manipulation of Facial Electromyographic Activity. Journal of Personality and Social Psychology, 52(4), 759–768. https://doi.org/10.1037/0022-3514.52.4.759

Mottaghi, A., & Zamani, E. (2014). Temporomandibular joint health status in war veterans with post-traumatic stress disorder. *Journal of Education and Health Promotion, 3*, 60. https://doi.org/10.4103/2277-9531.134765

Namvar, M.A., Afkari, B. F., Moslemkhani, C., Mansoori, K., & Dadashi, M. (2021). The Relationship between Depression and Anxiety with Temporomandibular Disorder Symptoms in Dental Students. *Mædica, 16*(4), 590–594. https://doi.org/10.26574/maedica.2021.16.4.590

National Institute of Mental Health. (2022, January). Major Depression. Retrieved February 15, 2022, from https://www.nimh.nih.gov/health/statistics/major-depression

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

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

Odobescu, A., Williams, H.B, & Gilardino, M. (2012). Description of a communication between the facial and zygomaticotemporal nerves. *Journal of Plastic, Reconstructive & Aesthetic Surgery*, *65*(9), 1188–1192. https://doi.org/10.1016/j.bjps.2012.03.033

Phelps, E.A., & LeDoux, J. E. (2005). Contributions of the Amygdala to Emotion Processing: From Animal Models to Human Behavior. Neuron (Cambridge, Mass.), 48(2), 175–187. https://doi.org/10.1016/j.neuron.2005.09.025

Ray, R. D., McRae, K., Ochsner, K. N., & Gross, J. J. (2010). Cognitive reappraisal of negative affect. *Emotion, 10*(4), 587–592. https://doi.org/10.1037/a0019015

Rolls, E.T. (2019). The orbitofrontal cortex and emotion in health and disease, including depression. *Neuropsychologia,* 128, 14–43. https://doi.org/10.1016/j.neuropsychologia.2017.09.021

Schneiderman, N., Ironson, G., & Siegel, S. D. (2005). Stress and health: psychological, behavioral, and biological determinants. *Annual Review of Clinical Psychology, 1*(1), 607–628. https://doi.org/10.1146/annurev.clinpsy.1.102803.144141

Schrader, Cook, I. A., Miller, P. R., Maremont, E. R., & DeGiorgio, C. M. (2011). Trigeminal nerve stimulation in major depressive disorder: First proof of concept in an open pilot trial. *Epilepsy & Behavior*, *22*(3), 475–478. https://doi.org/10.1016/j.yebeh.2011.06.026

Sendic, G. (2022, February 22). Facial Muscles. *Kenhub*. Retrieved on March 24, 2022 from https://www.kenhub.com/en/library/anatomy/the-facial-muscles

Singh, C., Dulku, A., Haq, A., Bhatti, T., & Bhatti, A. (2015). Why do females use botulinum toxin injections? *Journal of Cutaneous and Aesthetic Surgery*, *8*(4), 236-238. http://dx.doi.org/10.4103/0974-2077.172201

Sommer, B., Zschocke, I., Bergfeld, D., Sattler, G., & Augustin, M. (2003). Satisfaction of patients after treatment with botulinum toxin for dynamic facial lines. *Dermatologic Surgery*, *29*(5), 456–460. https://doi.org/10.1046/j.1524-4725.2003.29113.x

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

Strack, Martin, L. L., & Stepper, S. (1988). Inhibiting and facilitating conditions of the human smile. *Journal of Personality and Social Psychology*, *54*(5), 768–777. https://doi.org/10.1037/0022-3514.54.5.768

Tian, Z., Yamanaka, M., Bernabucci, M., Zhao, M.-G., & Zhuo, M. (2017). Characterization of serotonin-induced inhibition of excitatory synaptic transmission in the anterior cingulate cortex. Molecular Brain, 10(1), 21–21. https://doi.org/10.1186/s13041-017-0303-1

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

Wagenmakers, Beek, T., Dijkhoff, L., Gronau, Q. ., Acosta, A., Adams, R. ., Albohn, D. ., Allard, E. ., Benning, S. ., Blouin-Hudon, E.-M., Bulnes, L. ., Caldwell, T. ., Calin-Jageman, R. ., Capaldi, C. ., Carfagno, N. ., Chasten, K. ., Cleeremans, A., Connell, L., DeCicco, J. M., … Hess, U. (2016). Registered Replication Report: Strack, Martin, & Stepper (1988). *Perspectives on Psychological Science*, *11*(6), 917–928. https://doi.org/10.1177/1745691616674458

Wild, B., Erb, M., Eyb, M., Bartels, M., & Grodd, W. (2003). Why are smiles contagious? An fMRI study of the interaction between perception of facial affect and facial movements. Psychiatry Research. *Neuroimaging*, *123*(1), 17–36. https://doi.org/10.1016/S0925-4927(03)00006-4

World Health Organization. (2017). *Depression and Other Common Mental Disorders: Global Health Estimates*. https://apps.who.int/iris/bitstream/handle/10665/254610/WHO-MSD-MER-2017.2-eng.pdf