Annals of Medicine and Surgery 33 (2018) 1–6

Contents lists available at ScienceDirect

Annals of Medicine and Surgery

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

Review

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

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ARTICLE INFO

Keywords:
Electromyography
Diagnostic techniques
Face
Innovation

ABSTRACT

Background: Advances in digital technology hold promise in expanding the clinical and consumer applications of facial electromyography (EMG) through thedevelopment 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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https://doi.org/10.1016/j.amsu.2018.07.006
Received 13 February 2018; Accepted 5 July 2018

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 forth 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 Microsmia 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