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Review

Quantitative analysis of surface electromyography: Biomarkers for convulsive seizures

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HIGHLIGHTS

- Quantitative surface-EMG features differentiate between epileptic and non-epileptic muscle activation.
- Specific quantitative-EMG features constitute neurophysiological biomarkers, implemented in automated algorithms that can run real-time.
- These algorithms can accurately detect GTCS and can distinguish them from convulsive PNES.

ABSTRACT

Muscle activity during seizures is in electroencephalographical (EEG) praxis often considered an irritating artefact. This article discusses ways by surface electromyography (EMG) to turn it into a valuable tool of epileptology.

Muscles are in direct synaptic contact with motor neurons. Therefore, EMG signals provide direct information about the electric activity in the motor cortex. Qualitative analysis of EMG has traditionally been a part of the long-term video-EEG recordings.

Recent development in quantitative analysis of EMG signals yielded valuable information on the pathomechanisms of convulsive seizures, demonstrating that it was different from maximal voluntary contraction, and different from convulsive psychogenic non-epileptic seizures. Furthermore, the tonic phase of the generalised tonic–clonic seizures (GTCS) proved to have different quantitative features than tonic seizures. The high temporal resolution of EMG allowed detailed characterisation of temporal dynamics of the GTCS, suggesting that the same inhibitory mechanisms that try to prevent the build-up of the seizure activity, contribute to ending the seizure.

These findings have clinical implications: the quantitative EMG features provided the pathophysiologic substrate for developing neurophysiologic biomarkers that accurately identify GTCS. This proved to be efficient both for seizure detection and for objective, automated distinction between convulsive and non-convulsive epileptic seizures.

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1. Introduction

In spite of the advances in functional neuroimaging methods, we still know little about the pathomechanisms of the convulsive epileptic seizures in humans, and most of the evidence comes from animal models (Fusco et al., 2008; Zifkin and Dravet, 2008). Limited investigation time makes it unlikely that such an event is recorded in the scanner, and artefacts caused by excessive motor activity make it technically extremely challenging (Moeller et al., 2009). EEG and MEG signals are typically distorted by signals from the head muscle, and also by electrode artefacts. Thus, there is a need for a non-invasive method for characterising the activity in the motor system during convulsive epileptic seizures.

Neuromuscular junctions connect motor neurons and muscles. Long-term recording of surface EMG signals is technically easy, yet it provides, at high temporal resolution, direct evidence on the activity of the motor nervous system (Mothersill et al., 2000; Tassinari and Rubboli, 2008). This is different from functional MRI, which has poorer temporal resolution and provides indirect evidence, based on the neurovascular coupling (Lauritzen, 2001). Quantitative analysis of EMG signals in patients with extrapyramidal movement disorders provided valuable information that helped understanding the pathomechanisms of these conditions (Berardelli et al., 1998, 2001; Hallett, 1998, 2000).

Surface EMG has traditionally been part of polygraphic long-term recordings in epilepsy monitoring units (EMU) (Gastaut and Broughton, 1972; Mothersill et al., 2000; Tassinari and Rubboli, 2008). Qualitative analysis (inspection by trained experts) of EMG signals is helpful in characterising the motor phenomena during seizures, excluding artefacts, and in identifying and describing motor seizures (Fusco et al., 2008; Inoue et al., 2008; Mothersill et al., 2000; Tassinari and Rubboli, 2008). EMG channels can help to verify asymmetry of events and thus help with lateralisation; this is particularly important in seizures where lateralisation may be difficult to detect by observation only, such as spasms or tonic seizures. The temporal relation of EMG signal and EEG spike in an electroclinical event gives information on the source of the event (Bisulli et al., 2002). EMG signals during myoclonic seizures constitute trigger-points in time for averaging EEG traces. This method (EMG triggered back-averaging) by improving the signal-to-noise ratio allowed identification of small-amplitude cortical signals which otherwise were hidden by the ongoing EEG background activity (Shibasaki and Hallett, 2005). EMG is also an important tool for several methods of artefact detection and rejection such as normal eye movements, myogenic potentials, head movement causing slow posterior delta activity or sharp occipital theta activity in a seated patient (EMG from cervical muscles).

In spite of advances in signal analysis methods, quantitative analysis of surface EMG signals during convulsive seizures has so far received surprisingly little attention. We addressed this in a series of studies. First, in exploratory studies we investigated whether muscle activation during convulsive epileptic seizures is different from physiological muscle activation and muscle activation during non-epileptic convulsive events. Then we focused on the distinction between different types of convulsive seizures. We attempted to characterise the temporal dynamics of GTCS using quantitative EMG features. Based on the specific features yielded by the explorative studies, we constructed a neurophysiological biomarker for accurate identification of convulsive epileptic seizures. In clinical validation studies, we assessed whether this can be efficient for seizure detection and for automated distinction between epileptic and non-epileptic convulsive seizures. Our findings have been confirmed by other groups, whose studies are included in this review.

2. Surface EMG recordings

It is technically easy recording surface EMG using either conventional electrodes (9 mm, silver/silver chloride surface electrodes) and amplifiers in the EMU or recording devices specifically designed for this purpose, in an out-patient setting. The active electrode is placed on the belly of the muscle, while the reference electrode is placed on the nearby bone ("unipolar recording"). EMG can be recorded from many muscles simultaneously (up to 14 in our setting). Recording from many muscles makes it possible to follow the chronological order and the somatotopic pattern of muscle activation, even by inspection of the signals (Bisulli et al., 2002; Meletti et al., 2003). However, recording from many muscles is a disadvantage when designing devices for ambulatory, outpatient recordings, as the feasibility is lower and the discomfort to the patient considerable. Deltoid and biceps muscles proved to be involved early during generalised convulsive seizures. In most of our studies we analysed signals from the deltoid muscles, on both sides.

We recorded surface EMG from patients with generalised convulsive seizures (tonic seizures and GTCS), healthy controls acting generalised convulsive seizures and in patients with convulsive psychogenic non-epileptic seizures (PNES). These recordings were part of polygraphy during long-term video-EEG monitoring (LTM).

3. Neurophysiology: epileptic versus physiologic muscle activation

Fig. 1A, D and G shows typical surface EMG recordings from convulsive epileptic seizures (tonic seizures and GTCS) and seizures acted by healthy volunteers, instructed to imitate convulsive seizures. Surface EMG was recorded during 63 seizures from 20 patients with epilepsy (10 with tonic and 10 with tonic–clonic seizures). Twenty age- and gender matched healthy volunteer's imitated 100 convulsive seizures, and performed maximal voluntary contraction (MVC).