Functional Electrical Stimulation Applied to Facial Muscles can be used to Neuromodulate Emotions

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Abstract*— Major depressive disorder (MDD) is a common condition, for which available pharmaceutical treatments are not always effective. Research on facial expressions has shown that facial movements can induce the corresponding emotions, particularly when specific attention is paid to voluntarily activating muscles that are typically only activated involuntarily while expressing emotions. We hypothesized that FES applied to facial muscles may enhance this effect, due to its ability to modulate central nervous system plasticity. Thus, applying FES to the facial muscles associated with smiling (including the "Duchenne marker") may increase the activity of subcortical nuclei related to positive emotions and counteract symptoms of depression. 12 able-bodied subjects received FES and were compared to a group of 12 control subjects. Both groups underwent the same experimental procedures involving a cognitive task, and a deception was used such that subjects were unaware that the objective was to modulate mood. Assessments with the Positive and Negative Affect Schedule – Expanded Form (PANAS-X) were administered before and after the experiment. No significant between group differences were found in the change scores for our primary outcomes "Joviality" and "Positive Affect". However, significant differences were detected for secondary outcomes "Determined", "Daring", "Scared" and "Concentrating". These results suggest that modulating emotion using FES may be possible. *(This article is a shortened version of article [16]).

I. Introduction

Major depressive disorder (MDD) is a condition with a prevalence varying between 3 and 16% [1]. Although a number of pharmaceutical interventions are available, some MDD sufferers are partially or completely resistant to these treatments. Up to 50% of patients do not achieve full remission [2]. In addition, anti-depressant drugs have a number of side-effects, including nausea, insomnia and weight gain.

Facial expressions for basic emotions (happiness, fear, surprise, etc.) have been found to be well-defined and universal across cultures [3]. Certain facial muscle movements can be easily controlled voluntarily, while others occur primarily during "genuine" emotions. For example, voluntary smiles (e.g. smiles for social purposes, without any particular emotional involvement) usually consist only of the upward curving of the lips, whereas spontaneous smiles due to positive emotions also involve the eyes, i.e. Duchenne marker. Duchenne marker is characterized by a raising of the cheeks and the appearance of crows-feet wrinkles next to the eyes [4,5]. Voluntary smiles are initiated in the motor cortex and routed via the pyramidal motor system. In contrast, involuntary smiles arise mainly from subcortical nuclei and are routed via the extrapyramidal motor system: clinical evidence from Parkinson's patients displaying the "masked face" syndrome suggests that the basal ganglia is involved in the production of emotional expression [6]. A related observation has been that voluntarily producing and holding an expression can induce the corresponding emotion [9,10]. This effect has been linked to afferent facial feedback received as a result of the facial movements [11,12]. The induction of emotion is more effective when a person pays specific attention to voluntarily activating muscles that are usually only used involuntarily [13,14], possibly because the voluntary facial expression is then closer to a genuine one.

We therefore hypothesized that applying FES to the facial muscles associated with smiling (including the Duchenne marker) may increase the activity of the CNS regions related to positive emotions (e.g. in the basal ganglia). This hypothesis is based on the existence of a close neural connection between these muscles and brain regions, as evidenced by the importance of the extrapyramidal pathway in the expression of genuine emotion, combined with the greater effectiveness of the Duchenne marker for artificially inducing emotion using voluntary movements. In other words, we hypothesized that this neural connection will provide a pathway through which FES can be used to modulate mood. If this hypothesis proves correct, FES applied to facial muscles may lead to new methods to combat the symptoms of MDD.

II. Methods

A. Experimental Design

We investigated the ability of a single session of FES to modulate positive aspects of mood and emotion. An important component of the effectiveness of FES in other applications appears to be that the subject voluntary attempt to move the target muscles at the same time as they are being stimulated. In order to discriminate between the effects of the FES and the effects of voluntary holding a facial expression, a Control Group was used, which performed the same experimental procedures as the FES group but without any stimulation.

Our study involved measures of affect through standardized questionnaires and these reports were likely to be skewed if subjects were aware of the true purpose of the experiment. For that reason, a deception was used in our experimental design. A mock experiment was designed that allowed us to collect the data required to validate our hypothesis, while presenting the subjects with a different rationale for the procedures. Subjects were told that the goal of the experiment was to investigate applications of FES in Bell's palsy (a form of facial paralysis). We therefore told subjects that we were investigating whether distraction related to the sensations caused by FES during facial stimulation (mild to moderate pain) has any impact on cognitive function. Assessments related to affect were justified by citing links between emotional state and performance in cognitive tests. This study was approved by the Research Ethics Board of the Toronto Rehabilitation Institute – University Health Network.

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B. Experimental Procedures

At the beginning of the session, subjects were given specific instructions on how to voluntarily perform the Duchenne smile ("raise your cheeks, then let your lip corners come up" [7]), and were allowed to practice with guidance from the investigator. Subjects then sat in front of a computer screen, and were required to perform 3 different tasks in the alternating order below. Each task lasted 30s and the 2-min block was repeated 25 times in the course of a one-hour session, with short breaks after 10 and 20 blocks. The cognitive component of the tasks was implemented using a visual n-back test, a common method to produce a cognitive load for experimental purposes. In this test, a sequence of symbols is presented, and the subject is required to press a button when a symbol appears that had previously appeared exactly n steps before in the sequence [13,14]. In this study, n was set to 0, 1 or 2 in alternating blocks.

For the Intervention Group, the tasks were as follows: 1) Produce a continuous voluntary smile while receiving FES (no cognitive task); 2) Retain a neutral expression while performing the cognitive task; 3) Produce a continuous voluntary smile while performing the cognitive task and receiving FES; and 4) Retain a neutral expression while performing the cognitive task. Since 2 of the 4 tasks involve FES, the Intervention Group subjects received a total of 25 min of FES during the course of the 50 min experiment. The goal of task 1 (voluntary smile with no cognitive task) was to ensure that the FES group spent at least a portion of the session focusing entirely on assuming the correct expression, without the distraction of the cognitive test. To justify this procedure in the context of our deception (cognitive impact of FES for facial palsy), subjects were told that the goal was to give them breaks from the cognitive test while still replicating a clinically realistic amount of FES delivery. The neutral expression task was repeated to provide regular breaks from the FES and to ensure that the subjects remained comfortable. For the Control Group, the same tasks were used, with the exception that FES was not applied during tasks 1 and 3. Subjects were still instructed to perform the voluntary smile.

FES was delivered using Compex Motion stimulators (Compex SA, Switzerland). Bipolar surface adhesive electrodes measuring 2.5 cm by 1.25 cm (Nikomed USA Inc., USA) were placed bilaterally on the zygomatic major and orbicularis oculi muscles, which were stimulated simultaneously. 150μs biphasic pulses were delivered at 60Hz, with amplitudes in the 3-9mA range. The pulse duration and stimulation frequency were chosen based on preliminary stimulation attempts during the protocol development stage. Amplitudes were determined for each subject at the beginning of the session, with the objective of producing visible contractions in the target muscles while avoiding unnecessary pain or excessive movement (e.g. complete closing of the eye). Electrode placement is illustrated in Figure 1.

Subjects were interviewed at the end of the session in order to ascertain whether or not the deception was effective, and then informed of the true purpose of the experiment.

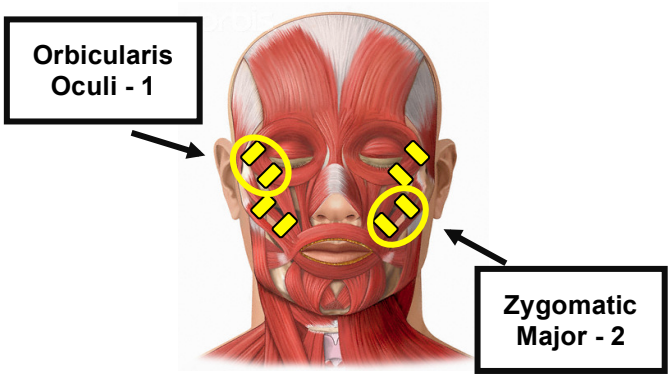
C. Assessments

The Positive and Negative Affect Schedule – Expanded Form (PANAS – X, [15]) was administered before and after the experimental session. This assessment asks the subject to rate 60 words or expressions that describe feelings and emotions on a scale of 1 to 5, depending on how strongly the expression describes their current state ("not at all" to "extremely"). In addition, aggregate scores are defined by combining several of the 60 base items. Our primary outcomes for this study were the PANAS-X scores for "happy" (base item), "joviality" (aggregate score comprising "happy", "joyful", "delighted", "cheerful", "excited", "enthusiastic", and "lively"), and "positive affect" (aggregate score comprising "active", "alert", "attentive", "determined", "enthusiastic", "excited", "inspired", "interested", "proud", "strong"). All other components of the PANAS-X were considered secondary outcomes.

D. Subjects

26 able-bodied subjects were recruited for the study, and divided randomly into Intervention (FES) and Control Groups. These subjects were drawn from the community and self-reported not to be suffering from any mood disorders. One subject in each group had to be excluded, in one case because the deception was not effective (i.e., the subject guessed the true purpose of the experiment), and in the other case because the subject was not able to reliably and voluntary active the orbicularis oculi to form a Duchenne smile. Thus, 12 subjects per group remained for analysis. The total sample contained 12 males and 12 females, with a mean age of 31.2 +/- 9.1 years; the Intervention Group contained 7 males and 5 females with a mean age of 26.7 +/- 5.6, and the Control Group contained 5 males and 7 females with a mean age of 35.3 +/- 9.7.

Figure 1: The locations of the bipolar stimulating electrodes, placed bilaterally on the muscles orbicularis oculi (electrodes labeled 1) and zygomatic major (electrodes labeled 2).



E. Statistical Methods

For each comparison, a Lilliefors test for normality was applied to each of the groups being compared. In within-group comparisons, if both sets of values were found to have a normal distribution, a paired t-test was applied, otherwise a Wilcoxon test was used. In between-group comparisons, if both groups were found to have a normal distribution, an unpaired t-test was applied, otherwise a Kruskal-Wallis test was used. Statistical significance was defined as $p < 0.05$.

III. Results

The PANAS-X scores (base items and aggregate scores) were used to perform three comparisons: initial vs. final scores in the Control Group, initial vs. final scores in the Intervention Group, and change in scores (final minus initial) in the Intervention Group vs. the Control Group. In case of missing values due to accidentally incomplete forms (2 instances out of 2,880 base item scores), initial and final values of the missing items were assumed to be equal.

A. Comparison of Intervention and Control Groups

The experimental procedures themselves had a substantial effect on the moods of the participants, whether or not FES was used. In order to better isolate the effects of the FES, Table 1 shows the results of the change score comparisons

between the Control and Intervention Groups, for base items that were statistically significant, as well as all aggregate scores in the PANAS-X. Significant differences were found for "daring" (increase), "scared" (decrease), "determined" (increase), and "concentrating" (decrease). A decrease in the "fear" aggregate score also very narrowly missed statistical significance ($p = 0.0535$, with a median change of -1 and a range of -3 to 0 in the FES group, compared to a median change of -0.5 and a range of -2 to 2 in the Control Group).

TABLE I: SIGNIFICANCE OF CHANGE SCORE COMPARISONS BETWEEN THE FES AND CONTROL GROUPS, FOR ALL ITEMS IN THE PANAS-X. A DIRECTION OF CHANGE OF ↑ INDICATES THAT THE FES SCORES WERE HIGHER THAN THE CONTROL SCORES, WHEREAS ↓ INDICATES THAT THE FES SCORES WERE LOWER THAN THE CONTROL SCORES. NP INDICATES THAT NON-PARAMETRIC STATISTICS WERE USED, AND P INDICATES THAT PARAMETRIC STATISTICS WERE USED.

	p-value	**Directio**		**p-value**	**Directio**
PANAS-X Base Items					
daring	***0.04*** (P)	↑	***determined***	***0.03*** (NP)	↑
scared	***0.03*** (NP)	↓	***concentrating***	***0.04*** (NP)	↓
PANAS-X Aggregate					
Negative affect	0.45 (P)		Self-Assurance	0.40 (NP)	
Positive affect	0.34 (P)		Attentiveness	0.72 (NP)	
Fear	0.05 (NP)	↓	Shyness	0.92 (NP)	
Hostility	0.24 (NP)		Fatigue	0.84 (P)	
Guilt	0.79 (NP)		Serenity	0.75 (P)	
Sadness	0.92 (NP)		Surprise	0.43 (P)	
Joviality	0.81 (NP)				

B. FES Sensation

When asked to rate the pleasantness or unpleasantness of the FES sensation, the FES group reported a mean score of 3.08 ± 0.76. In other words, the subjects on average reported finding the sensation "neither pleasant nor unpleasant".

IV. DISCUSSION

The effects of the FES on mood may be mediated through the neural pathways relating emotion to facial expression, as per our hypothesis, or through a reaction to the sensory signals produced by the stimulation. The decrease in "concentrating" as a result of the FES does not have an obvious link with the specific facial expressions used in the experiments, but is consistent with the additional distraction caused by the FES sensation. The increases in "daring" and "determined" and the decreases in "scared", on the other hand, could possibly be linked to short-term plasticity in the neural pathways of emotion. Although these were not the emotions that we were aiming to elicit, the orbicularis oculi motion that the subjects performed (slight narrowing of the eyes) is consistent not only with the Duchenne smile but is also closely related to the stereotypical expression of determination. It is also worth noting that "daring", "determined", and "scared" are all related emotions, making it unlikely that our results are due simply to type 1 errors in our sample. The decrease in "fear", which was very close to statistical significance, is also in line with this analysis. Our results are therefore consistent with the hypothesis that FES can modulate brain regions involved in the facial expression of emotion.

Numerous previous studies have demonstrated the close link between emotion and facial expression [10, 12-14]. Our work relied more specifically on the existence of two separate neural pathways, mediating on one hand voluntary facial movements and on the other one hand spontaneous facial expressions resulting from emotions. The novelty of our work lies in our use of FES, which to the best of our knowledge has not previously been used to modulate the neural pathways underlying emotion. Deep-brain stimulation (DBS) and transcranial magnetic stimulation (TMS) are other electrical modalities that are being explored for the treatment of psychiatric disorders. The application of FES to facial muscles is appealing because it is simultaneously non-invasive (unlike DBS) and precisely targeted (unlike TMS). Rather than alter the activity of the neural circuits directly responsible for MDD, which are widespread and not fully understood, our approach aims to directly modulate the mood of the subject. Thus, it would not treat the underlying cause of the disease, but rather compensate for its symptoms

V. CONCLUSIONS

We investigated whether FES might enhance the mood-related effects of voluntarily activating facial muscles with close neural connections to the subcortical nuclei regulating emotions. Although the primary outcomes in our Intervention Group were not significantly different from those in our Control Group, several secondary outcomes with potential relevance to MDD did show significant differences. This provides some initial evidence that FES may indeed be able to modulate mood, even with small doses, but the specific effects are not easily controlled: in our case, effects were found in the PANAS-X items "determined", "daring", "scared" and "concentrating", rather than in our primary outcomes of "happy", "joviality", and "positive affect". Further work is warranted to more precisely target the effects of this approach and to explore clinical applications in MDD.

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