Surface electromyography and mechanomyography recording: a new differential composite probe

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Abstract—*The objective of the study was to develop a new surface probe for differential mechanomyographic (MMG) and electromyographic (EMG) recording. Differential amplification is commonly used in electromyography to improve the signal-to-noise ratio. A new composite probe was developed with two electrodes (EMG) and two identical piezo-electric membranes (MMG) to be positioned on muscle. The probe had two built-in fixed-gain differential amplifiers: one to amplify the electric signal and the other to amplify the vibration signal. A similar non-differential MMG probe was used for comparisons. Burst muscular activity was recorded using the non-differential and differential probes and was used to test the performance of the two probes in suppressing artifacts of non-muscular origin. Power spectrum analysis of signals from the two probes showed that differential amplification significantly improved the signal-to-noise ratio in MMG recordings and significantly suppressed artifacts (power difference >90%). The composite probe allowed simultaneous differential recording of MMG and EMG signals from the same muscular site. It recorded muscular activity more efficiently than the non-differential probe and could therefore be useful in studying fatigue and neuromuscular diseases.*

Keywords—*Surface EMG, Mechanomyogram, Acoustic myogram, Differential probe*

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1 Introduction

NON-INVASIVE SURFACE recording of muscle activity is widely used in sports medicine and rehabilitation, long-term monitoring and multisegmental recording (BARRY *et al.*, 1985; CLANCY and HOGAN, 1995; D'ALESSIO *et al.*, 1993; DE LUCA and MERLETTI, 1988; NAKATA *et al.*, 1998; HEMMERLING *et al.*, 2000; MAMAGHANI *et al.*, 2001). It is also useful for neuromuscular diagnosis (AKATAKI *et al.*, 1996; BARRY *et al.*, 1986; 1990; ESPOSITO *et al.*, 1996; KNAFLITZ *et al.*, 1994; TORTOPIDIS *et al.*, 1998).

Various approaches have been described to optimise surface recording. These include multisite electromyographic (EMG) recording, by means of an array of surface electrodes (GUGLIELMINOTTI and MERLETTI, 1992; MERLETTI, 1994) and subsequent analysis of the parallel recorded signals to extract motor unit activity, non-linear analysis of the surface electrical signals (FILLIGOI and FELICI, 1999) and correlation between EMG and mechanomyographic (MMG) signals gathered from the muscle surface (ACCORNERO *et al.*, 1989; BOLTON *et al.*, 1989; DALTON *et al.*, 1992; LEE *et al.*, 1992; ZWARTZ MACHIEL and KEIDEL, 1991; MATON *et al.*, 1990; ORIZIO *et al.*, 1992; ORIZIO, 1993; RODRIQUEZ *et al.*, 1993; 1996; STOKES *et al.*, 1991).

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Condenser microphones have been widely used in mechanomyography, together with accelerometers and piezo-electric contact sensors (COURTEVILLE *et al.*, 1998; WATAKABE *et al.*, 1998; 2001). The technical reliability of MMG recording remains questionable, chiefly owing to disturbance of the recorded signals from environmental noise, skin artifacts and pressure on the probe (PARKERS *et al.*, 1986; SMITH and STOKES, 1993).

Simultaneous MMG and EMG surface recording of muscle activity has advantages in many applications, because it is non invasive and could be useful in studying fatigue and in evaluating neuromuscular diseases (AKATAKI *et al.*, 1996; BARRY *et al.*, 1986; 1990; ESPOSITO *et al.*, 1996; KNAFLITZ *et al.* 1994; TORTOPIDIS *et al.*, 1998). Furthermore, the relationship between EMG and MMG signals recorded from the same muscle site may provide some correlated information on the two signals. To achieve this possibility and to simplify the recording set-up, we built up a composite active probe for simultaneous surface EMG and MMG recording that uses differential amplification of the two signals. We tested the performance of this probe in improving the signal-to-noise ratio, in comparison with a non-differential piezo-electric MMG recording system.

2 Methods

The probe was assembled on a single-side printed circuit board (PCB) (50 × 30 mm). The copper side was etched (Fig. 1*a*)

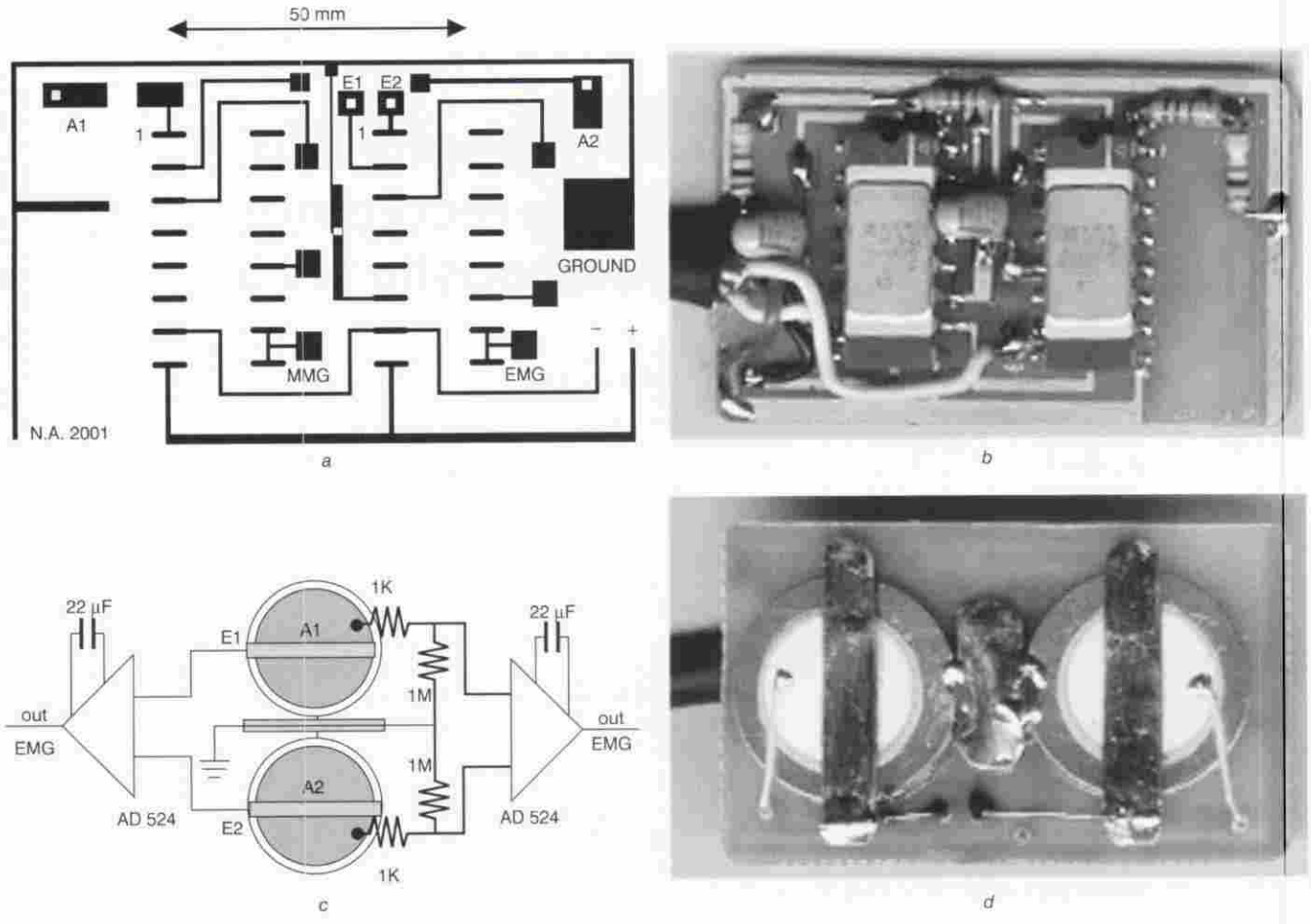

Fig. 1 *(a) Printed circuit layout (surface mount). (b) Probe viewed from above before epoxy encapsulation (components side). (c) Electronic circuit layout of probe. (d) Probe viewed from below (piezo-electric membranes and electrodes)*

to allow surface mounting of two instrumentation amplifiers*, two capacitors and four resistors (Fig. 1*b*), as described in the electronic layout (Fig. 1*c*).

On the back of the PCB, two piezo-electric ceramic discs†, 20 mm in diameter, were epoxy-glued side by side (25 mm centre to centre). The piezoceramic plates had a dynamic response of approximately 250 mV N^{-1}, a non-flat frequency response from 1 Hz to 100 kHz and a resonant peak at 6.3 kHz. The plates were then connected with fine wires passing through the PCB, and an insulating varnish was applied over the piezo-electric membranes. Two stained PCB strips, 3 mm wide, 20 mm long and 0.2 mm thick (EMG electrodes, 25 mm inter-electrode distance), were then glued on top and at the centre of the piezo-electric membranes; a similar strip (ground) was placed between them (Fig. 1*d*). This setting left the spectral response of the piezo-electric membrane in the MMG frequency range practically unchanged (ACCORNERO *et al.*, 1989). The EMG electrodes were then wire-connected to the second amplifier on the same PCB. This montage was designed to minimise the distance between transducers and amplifiers, thus improving the signal-to-noise ratio. The differential piezoceramic electronic montage suppressed vibrations coming from the PCB to the ceramic discs and selectively amplified vibrations originating below each disc.

The AD 524 is a precise differential instrumentation amplifier that provides fixed gain steps (1–10–100–1000) by connecting two pins of the integrated circuits. Connecting the two pins with an appropriate capacitor (22 μF) yielded a frequency cutoff below 1 Hz that minimised artifacts below this frequency and also eliminated the offset due to electrode polarisation. The gain was set to 1000× for the EMG channel and to 100× for the MMG channel. After the circuit had been checked, the component side was encapsulated with epoxy cement.

To reduce AC interference and guarantee the subject's safety, instead of an insulated power supply from the AC main, we used a dual symmetric (±9 V) power supply provided by a battery pack.

Because the recording equipment normally has to be optically isolated from AC mains or be battery operated we used an A/D converter‡, connected to the parallel port of a portable battery-operated computer, that can sample two channels up to 16 kHz, although we set the bandpass filters of the converter from 2 Hz to 2 kHz.

The probe, weighing 35 g, was placed on the biceps brachii in the best position to obtain reproducible and clear simultaneous EMG and MMG signals. The relatively small dimension of the probe allowed various regions of the muscle to be tested. The position chosen for recording was approximately 1.5 cm from the centre of the muscle belly. The electrodes were aligned with muscles fibres and fixed with a 10 cm wide elastic bandage that pressed the probe on the muscle at a force of about 0.3 N on 15 cm^2 (area of the probe). A similar probe for EMG (differential) and MMG (non-differential) recordings was used for comparison.

EMG and MMG signals were recorded during transient or sustained voluntary isometric contraction in normal subjects. Artifact suppression was also evaluated.

*AD 524 Analog Devices

†Stettner and Co TS-50-06-9 or similar

‡PICO technology

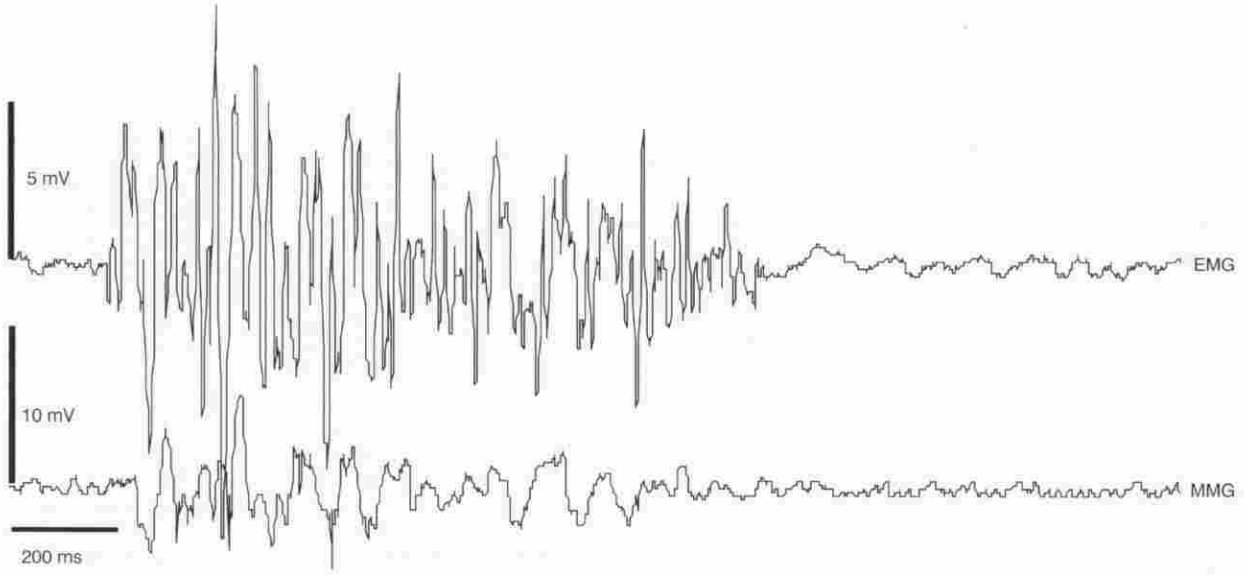

Fig. 2 *Electrical and vibration recording during isometric voluntary contraction of biceps muscle*

3 Results

The EMG and MMG signals recorded during a transient (1 s duration) voluntary maximum isometric contraction of the biceps brachii muscles differed in their spectral component, and, as expected, the MMG signal had a delayed onset: it started a few milliseconds after the EMG signal (Fig. 2).

When we recorded signals with different MMG probes, one with a differential amplifier and one with a non-differential amplifier, both positioned close together on the centre of the muscle during a transient isometric contraction, the signals from the two devices had similar amplitudes and morphology. They also had similar power spectra (power difference <5%). Conversely, when the two signals were generated by gentle rubbing of the skin by a finger at the same distance from the two probes, 5 cm along the muscle, they had distinctly different power spectra. The differential probe yielded a much weaker signal, (power difference >90%), because it cancelled the coincident signal components under the two piezo-electric membranes (Fig. 3). Because the two probes picked up energy

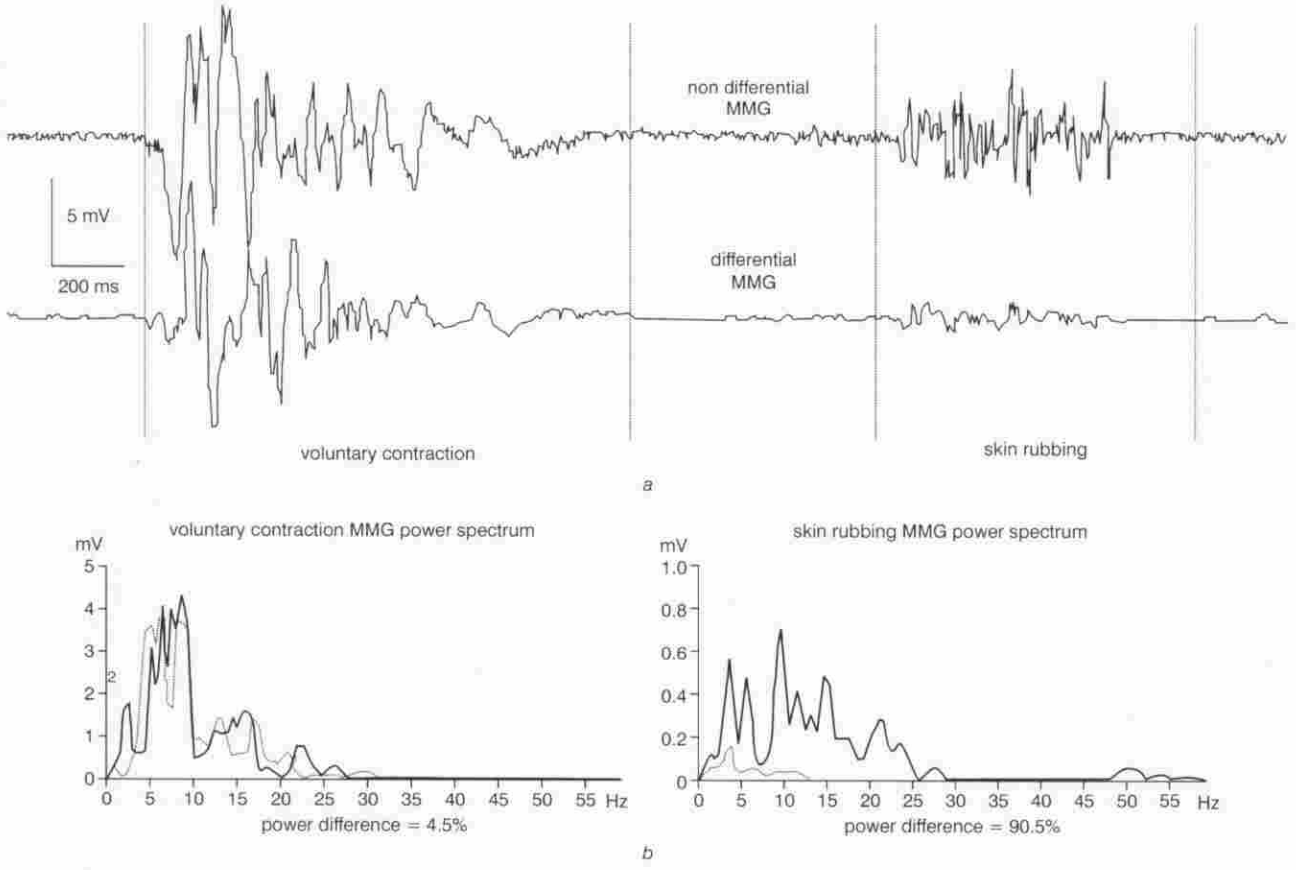

Fig. 3 *Comparison of differential and non-differential MMG recordings. (a) MMG signals simultaneously recorded by differential and non-differential probes during voluntary contraction and skin rubbing. (·····) Vertical dotted lines denote epochs of signals used for spectral analysis. (b) Difference in power spectra of two signals from two probes: (—) single; (·····) differential. Vertical scale of right spectrum is one-fifth scale of left spectrums*

simultaneously from sites more than 20 mm apart, they yielded non-identical signals. Nevertheless, sequential recording with the two different probes, from the same muscle site, yielded analogous results.

4 Discussion

The composite probe described here allows simultaneous differential recording of EMG and MMG signals; it is compact and inexpensive and simplifies the recording set-up. Because the probe differentially amplifies both signals and the pre-amplifiers lie close to the EMG electrodes and piezoceramic plates, it also substantially improves the signal-to-noise ratio.

The differential probe performed better than a non-differential probe in recording muscle activity as it rejected more artifacts.

Nevertheless, the combined EMG-MMG recording procedure has not yet been standardised. Technical factors and recording procedures differ in the various studies. In particular, the source of the MMG signal remains controversial (BARRY *et al.*, 1985; ORIZIO, 1993). Moreover, the position of the electrodes on the muscle could affect estimation of the EMG owing to possible artifacts related to anatomical and physiological factors (MASUDA *et al.*, 1999; HERMENS *et al.*, 2000; RAINOLDI *et al.*, 2000). In our study, the probe was not positioned over the centre of the muscle belly, which is considered the worst position for EMG surface recording, but more than 1 cm away. Although the best positions for EMG and MMG recording can differ, the distinctive feature of our procedure (i.e. the simultaneous EMG–MMG recording by a single composite probe) required the selection of an adequate position either for electrical or acoustic signals.

Our device has the distinct advantage of allowing both EMG and MMG signals to be differentially recorded from the same muscle site, with a simple procedure using a single, tiny, inexpensive probe. This method could provide useful information on muscle activity, even in a routine clinical settings.

Acknowledgments—The experiments complied with the current laws of the country in which the experiments were performed.

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