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Sensitivity of fasciculation potential detection is dramatically reduced by spatial filtering of surface electromyography

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Bipolar electrode configuration is most commonly used in surface electromyography (EMG) recording because a differential amplifier can eliminate any “common mode” components from the two closely placed recording surfaces. Higher order spatial filtering of surface EMG with an electrode array can further highlight activity of superficial motor units and thus provides a useful approach for single motor unit activity detection using surface EMG (Farina et al., 2003). However, in this letter we demonstrate that to achieve the best capacity for fasciculation potential detection, as may be used to investigate amyotrophic lateral sclerosis (ALS), a monopolar surface electrode configuration provides a more accurate approach.

Fasciculation potentials may be an important marker in studying ALS (Mills, 2011). They can also contribute to help diagnosis of ALS according to recent consensus of the Awaji criteria (De Carvalho et al., 2008). Fasciculation potentials can be recorded readily by concentric needle and conventional bipolar surface electrodes (Howard and Murray, 1992), which are routinely available in clinical EMG laboratories. Recently, high-density surface electrode arrays comprised of a number of closely placed tiny recording probes have achieved increasing applications for research laboratory based investigation of neuromuscular diseases, including examination of fasciculation potentials from ALS patients (Drost et al., 2007; Kleine et al., 2008, 2012; Zhou et al., 2011, 2012; Zhang et al., 2013). It is important to optimize the detection of fasciculation potentials for such investigations. In this letter we attempt to quantify the effects of different spatial filtering

techniques (which are often used for electrode array surface EMG recordings) on sensitivity of fasciculation potential detection, with the view toward determining the most appropriate electrode configuration.

Eight subjects (57 ± 9 years; 6 males, 2 females) with definite ALS or probable ALS with laboratory support participated in this study. The study was approved by the local Human Studies Committee, and all the subjects gave their written informed consent. Fasciculation potentials were recorded using surface electrode arrays from 18 muscles in total. These include 10 biceps brachii muscles, 4 first dorsal interosseous (FDI) muscles, and 4 thenar muscles. During the recording, subjects were asked to completely relax their tested arm. After skin preparation, a 20-channel linear electrode array (Fig. 1a), designed and fabricated in our laboratory, was used for biceps brachii muscle recording. The electrode array was placed on the middle of the muscle belly from proximal to distal tendons along muscle fiber direction. For the FDI and thenar muscles, a 64-channel 2D flexible surface electrode array (Fig. 1b, TMS International BV, the Netherlands) was used for recording. The electrode array was placed with one column along the muscle fiber direction. The duration of the resting muscle recording maintained at least 200 s for the biceps brachii muscle and 300 s for the FDI or thenar muscle. The signals were amplified by the Refa128 EMG system (TMS International BV, the Netherlands). Reference electrode was placed near the elbow. The signal was sampled at 2 kHz per channel, with a band pass filter setting of 20–500 Hz. It is noted that for each channel a common feedback subtraction (average of all the recording channels) was imposed by the system. Because of this system feedback, in this letter, we call such a setting as initial mode (instead of usually called “monopolar configuration”). However, such a common feedback would not have any influence on implementing different linear spatial filters.

All the signal processing was performed offline using Matlab (MathWorks, Natick, MA). Fasciculation potentials were detected using a previously described algorithm (Jahanmiri-Nezhad et al., 2014). In brief, the algorithm transforms the multi-channel signal to a single-dimensional data by calculating the maximum difference across all channels of the electrode array. Such processing can reduce computational complexity, yet maintain useful information from the electrode array recording as much as possible. A spike detection threshold was applied to the one-dimensional signal (smoothed by a Hamming window) to identify the firing times of each fasciculation potential. In this study, the spike detection threshold was set as 20% of the maximum amplitude of the smoothed one-dimensional signal.

The number of fasciculation potentials was first obtained in the initial mode. Then, different spatial filters were applied. For the linear electrode array, a longitudinal single differential (bipolar) filter and a longitudinal double differential (DD) filter were used for processing. For the 2-D electrode array, a longitudinal bipolar filter and a Laplace filter was tested. Each spatial filter corresponded to an electrode configuration comprised of several neighboring electrodes with different weights, as demonstrated in Fig. 1(a) and (b). The spatially filtered signal was obtained by weighted summation of neighboring electrode recording. The number of the fasciculation potentials was then identified for each spatial filter configuration.

Fig. 1c shows an example of EMG recordings using different electrode configurations, which demonstrates that some fasciculation potentials recorded in the initial mode were not observable after the spatial filtering. Because of this, the number of fasciculation potentials detected was dramatically reduced by spatial filtering of surface EMG.

For the 10 biceps brachii muscles, the average number of fasciculation potentials detected per 100 s was 149 (range: 13–407). After the bipolar filtering, this number was reduced to 28 (range: 1–75). Calculation of the reduction rate for each muscle indicates that on average 73.7% of the fasciculation potentials recorded in the initial mode could not be captured with the bipolar electrode configuration. The average detection rate per muscle was further reduced by 84.3% with double differentiation compared with the initial mode. For the 4 thenar muscles, the average number of detected fasciculation potentials per 100 s was 264 (range: 10–545). Calculation of the reduction rate for each muscle indicates that the average reduction rate of fasciculation potential detection was 53% for the bipolar electrode configuration, and 70.3% for the Laplace electrode configuration, respectively, compared with the initial mode. Similar findings were also observed from the FDI muscle. The average reduction rate of fasciculation potentials per FDI muscle was 47% for the bipolar configuration, and 86.4% for the Laplace configuration, respectively, compared with the initial mode.

We conclude that for robust detection of fasciculation potentials in ALS, spatial filtering of surface EMG dramatically reduces the detection sensitivity and thus should not be applied. The electrode configuration is of the user's construction, and the EMG signal as recorded is influenced by our choice of different electrode configuration methods. How to determine the most appropriate electrode configuration depends on the investigatory objective of the recording. For best capacity of fasciculation potential detection using surface EMG, our analysis indicates monopolar surface electrode configuration should be used.

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Fig. 1.

(a) A schematic plot of the 20-channel linear electrode array used for the biceps brachii muscle recording. Each recording bar is 1 mm in width and 10 mm in length, and the inter-bar distance is 10 mm. (b) A schematic plot of the 2D flexible electrode array used for the FDI or thenar muscle recording. Each recording probe is 1.2 mm in diameter, and the center to center distance between two adjacent probes is 4 mm for both horizontal and vertical directions. (c) A comparison of fasciculation potentials recorded from biceps brachii muscle of an ALS subject using the initial mode, the bipolar and double differential configurations, respectively.