Clinical Neurophysiology 127 (2016) 3000–3006

Contents lists available at ScienceDirect

Clinical Neurophysiology

journal homepage: www.elsevier.com/locate/clinph

# Using facial electromyography to detect preserved emotional processing in disorders of consciousness: A proof-of-principle study

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A R T I C L E I N F O

*Article history:*
Accepted 11 June 2016
Available online 17 June 2016

*Keywords:*
Disorders of consciousness
Vegetative state
Emotion
Facial electromyography

H I G H L I G H T S

- A vegetative state patient can show intact emotional responses as measured by facial muscle activity.
- Responses in a VS patient mirrored the pattern of muscle activity observed in healthy controls.
- This methodology may serve as a feasible bedside tool to probe emotion in VS patients.

A B S T R A C T

*Objective:* To examine whether emotional functioning can be observed in patients who are behaviourally non-responsive using peripheral markers of emotional functioning.
*Method:* We tested two patients, both diagnosed as being in a vegetative state (VS) following hypoxia secondary to cardiac arrest. Thirty-seven healthy participants with no history of neurological illness served as a control group. The activity of two facial muscles (*zygomaticus major*, *corrugator supercilii*) was measured using facial electromyography (EMG) to probe for patterned responses that differentiate between auditorily presented joke and non-joke stimuli in VS patients.
*Results:* One of the two VS patients we tested demonstrated greater *zygomatic* and reduced *corrugator* activity in response to jokes compared with non-jokes. Critically, these responses followed the pattern and temporal profile of muscle activity observed in our healthy control sample.
*Conclusions:* Despite their behaviorally non-responsive profile, some patients diagnosed as VS appear to retain some aspects of emotional experience.
*Significance:* Our findings represent, to our knowledge, the first demonstration that a patient diagnosed as VS can exhibit intact emotional responses to humor as assessed by facial EMG. Therefore, our approach may constitute a feasible bedside tool capable of providing novel insight into the mental and emotional lives of patients who are behaviourally non-responsive.


## 1. Introduction

There is now a substantial body of evidence suggesting that patients with disorders of consciousness (DOC) can exhibit a remarkable degree of residual cognitive functioning despite their inability to respond overtly to command (Owen, 2013). For example, studies using modern neuroimaging methods (e.g., fMRI, EEG) have demonstrated that some DOC patients can wilfully modulate their brain activity in response to external commands (Monti et al., 2010; Owen et al., 2006; Cruse et al., 2011), and often exhibit a strikingly similar pattern of neural activity to that of healthy controls across a wide range of cognitive tasks (Naci et al., 2014; Coleman et al., 2007). These advances have made the prospect of communication with these individuals possible through brain-computer interfaces (BCIs) that map reliable patterns of neural activity on to yes/no answers and other forms of wilful communicative responses in such patients (Monti et al., 2010; Cruse et al., 2011; see Naci et al., 2012, for review). Together, these findings have challenged the notion that such patients lack conscious awareness, suggesting instead that some of them are actively engaged with their environment despite their unresponsive outward appearance.

In the present study, we aim to build on these findings with a different methodological approach that uses recordings of facial

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http://dx.doi.org/10.1016/j.clinph.2016.06.006
1388-2457/

muscle activity to examine emotional functioning in patients diagnosed as being in a vegetative state (VS). This approach is based on an extensive body of research demonstrating that different emotional states are associated with unique patterns of facial muscle activity (Ekman, 1992, 1993; Ekman et al., 1990; Cacioppo et al., 1986). Happiness, for instance, is characterized by the contraction of the *zygomaticus major* and *orbicularis oculi* muscles, which raise the corners of the mouth to create a smile, and raise the cheeks to form wrinkles around the eyes, respectively (Ekman et al., 1990). For the current purposes, these documented emotion-specific changes in facial muscle activity afford a unique and powerful opportunity to examine whether residual emotional processing in VS includes patterned changes in peripheral physiology. The advantages of this approach are threefold. First, the use of facial electromyography (EMG) at bedside to probe muscle activity in these patients provides a more feasible approach to assessing residual emotional processing compared with more invasive and costly neuroimaging methods. Second, the established specificity of facial muscle activity with respect to different emotional states (Cacioppo et al., 1986) may offer insight into the nature of the elicited emotional response in patients. Third, facial EMG provides a sensitive index of muscle activity, and can detect potentially subtle muscle responses in VS patients that cannot be discerned through visual observation (Cacioppo et al., 1986). These properties suggest that facial EMG may provide a promising window into emotional functioning in VS.

Currently, there is limited evidence pertaining to this issue, although a handful of neuroimaging studies have hinted that some forms of emotional processing may be at least partially preserved (Bekinschtein et al., 2004; Yu et al., 2013; Zhu et al., 2009; Di et al., 2007; Staffen et al., 2006). One such study reported activity in emotion-related brain regions, including the amygdala and insula, in a minimally conscious (MCS) patient that was unique to hearing a story read by the patient's mother as compared to a stranger (Bekinschtein et al., 2004). Similarly, a recent fMRI study in a group of VS patients found activity in 30% of them in the affective component of the pain matrix (i.e., network of regions associated with pain perception) in response to hearing another person crying out in pain (Yu et al., 2013). While these studies are certainly suggestive of residual emotional functioning in some VS patients, the interpretation of these neural responses remains somewhat unclear. Moreover, it is yet to be determined whether responses to emotional stimuli in this patient population are also associated with changes in peripheral physiology. Indeed, emotional experience in healthy adults is characterized not only by activation of affective centers in the brain, but also by patterned changes in autonomic and skeletal muscle activity (see Kreibig, 2010; Stephens et al., 2010; Levenson et al., 1990).

To examine whether any residual emotional functioning in VS can be observed with measures of peripheral physiological signals, we used facial EMG to measure activity from the *zygomaticus major* (smiling) and *corrugator supercilii* (frowning) muscles while patients and healthy controls listened to jokes and carefully matched non-joke stimuli. This approach was previously validated in a group of healthy control participants (Fiacconi and Owen, 2015), in which it was demonstrated that joke relative to non-joke stimuli elicited a robust increase in *zygomatic* activity and a reduction in *corrugator* activity. Note that one advantage of this approach is that, in addition to providing insight into emotional functioning, joke stimuli also necessarily draw on high-level language comprehension processes that underlie humor appreciation. We chose to use these stimuli based, in part, on previous neuroimaging work that has shown that some VS patients are in fact capable of complex language processing (Coleman et al., 2007, 2009). Therefore, an observed increase in *zygomatic* muscle activity in response to jokes would imply the preservation of complex speech perception and language comprehension processes as well as intact emotional responses to humour. Here, we examined whether these abilities are preserved in some VS patients, as reflected in similar patterns of facial muscle activity to that of healthy controls.

## 2. Method

### 2.1. Healthy control participants

Thirty-seven healthy undergraduate students from Western University participated in this study in exchange for monetary compensation or course credit. There were 21 females ($M$ = 22.8 years, $SD$ = 5.48 years) with ages ranging from 17 to 41 years. No participants declared any history of neurological or psychiatric illness. One healthy control participant was excluded from all EMG analyses due to the presence of many large artifacts in the EMG signal from both the *zygomatic* and *corrugator* muscles. Seven participants were excluded from our analysis of onset latencies of the *zygomatic* response to jokes, as these participants' responses did not exceed the required slope threshold (see Section 2.5) during the time-window used for estimating onset latency. Data from this sample of healthy control participants was collected as part of a previous study (Fiacconi and Owen, 2015) investigating the relationship between muscle activity and cardiovascular changes associated with humor. All currently reported analyses and results concerning changes in muscle activity in the current study differ from those presented in our prior study.

### 2.2. Patients

We tested two patients (ages 35 and 49), both of whom received a diagnosis of VS based on behavioural assessment with the JFK coma recovery scale – revised (CRS-R) on the day of testing. The relevant demographic and clinical characteristics of each patient as well as their CRS-R scores are provided in Table 1. Patients were selected from a convenience sample to be closely matched in etiology (anoxia secondary to cardiac arrest) and behavioral profile. All experimental procedures were conducted after receiving informed consent from the legal guardian of the patient. All experimental procedures were approved by the Medical Research Ethics Board at Western University.

### 2.3. Materials

Stimuli consisted of 88 different sentences, half of which were jokes, and the other half non-jokes (Bekinschtein et al., 2011; Fiacconi and Owen, 2015). Both of these stimulus categories were made up of sentences that followed a common syntactic structure including an initial setup line, followed by a punchline. We operationally-defined the punchline as the critical phrase or word that allowed the global meaning of the sentence to be understood (e.g., Do you know what happens when frogs park illegally? They get *towed*; see Fiacconi and Owen (2015) for additional examples). Both stimulus types were closely matched in number of words, syllables, and syntactic structure. The duration of each sentence was on average 5.02 s, and ranged from 3.4 to 7.8 s. All sentences were recorded by a native English speaker using a lively prosody, rhythm, and intonation. For healthy control participants, the sound intensity level was set such that all participants heard the stimuli at a comfortable and clearly perceptible intensity. For patients, the sound level was adjusted to be slightly louder than that used in casual experimenter-patient interactions.