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Machine-learning based evaluation of mechanic muscle responses elicited by tSCS

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Abstract: Transcutaneous spinal cord stimulation can reduce spasticity and enhance voluntary movement. However, electrode position and therapy intensity must be determined in a tuning process before the treatment. For that, electromyographic signals of the leg muscles are recorded during isolated double-pulses and categorized as "no response", "reflex response" and "muscular response". This procedure involves time-consuming skin preparation and electrode placement. In this contribution, mechanical muscle responses (accelerations) are recorded additionally to the electromyogram in nine healthy subjects to train a machine learning algorithm, which classifies the acceleration signals with an accuracy of 87 %, when considering EMG classification as ground truth.

I. Motivation

Injuries and diseases regarding the upper motor neuron such as spinal cord injury (SCI) or multiple sclerosis (MS) can cause spasticity, gait deficits or even full loss of motor function. Transcutaneous spinal cord stimulation (tSCS) can enhance voluntary movement and reduce spasticity [1]. Hence, it provides a promising therapy option for these patient groups. However, to ascertain a therapy effect, the stimulation parameters as intensity and electrode position must be identified prior to the tSCS therapy. Typically, a tuning process is conducted using isolated double pulses of increasing intensity while electromyogram (EMG) signals of the posterior root muscles (PRM) in the legs are recorded in a supine position [2]. The EMG-responses differ in amplitude A_1 regarding the first pulse and in the extent of suppression S of amplitude A_2 regarding the second pulse in relation to A_1. The response of each muscle can be categorized in:

class 0: No response, if $A_1 < 50\mu V$
class 1: Reflex response, if $A_1 > 50\mu V$ and $S > 60\%$
class 2: Muscular response, if $A_1 > 50\mu V$ and $S < 60\%$

Based on the number of class 1 responses among the PRM at the different stimulation intensities suitable stimulation parameters can be found [2]. However, this tuning process involves time consuming skin preparation and EMG-electrode placement as well as professional expertise. To simplify the procedure, this paper investigates a new approach which aims at replacing the EMG sensors by inertial measurement units (IMU) which record the acceleration (ACC) signal of the PRM activity and don't require any electrodes or skin preparation. A machine learning approach was implemented for the classification of ACC responses. To the best of our knowledge, ACC signals have not been used in a tSCS tuning process before.

II. Material and methods

A tSCS tuning process was performed on nine healthy subjects (age: 32.2±9, 7 men, 2 women) in a supine position. Isolated double as well as single pulse stimuli of increasing intensity, starting at minimum 5 mA with an increment of 5 mA and closing with a maximum of 80 mA, were applied with the RehaMove3 (Hasomed GmbH, Germany) while recording synchronized EMG and ACC signals in the quadriceps and triceps surae muscles with the MuscleLab (Ergotest Innovation AS, Norway) sensor system. The sampling frequencies were 1000 Hz for the EMG and 200 Hz for the ACC signals, respectively. In this approach, only ACC signals orthogonal to the skin were considered which corresponds to the z-direction of the

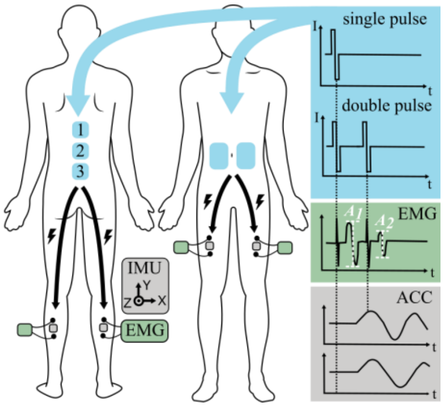

Figure 1: Electrode placement of the three back electrodes and the counter electrodes on the abdomen, EMG and IMU sensor placement on the PRMs and simplistic ACC and EMG responses on stimulation pulses.

IMU. As shown in Fig. 1, the IMU sensors were placed in between the EMG electrodes with elastic straps to record activity signals of the same muscle. Response signals of three different positions (Fig. 1) of 5x5 cm electrodes on the back were recorded. Interconnected counter electrodes of size 7x13 cm were placed on the abdomen. The preprocessing chain of EMG and ACC signals include artifact detection (in EMG), filtering, similarity check and averaging of three repetitions. Subsequently, each stimulation event was classified according to the characteristic of the EMG response to a double stimulus. The EMG classification is considered as ground truth. Preprocessing as well as the machine learning approach were implemented in Python. As an approach to solve the classification problem of the ACC signal, a support vector machine (SVM) with a radial basis function (RBF) kernel was implemented and a feature table was extracted from the acceleration data of the PRM. As the mechanical muscle activity response in the ACC signal is much longer (see Fig. 1), amplitude parameters resulting from double and single stimulus are extracted. The corresponding difference (DIFF) between the ACC response to a double and single pulse was calculated as a simple approach for dissolving the superposition of mechanical muscular responses to a double pulse. Features include window-based amplitude values (e.g., peak-to-peak amplitude, mean), mean-power-frequencies, stimulation properties such as current and electrode position, as well as meta data of the patient such as BMI, age, and sex. The windows for the amplitude parameters were set to 10-45 ms for the single pulse data and to 50-110 ms regarding the DIFF and double pulse data. Stimulation pulses occur at 0 and 50 ms (double pulse), respectively. For ACC data of the triceps surae both windows were shifted 5 ms to the right. In total 38 features of 1271 stimulation events in the PRMs were obtained. Before training the SVM, more events of ground truth class 2 were artificially generated by means of synthetic minority oversampling technique (SMOTE), in order to diminish class imbalances. Finally, the implemented SVM was evaluated by means of a leave-one-subject-out (LOSO) cross-validation approach with standardized training and test data. This also includes hyper parameter tuning on the regularization parameter and the kernel coefficient in each LOSO loop.

III. Results

The summed total and ratio confusion matrices of the LOSO cross-validation are shown in Fig. 2. The total results display the imbalance between the classes without the generated SMOTE data. The low appearance of class 2 results in more falsely classified events in this class than its actual number of occurrences. However, in all classes more than 87 % of the events are correctly classified. The mean accuracy of all subjects is 0.87 ± 0.1. To prevent a misinterpretation due to class imbalance a balanced accuracy score was calculated, taking the total number of class members into account.

The stimulation parameters intensity and electrode position were determined similar as described in [2] for both conventional EMG classification and introduced ACC classification. The mean difference between the determined intensity based on the ground truth EMG classification and ACC classification among the nine subjects is 2.2 ±11.8 mA. As the intensity jumps are fixed to 5 mA, the standard deviation is considerably high. This deviation is mainly caused by one subject due to falsely classified green labels in low intensities. In two subjects, the electrode position considering ACC differed from the EMG results. However, one of the subjects shows similar amounts of reflex responses in both electrode positions.

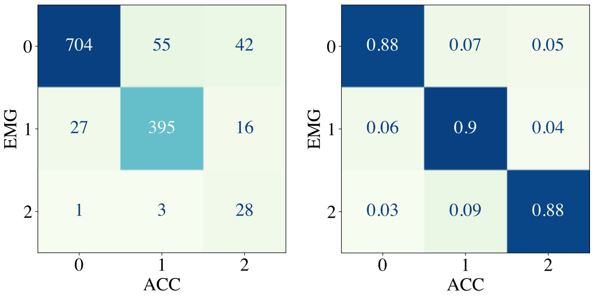

Figure 2: Summed total (left) and ratio (right) confusion matrices of classifier using LOSO cross-validation, EMG classification are considered ground truth, ACC parameters are used for prediction.

IV. Discussion and conclusions

Even though the accuracy of the classifier is promising, there are still several wrongly classified stimulation events. A reason for that could be inaccurate alignment of single and double response in ACC before subtraction. A suitable solution could be dynamic time warping to optimize the alignment. Other issues could be crosstalk from other muscles or twitch summation, which describes the increase of force if two twitches are initiated on a muscle within a short period of time.

The promising results of the introduced SVM approach imply that acceleration signals might be suitable in replacing the conventional EMG measurements during the tuning process prior to the tSCS stimulation. With this, the procedure can be simplified to a less time-consuming and complex process. However, to verify these first results, the algorithm should be tested on a bigger data set which also includes patient data. Moreover, further improvements might be possible regarding the preprocessing chain or the feature selection. If the classification should be fully relied on ACC data, stimulation and data acquisition need to be synchronized, as no stimulation artifacts are visible in the signals.

AUTHOR'S STATEMENT

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