



## Review

# A systematic recurrent theme analysis of the reported limitations of facial electromyography



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## ABSTRACT

**Background:** Advances in digital technology hold promise in expanding the clinical and consumer applications of facial electromyography (EMG) through the development of wireless pervasive systems capable of operating in a nonclinical environment. This systematic review aims to appraise the most commonly reported limitations of the technology in clinical research and practice.

**Methods:** A systematic search for clinical facial EMG literature was performed using MEDLINE, EMBASE, PsychINFO and CINAHL. No language limits were applied. Search results were screened using defined criteria by two authors with disagreements resolved by a third. Practical limitations in the technology, as reported by the authors, were recorded and characterised using recurrent theme analysis.

**Results:** A total of 4,983 records were identified. Of those, 1,061 articles met eligibility criteria and were subsequently reviewed. In the medical domain, the most common area of application was in psychosocial studies (28% of medical studies); in the surgical domain monitoring of facial nerve integrity was the most common application of facial electromyography (27% of surgical studies). Collectively, the three most commonly reported limitations were motion artefact (13.7%), inter-subject variability in response and anatomy (13.1%), and muscle crosstalk (12.0%).

**Conclusions:** This is the first study to evaluate the limitations of facial EMG using a systematic analysis of author reports. Highlighting technology limitations in this non-biased manner raises awareness to users key issues and reliably informs the development of future systems.

## 1. Introduction

The human face demonstrates unparalleled intricacy as a functional unit with unique kinematics and biophysical properties. The face is involved in a multitude of essential functions including air humidification, breathing, sight, mastication and production of intelligible speech [1]. As a highly social species, the functionality of the human face has further evolved as a vector for social interaction through dynamic exchange of non-verbal information [2].

As described by Rinn et al., two cortical pathways exist in the control of facial movement [3]. The cortical pyramidal motor system controls voluntary facial expression, with disorders resulting from both global neurodegenerative processes, such as Parkinson's disease [4], and focal neurological deficits such as facial neuropathies [5]. Involuntary facial movements generated via the sub-cortical extrapyramidal tracts are thought to reflect innate emotional processing,

with abnormal involuntary facial movements involved in a range of psychiatric conditions including depression and schizophrenia [6]. Therefore facial movement not only reflects the integrity of neural pathways, but also provides quantifiable physiological data reflective of an individual's emotional state and social communicative behavior.

Measuring facial movement has clinical importance in planning and evaluating neurological [7] and craniofacial [8] surgical procedures. Classical methods used to quantify facial expression have relied on subjective inference, based on early psychosocial experiments conducted by Campbell (1978) where raters were asked to interpret the 'happiness' of presented faces [9]. Scoring systems such as the Facial Action Coding System (FACS) and the House-Brackmann score are widely used to systematically categorise facial movement and grade the severity of expressive dysfunction. Specific variants of such scores such as the Emotion FACS (EMFACS) have been developed to assess emotional reactions in psychological and psychiatric illness [10]. Despite

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widespread utility, such methods have received criticism regarding insensitivity to change [11] and poor validity [12], highlighted by Wu et al. (2005) following comparative analysis between subjective and objective computerised systems in the quantification of facial synkinesis [13].

The development of electromyography (EMG) as a clinical tool stemmed from zoological observations made by Redi in 1666 [14], with subsequent findings published by Galvani providing evidence for the electro-mechanical coupling of muscle contraction [15]. In recent years, further refinement has led to the development of small, light-weight surface electrodes and amplification systems enabling real-time measurements of action potentials generated by the contraction of superficial muscles [16].

Despite the transformative innovation of electromyographic technologies, facial EMG has a series of challenging technological and practical limitations [17]. Advances in digital methods such as near field communication, Bluetooth and improvements in hardware such as miniaturisation and increased battery life have led to evolution of healthcare technology. Harnessing such advancements has great promise in the expansion of clinical applicability of fEMG through development of wireless pervasive wearable platforms to abrogate the need for testing in controlled conditions.

To target specific areas for development of fEMG platforms, an objective analysis of the limitations is required. Herein, this work aims to review the clinical applications of facial EMG and systematically evaluate the direct limitations reported by authors using recurrent theme analysis.

## 2. Methods

A systematic review of the literature was conducted to identify reported limitations in the use of fEMG in medical and surgical domains through recurrent theme analysis. This review was conducted in accordance with the Cochrane Handbook and is reported in line with the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines [18].

### 2.1. Eligibility criteria for study selection

All studies that reported use of facial electromyography in adult human subjects were eligible for inclusion. Results from randomized controlled trials, retrospective and prospective observational studies, case-reports, case series and clinical studies were included. Studies reporting the use of fEMG in non-human subjects were excluded.

### 2.2. Search strategy

Articles reporting the use of fEMG were identified through electronic searches of PubMed, CINAHL, PsychInfo and Embase published up until the 1st December 2016. Combinations of keywords and MeSH terms related to fEMG were developed in conjunction with a search strategist and used to identify suitable articles (Appendix 1). No language restrictions were applied. Reference lists of eligible articles were further reviewed to identify any relevant publications. The bibliographic EndNote database, version X7 (Thomas Reuters, NY, USA) was used as a reference management tool and to filter duplicate articles.

### 2.3. Eligibility assessment

Three reviewers conducted title and abstract screening independently and disagreements were resolved by consensus decision following consultation by a fourth reviewer. Eligibility assessment was conducted using an inclusion criteria checklist with journal titles, author names and supporting institutions not masked.

**Table 1**

Exemplar thematic framework based on data abstraction and subsequent analysis. A meta-thematic approach was adopted to improve data resolution and analysis given the heterogeneity of included studies.

Meta-theme	Primary themes	Definition
Physiology	Expiratory strength training Respiratory function Swallow physiology Ocular movement Oro-motor training Masticatory function Speech physiology Exercise physiology Sleep physiology Endocrine physiology	Quantification and comparison of muscle recruitment during physiological tasks in healthy individuals
Psychophysiology	Explicit emotional facial display Detection of sub-clinical emotional facial display & unconscious bias Facial mimicry Social communication Cognitive stress	Quantification of facial expression changes and patterns of facial muscle recruitment following non-nociceptive stimuli in healthy individuals.
Neurophysiology	Startle reaction Blink reflex Auditory autonomic reflex Masseter stretch reflex Inhibitory jaw reflex Cognitive processing speed Anticipatory reflex to mechanical stimuli Transcranial magnetic stimulation studies	Quantification of muscle recruitment following neurological reflex response to non-emotional stimuli
Pain physiology	Facial pain expression Maximal voluntary contraction and experimental pain	Quantification of muscle recruitment following nociceptive stimuli

### 2.4. Data abstraction

A data abstraction form was piloted using a proportion of included studies by two reviewers (LG and DP). The following data were abstracted from each included trial: medical or surgical domain, primary theme, perioperative use (if surgically themed) and statements made in the discussion that were considered to be study limitations. Limitations were recorded using recurrent theme analysis with theme headings decided by consensus discussion between all authors [19].

Due to heterogeneity in reporting, indications for fEMG were thematically grouped, overseen by the senior clinical author. For example, Hemifacial Microsomia was thematically grouped into the congenital malformation cohort to improve data resolution. Notably, indications such as cleft lip and palate were analysed as separate entity due to the relatively high reporting incidence within the literature. Further to that effect, studies reporting facial expression changes following affective stimuli in healthy volunteers were collectively grouped within the 'Emotional Psychophysiology' thematic cohort. Distinctions between apparently similar thematic cohorts are described in Table 1.

### 2.5. Recurrent theme & free text analysis

Recurrent thematic analysis utilises interpretative and reductive methods to thematically categorise textual descriptions into individual themes. Thematic analysis is a qualitative analytical technique previously reported in the appraisal of strengths and weaknesses in Single Technology Assessment (STA) applications made to the National Institute of Clinical Excellence (NICE) [20].

In the context of this study, thematic analysis was used in the first

instance to reduce primary study themes into grouped meta-themes, reflective of all individual studies. Definitions for meta-themes were developed following pilot data abstraction, as outlined in [Table 1](#). Free text analysis of the discussion (or equivalent) paper section to identify reported limitations. For each limitation, direct quotations were recorded and categorised under recurrent themes, see [Supplementary Table 1](#). Thorough documentation of recorded limitations allowed cross comparison by a forth independent reviewer (RMK) to monitor reliability and consistency across reviewers.

## 2.6. Statistical analysis

Inter-observer differences for reported limitations were measured using Cronbach's alpha statistic. Statistical analyses were performed using IBM SPSS v.23.0 (SPSS, Chicago, USA).

## 3. Results

The literature search identified 4983 titles for consideration; 3501 from Medline, 777 from Embase and PsychINFO derived from the Ovid database and 705 from CINAHL. 1437 full text articles were assessed for eligibility. 1066 studies met inclusion criteria and are included in this review ([Fig. 1](#)).

Of the 1066 papers included for systematic review, 861 (80.8%) were classified as medical and 205 (19.2%) were classified as surgical (defined by fEMG use at any time during the perioperative period). Overall, 74% of studies reported use of surface EMG, 24% reported needle EMG and 2% reported use of both.

Collectively, 474 thematic limitations were reported across all studies, agreement between reviewers for limitation identification and categorization was excellent (alpha statistic = 0.94). The top three reported limitations across all domains were motion artefact (13.7%) defined as sensor movement at the surface-skin interface leading to recorded electrical activity not of cerebral origin [21], inter-subject variability in response and anatomy (13.1%), and muscle crosstalk (12.0%) defined as recorded electrical activity over a non-active muscle generated by an active adjacent muscle [22], see [Fig. 2](#). Overall, nineteen thematic limitations represented 97% of all limitations reported.

### 3.1. Surface vs needle EMG

Patient discomfort, haematoma, and arterial bleeding were cited limitations of needle EMG (nEMG), reported in 8.7%, 2.8%, and 1.4% of studies respectively. Further comparative analysis revealed the relative reported incidence of inter-operator variability in electrode placement to be 49.9% greater in studies using surface EMG (sEMG). Further, studies using sEMG demonstrated 57.8% higher relative reported incidence of muscle crosstalk and 52.2% higher incidence of electrode malfunction, predominantly due to imbalanced impedance.

### 3.2. Medical uses & reported limitations

In the 861 medically classified papers, 68 grouped themes were identified, see [supplementary table 2](#). The most common use of fEMG was in the psychophysiological domain (21.72%) The top 10 identified medical themes are presented in [Fig. 3A](#); which accounted for 76.77% of the 861 medically classified papers reviewed.

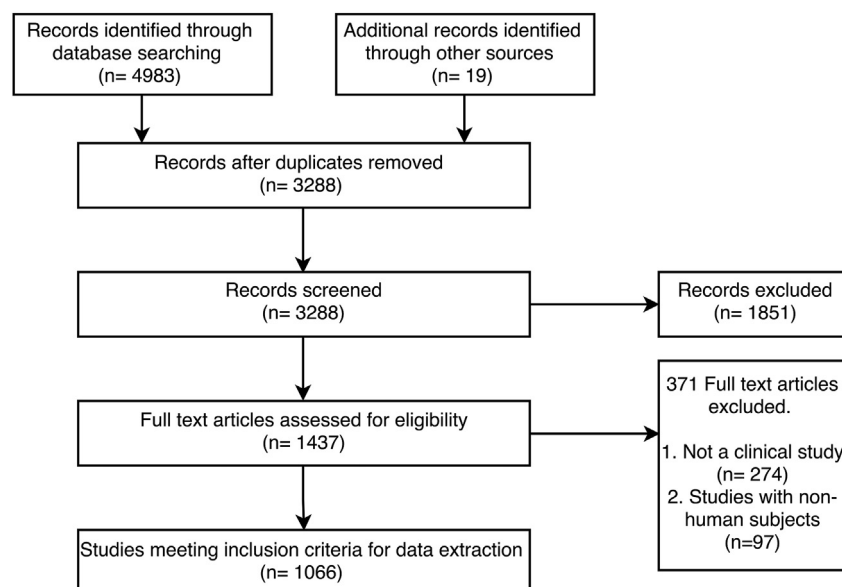
A total of 321 medically themed papers (37.2%) reported limitations to the use of fEMG. The top three reported limitations across medically themed papers were motion artefact (15.9%), inter-subject variability in response and anatomy (14.3%), and muscle crosstalk (12.4%), see [Table 2](#). Frequencies are expressed as percentage of all medically themed papers which reported limitations.

### 3.3. Surgical uses & reported limitations

Surgical papers (n = 205) were grouped into 16 distinct themes, see [Supplementary Table 3](#), with 61 papers (29.8%) reporting limitations. The top 3 reported limitations were low sensitivity (15.6%), ambient noise (14.6%) and intraoperative logistical challenges (10.4%), see [Table 3](#). Frequencies are expressed as percentage of all surgically themed papers which reported limitations. An inherent limitation to the surgical use of EMG was that of a learning curve in the identification of specific nerves described in 5.21% of included papers. The top 10 identified surgical themes are presented in [Fig. 3B](#).

## 4. Discussion

A systematic review of the literature was conducted to evaluate and quantify the reported limitations of fEMG across both medical and surgical clinical settings. The limitations of electromyographic



**Fig. 1.** PRISMA flow diagram detailing the literature search and study selection methodology.

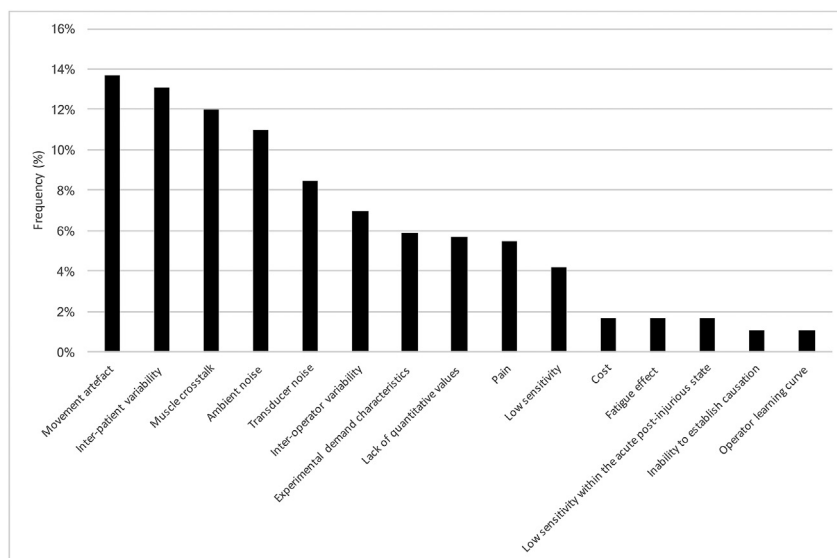


Fig. 2. Global limitations with a reporting frequency greater than 1%. The acute post-injurious state is defined as within two weeks of neural injury.

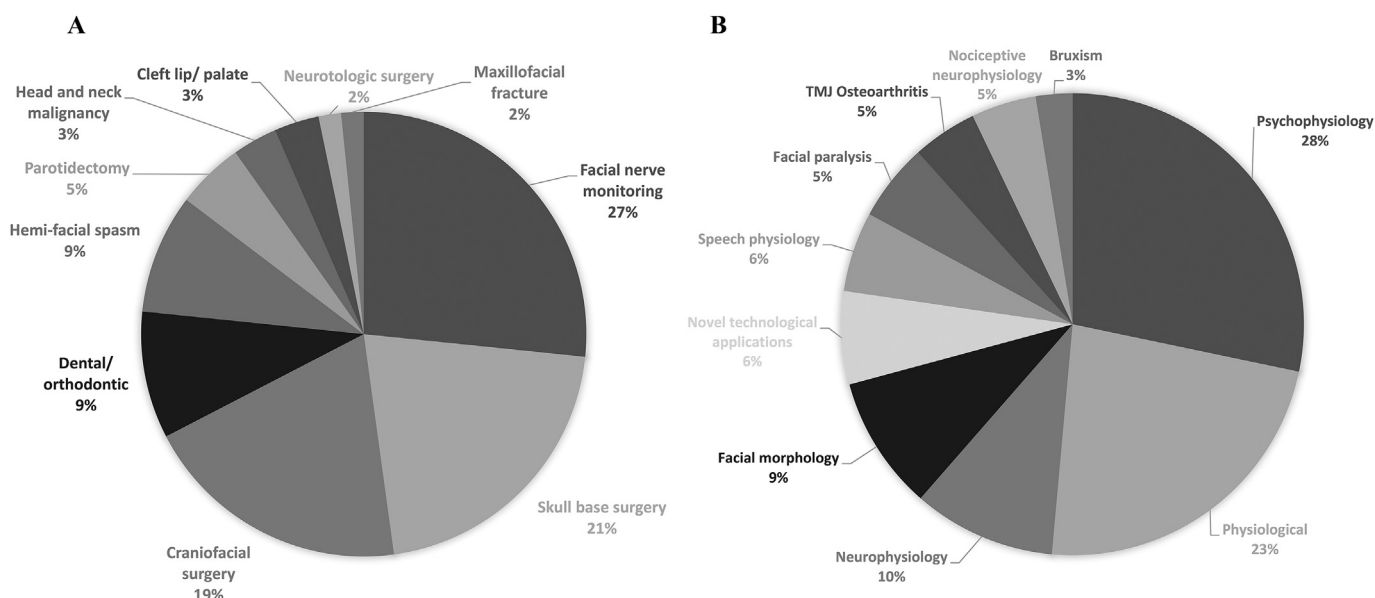


Fig. 3. **A** Graphical representation of the top ten medical themes reporting fEMG use. Collectively these themes accounted for 76.77% of the 861 medically classified papers reviewed. **B** Graphical representation of the top 10 surgical themes reporting fEMG use with relative percentage proportions indicated. Collectively these themes accounted for 70.49% of the 261 surgically classified papers reviewed. Relative percentage proportions are further indicated.

techniques have previously been described [17] however this is the first objective report to collate and quantify the limitations using recurrent theme analysis.

The majority of studies included report the use of surface EMG and therefore the complications of needle EMG such as pain, bleeding and infection are largely avoided. However, the use of non-invasive techniques appears to be at the detriment of procedural accuracy with a

comparative difference in reported incidence of muscle crosstalk and inter-operator variability between studies reporting use of surface and needle EMG. Facial electromyography has broad clinical applicability across both medical and surgical domains; the higher reported incidence of fEMG use within the medical literature is likely explained by the general increased volume of literature and is unlikely to be of any significance in the interpretation of the results of this study.

Table 2

The frequency of reported limitations within medically themed papers. The corresponding thematic definitions of limitations are outlined.

Reported limitation	Frequency	Definition
Movement artefact	15.87%	Sensor movement at the surface-skin interface leading to recorded electrical activity not of cerebral origin
Inter-patient variability	14.29%	Inter-subject differences in morphology and physiology inhibiting comparative analysis
Muscle crosstalk	12.43%	Recorded electrical activity over a non-active muscle generated by an active adjacent muscle
Transducer noise	10.58%	Artifact generated at the electrode-skin interface.
Ambient noise	10.05%	Artifact generated by local electromagnetic devices

**Table 3**

The frequency of reported limitations within surgically themed papers. The corresponding thematic definitions of limitations are outlined.

Reported limitation	Frequency	Definition
Low sensitivity	15.63%	Inability to correctly identify neuromuscular pathology
Ambient noise	14.58%	Artifact generated by local electromagnetic devices
Surgical challenges	10.42%	Intra-operative logistical challenges
Muscle crosstalk	10.42%	Recorded electrical activity over a non-active muscle generated by an active adjacent muscle
Inter-patient variability	8.33%	Inter-subject differences in morphology and physiology inhibiting comparative analysis

The key limitations to the use of facial electromyography across all domains were motion artefact, muscle cross talk and inter-subject variation in stimulus response and anatomy. The limitations can be broadly classified into equipment, operator and patient limitations. Commonly reported equipment limitations included ambient and transducer noise. Electromyographic noise is a form of artifact that interferes with signal acquisition from the neuromuscular junction which may overlay or cancel the physiological signal recorded [15]. Given the multitude of sources for both ambient and transducer noise, some interference is inevitable, however the signal-to-noise ratio should be maximised in order to improve accuracy [23]. A new technique developed utilising bipolar recordings with differential pre-amplification has improved the signal to noise ratio of conventional EMG systems, however the process of differential amplification is dependent upon the fidelity of the electrode-skin interface [24]. Specific equipment limitations relating to the intraoperative use of fEMG were noted. Such limitations include electrical interference during coagulation [25], contact between surgical instruments and the electrode [26] and the impossibility of monitoring facial nerve integrity upon neuromuscular blockade [27]. Recognition of these specific intraoperative limitations by theatre staff and team based simulation using such equipment may improve true EMG resolution and concurrent intraoperative accuracy.

For operator limitations, two of the main issues were variability in electrode placement between participants and muscle cross talk. The effect of both limitations can be mitigated partially with training and experience of the variations in facial muscular anatomy. Epidermal, dermal and hypodermal tissues act as act as a spatial filter with low pass frequency properties meaning that the amplitude of EMG signals decay exponentially with distance from the recording electrode [28]. Thus appropriate selection of electrode size and inter-electrode distance can mitigate the effect of muscle crosstalk. The production of electrodes specifically sized to individual facial muscles and facial areas, where more than one muscle is being monitored, may improve the accuracy of electrode placement and decrease the effect of crosstalk.

Patient limitations included movement artefact and inter-subject differences in morphology and physiology inhibiting comparative analysis. Patient education can be used to minimise movement artefact; however, the use of direct instruction should be tempered against the fact that conscious recognition of fEMG recording may reduce spontaneous emotional expression and confound the results of psychosocial studies, a limitation reported in 9.28% of medically themed reports. Moreover, the development of differential amplification has led to the advent of high pass filtering where low bandwidth frequencies, that are typically in conjunction with movement artifact, are removed to improve the signal-to-noise resolution [29].

The results of this study must be considered in the context of the studies limitations.

A subjective approach was taken through both thematic grouping and identification of reported limitations which may result in a loss of semantics and a predisposition to selection bias. The risk of human error in the identification and thematic allocation of reported

limitations cannot be overlooked due to the largely interpretative nature of the current study, however this is mitigated somewhat through cross-referencing with multiple reviewers. Further, a robust methodology was used to perform the literature search however certain articles may have been overlooked due to the sheer number of studies that met inclusion criteria.

The study is strengthened by its systematic approach, pre-defined data abstraction methods and broad study eligibility criteria producing a large amount of data for comprehensive analysis. No other known studies have collated the technical limitations of facial electromyography with both applications and limitations sporadically reported in a narrative sense. Huang et al. (2004) explored the application of electromyography in evaluation of masticatory function, speech analysis and observation of emotional expression and expressed objective opinion regarding the current limitations limiting system performance in the clinical setting [17]. The current study comprehensively appraises EMG application and provides quantitative metrics, rather than singular subjective opinion, regarding the limitations of fEMG.

Facial EMG has broad clinical applicability and is a useful tool in the interrogation of cortical pathways controlling facial movement and a good adjunct to clinical examination and grading scales. This study objectively highlights and quantifies the key limitations of fEMG as reported by authors in the related literature.

Systematic refinement is essential for the continued use of fEMG in both medical and surgical domains. This study has systematically reviewed the reported limitations of fEMG which must be addressed to improve system accuracy and increase the clinical applicability of measurement systems. The quantification of such limitations in a non-biased manner raises awareness of fundamental limitations to users in a clinical setting and reliably informs the continued development of future systems to enable the full potential of electromyography to be realised.

### Ethical approval

Ethical approval was not required for this study.

### Sources of funding

No funding was received for the conduct of this study.

### Author contribution

LG, RMK & CN were involved in study design. LG, SK and DP collected the data. LG and RMK analysed the data. LG, RMK and CN wrote up the results and concurrent findings.

### Conflicts of interest

There are no conflicts of interest to declare.

### Trial registry number

N/A.

### Guarantor

I, Luke Geoghegan, accept full responsibility for the work.

### Appendix A. Supplementary data

Supplementary data related to this article can be found at <https://doi.org/10.1016/j.amsu.2018.07.006>.



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