Detection algorithm for the firing of a single motor unit in surface electromyography from the trapezius muscle during a mental task

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Abstract— **Work-related musculoskeletal disorders (MSD) of the neck and the shoulders are a growing problem in society. An important cause of this MSD is mental stress. An interesting pattern of muscle activity in the trapezius muscle is detected during a laboratory study. During the rest condition and/or the mental stress condition, the firing of a single motor unit is noticed. This single motor unit was visible in 65% of the test subjects on one or both trapezius muscles although there was no change in posture of the test subjects. A spike train detection algorithm is used to localize this phenomenon. The detection algorithm can be used to gain insight in the physiological origin of this phenomenon. In addition, the algorithm can also be used in a biofeedback system to warn the user for this undesired contraction to prevent MSD.**

Keywords— **Mental stress, Single motor unit firings, spike train detection algorithm**

I. INTRODUCTION

Work-related musculoskeletal disorders (MSD) [1] of the neck and the shoulders are a growing problem in society. MSD are caused by a combination of factors such as bad posture, repetitive movements and force exertion. But also psychological stress is related to MSD. MSD have personal consequences, such as discomfort, pain, malfunctioning and disability, as well as socio-economical consequences such as reduced productivity, reduced performance and increased absenteeism [2]. Forty to fifty percent of all work-related absences are affected by MSD. This problem leads to losses of 0.5 to 2% of GNP per year. The problem is noticed by the European Commission and reported in two memo's [3] [4]. The EU Advisory Committee on Safety, Hygiene and Health at work emphasizes that a number of measures should be taken to enable successful prevention of MSD.

Stress is defined as a mismatch between perceived demands and perceived capacities to meet those demands. Stress induces a number of physiological reactions, known as the fight or flight reaction. This reaction is hormonal, neurological, cardiovascular, metabolic and muscular. The influence of mental stress on various physiological functions is well documented [5]. Frequently used biomarkers of stress are blood pressure, heart rate, heart rate variability and catecholamine and cortisol secretion. The influence of mental load on muscle activity of the trapezius muscle has been investigated in some recent studies and a significant increase in trapezius muscle activity had been found during mental stress [6]. Chronic stress can lead to an overload or exhaustion of physiological systems.

The electrophysiological activity of a muscle can be measured with surface electromyography (sEMG), which is a differential measurement of the electrical activity of the muscle detected with electrodes placed on the skin. The detected electrical activity is the summation of all motor unit action potentials in the detection area of the electrodes.

In this paper we present a special type of low activity muscle contractions of the trapezius muscle discovered in sEMG signals: the firing of a single motor unit is seen. To our knowledge, little has been reported on this phenomenon, especially with a differential measurement. We present also an algorithm to detect this specific type of muscle activity. The algorithm was developed by Deburchgraeve et al [7] for spike train detection in neonatal EEG.

II. DATASET

28 participants were monitored, 15 men and 13 women with mean age of 22 (±1.96) years and an average body mass index of 22.2 (±0.43) kg/m^2. The study population consisted of students and young people working at the Katholieke Universiteit Leuven. In a laboratory environment, the subjects went through a protocol with four different

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conditions. During the rest condition, relaxing pictures were shown to put them at ease. There were three active conditions in the protocol: a condition with a postural task: a 45° shoulder abduction for 6 minutes, a condition with a mental task (an IQ-test) and a condition with both postoral and mental load (45° shoulder abduction and an IQ-test). Each active condition was followed by a rest condition. The sequence of the active conditions was fully randomised amongst the participants.

We used contact electrodes (Ag-AgCl, 10 mm diameter, Nikomed, Denmark) which were located on the muscles according to SENIAM recommendations [8] and palpation of the muscle. In the experiment, the left and right m. Trapezius pars descendens, m. Deltoideus medius, and the m. Infraspinatus were measured. The data were registered with EMG preamplifiers from Mega Electronics Ltd (Finland). These analog signals were amplified and low pass filtered (450Hz). The Daqbook 2005 (IoTech, Ohio, USA) was used to digitize the signals at a frequency of 1000 Hz with 16-bit resolution. Posture was recorded during the stress and muscle fatigue test with a Sony (DCR-HC37E) camera.

III. SINGLE MOTOR UNIT FIRING

After removing the ECG-interference [9] on the EMG signals, the amplitude of the muscle activity of the muscles of the test subjects is analysed. On group level, there was a significant difference in amplitude of the sEMG of the trapezius muscle between the overall rest condition (which is the mean of all the rest periods during the test) and each of the three active conditions. The significant difference between the rest condition and the two conditions with postural load is obvious as the trapezius muscle is one of the main actors for the shoulder abduction. The increase in muscle tension of the trapezius muscle during the mental task is more remarkable. Although there is no physical change in posture, there is an increase in muscle tension. This in agreement with the findings of Lundberg et al [5,6]. We reported earlier [10] that there were significant differences in heart rate variability between rest and the mental task, confirming together with the findings here, that we induce a mental stress to our test persons with the IQ-task.

During visual inspectation of the sEMG signals, there were specific patterns visible for the m. trapezius left and right during the mental task and the rest period: a specific burst of peak activity was visible in these signals (see the figure below). The x-axis represents the time dimension. The peaks appear at a rate of approximately 10 peaks per second. It is impossible that this is a contamination from the heart activity. Peak shapes are very similar, which means that this burst of peaks is the firing profile of one motor unit: i.e. a single motor unit firing. This profile differs from the normal EMG signal, which has a normal and conscious contraction.

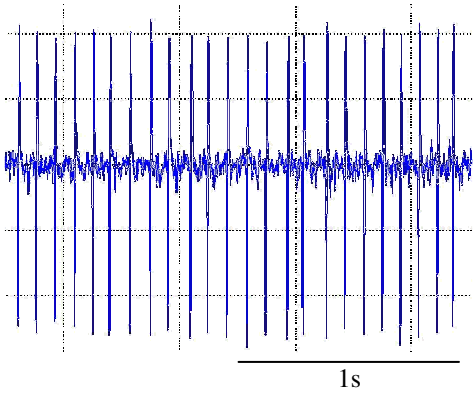

Figure 1: Example of a spike train from a single motor unit

The physiological meaning of a single motor unit firing is a very low contraction of the muscle, frequently performed subconsciously. It is possible that stress is the source of this single motor unit firing. Westgaard [11], however, considers that this low-threshold motor unit activation may come from mental stress or possibly respiratory activity.

At the moment, there is no clear evidence for the origin of these motor unit firings. A sustained contraction of a muscle fibre could lead to exhaustion of that fibre. However, mental stress cannot be concluded from the detection of these patterns. They may be significant to the avoidance of neck muscle strain injuries; however, spontaneous firings of muscle fibres without contribution to physical activity should be avoided.

These patterns provide clear evidence of a different type of muscle activity in the m. Trapezius. This type of activity is not seen in the other measured muscles: m. Infraspinatus and m. Deltoideus. The patterns during rest and mental tasks differ during the postural or combined mental and postural tests. It is possible that the test subjects were not at ease during the rest periods, or were nervous for their results. On the other hand, there is no evidence that this spiky type of activity is related to mental stress or that this type of activity only appears in a mentally stressful situation. Further research is necessary to draw conclusions on these issues.

IV. DETECTION ALGORITHM

To detect the spikes in the EMG we used the spike train detection algorithm as described by Deburchgraeve et al. [7]. The algorithm is developed for the detection of seizures in the EEG of neonates and is fully automated. This detection algorithm consists of three consecutive steps (Fig. 2).

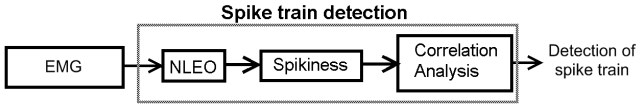

Figure 2: Schematic overview of the spike train detection algorithm.

In a first step, high energetic parts of the EMG are segmented using a Non Linear Energy Operator (NLEO) [12]. This operator is proportional to the square of both the immediate frequency and amplitude. Because of these properties, the NLEO amplifies the high-frequency spikes of the spike train relative to the background EMG, facilitating the segmentation.

The second step (Fig. 2) analyzes the spikiness of the detected high energetic segments. This spikiness defines that the spikes need to be 'isolated' in the EMG by comparing the energy of the detected segment with its immediate background activity.
The final step is the correlation analysis (Fig. 2). To detect the occurrence of a repetitive pattern of segments, a correlation scheme was developed that grows a set of highly correlated segments [7]. If more than 6 correlated segments are detected, the segments are classified as spikes of a spike train.
Finally, the output of the algorithm is a set of highly correlated, high energetic spike-like segments corresponding to the spikes of the spike train.

Figure 3A shows the beginning of the spike train. Initially the muscle is in rest. At the black arrow, a single motor unit starts firing. This is detected by the algorithm. At this moment, the test subject is in the rest condition, watching relaxing pictures. There was no change in posture noticed at this moment when the movie of the test was analyzed. Figure 3B shows the end of the same spike train. The black arrow indicates the beginning of the shoulder abduction in combination with the IQ-test. This whole spike train with firings from a single motor unit lasted in this particular case 46 seconds. The algorithm is able to detect the spike trains originated by the firing of a single motor unit. All the segments in the data that we determined were detected by the algorithm.

This special type of muscle contraction was found in 18 out of the 28 test subjects on at least one of both trapezius muscles during a rest condition or during the condition with the mental load. In 9 of the 10 persons without single motor unit firings, there was no muscle activity at all during the rest conditions or the mental condition. These people showed no response on both trapezius muscles during the test. This type of muscle activity could not be found during the postural condition (with and without mental load). This explanation is straight-forward as the trapezius muscles contract always during the shoulder abduction.

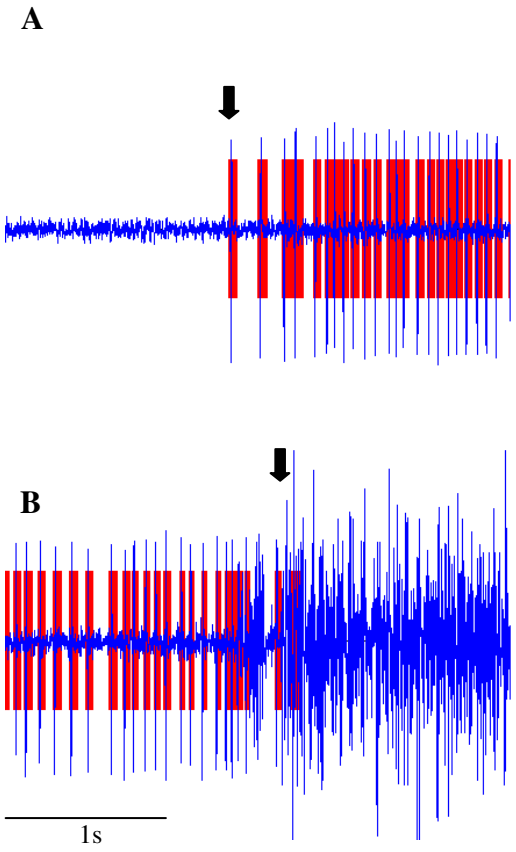

Figure 3: (A) Example of the detection of a firing spike train from a single motor unit after muscle in rest, (B) end of the same spike train before the shoulder abduction in combination with the mental task.

For a conscious contraction, several motor units are firing, making the detection of a single motor unit impossible with the differential measuring method we used.

V. CONCLUSION

In this paper, we described a special type of muscle contraction, discovered during a laboratory test. In the test, the test subjects were performing a mental task in combination with and without a postural task. On the trapezius muscle, in 65% of the test subjects, we found a pattern of the firing of a single motor unit. This is remarkable as the electrical activity was measured differentially with a single channel. The physiological meaning of this firing pattern is a very low and subconscious contraction of the muscle. A long term contraction could lead to the exhaustion of the muscle fibers, leading to musculoskeletal disorders. The origin of these firings is unknown. They appeared during rest or during the mental task, leading to a small force that does not lead to a postural change. A certain mental load, leading to a small

increase in muscle tension, could be a possible explanation for the single motor unit firings, but the presence of the activity was not synchronized with the mental task in the test. The test subjects were not aware of this muscle tension. Longer muscle tension could lead to the exhaustion of the muscle fibers. Long periods of these single motor unit firings appear at this moment to be undesired, so it is beneficial to detect this type of firings.
An algorithm to detect this single motor unit firing was also presented. This algorithm detects a train of consecutive, highly correlating, spikes. The algorithm was able to detect all the spike trains that were localized by visual inspection of the individual EMG signals. The applications of this algorithm are twofold. On one hand, it can be used as a biofeedback system to warn the user for this undesired muscle activity to prevent musculoskeletal disorders. On the other hand, the algorithm can be used for offline assistance to analyze the signals and try to find a physiological explanation.

Further research is necessary to gain insight in the physiological origin of this interesting phenomenon. In future research, we suggest to measure the trapezius muscle with high density sEMG, to have both spatial and temporal information of the muscle activity.

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