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Evaluation of Lumbar Muscle Activation Patterns during Trunk Movements using High-Density Electromyography: A Preliminary Report

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Abstract— **Lumbar paraspinal muscles are heavily involved in daily and work-related activities including trunk bending, trunk twisting, and lifting. Repetitive or inappropriate activation of the lumbar muscles while performing these activities can lead to low back pain. The aim of this preliminary study was to quantify the activation patterns of multiple lumbar muscles when participants performed three different trunk movement tasks, including sustained lumbar flexion posture, dynamic lumbar flexion and extension, and left-right twisting movements. Two 8×8 high-density electromyogram (HD-EMG) electrode arrays were used to record the lumbar muscle activity during these movements. We observed a symmetric and rapid increase in the amplitude of EMG in the erector spinae muscles during the sustained flexion or oscillation tasks. Asymmetric activation patterns were observed in bilateral lumbar muscles during the trunk twisting task. In addition, we observed substantial bilateral co-activation of the lumbar muscles for both twisting directions. These preliminary results demonstrated the potential feasibility of using HD-EMG as a tool to monitor spatial activation patterns of the lumbar muscles during different trunk movements. This approach can also be further developed to assess lumbar muscle function in individuals with low back pain.**

I. Introduction

Low back pain affects approximately 80% of people in their lifetime and is one of the most common causes of outpatient healthcare visits, work related disability and healthcare costs in the US [1]. Low back dysfunction and fatigue can arise from many factors given the complex biomechanical relationships between anatomical structures in this region. The evaluation of lumbar muscle activation patterns is an important area to explore when considering prevention of low back pain. One of the most common dysfunctions associated with work-related disability is low back strain, typically arising from multifidus, erector spinae, rectus abdominus, external/internal obliques or quadratus lumborum muscle strain [2], [3]. The erector spinae are thought to be one of the most significant structures involved in low back dysfunction due to their role in counteracting external loads, in both dynamic and static conditions [4]. These muscles work together, in a complex interplay of coordinated activity, to stabilize the spine and provide truncal motion.

Proper assessment and diagnosis of low back pain assists in providing efficient recovery. Electromyography has been utilized in previous studies to help assess the role of these muscles in different spine biomechanical tasks to better understand the underlying causes and the severity of injury and dysfunction [5], [6].

Conventional surface electromyography (sEMG) has been widely adopted as an assistive diagnostic or assessment technique [7], [8], partly due to its non-invasive nature and ease of implementation. Conventional sEMG typically uses one or two electrodes placed over the muscle belly to capture muscle activity, and the amplitude or frequency information are commonly extracted to evaluate the underlying physiology during the control of muscle activation [9]. However, this recording method is prone to interference [10]–[12]. For example, the electrode placement relative to the targeted muscle and the quality of the electrode-electrolyte interface contact is critical for accurate and consistent evaluations of muscle physiology. Interference noise, such as background noise from the ambient environment and motion artifact, is commonly captured in EMG signals. These issues limit the diagnostic or assessment value of EMG recordings.

Recently, High-density EMG (HD-EMG) electrode arrays have been developed to address some of these limitations. These HD arrays have a large number of electrodes organized in a two-dimensional (2D) film, which can cover a large portion of the muscle and can be used to capture multiple adjacent muscles concurrently. This recording approach can provide detailed information about muscle activation pattern, and allow us to capture muscle activity in topographic 2D representations [13], [14]. Accordingly, using HD-EMG recordings of the lumbar muscles, the purpose of this preliminary study was to quantify the activation patterns of multiple lumbar muscles as healthy participants performed common trunk movement tasks. We quantified the amplitude and 2D spatial distribution of the lumbar muscle activity at different phases of the trunk movements. Our preliminary results demonstrate the feasibility of using HD-EMG as a tool to monitor activation patterns of the lumbar muscles during different trunk movements, which may prove helpful in muscle workload monitoring and the assessment of low back muscle function.

II. Methods

A. Participants

Three male subjects (24-26 years of age) with no neurological disorder and no lumbar muscle injury were recruited in this preliminary study. All participants gave informed consent via protocols approved by the Institutional

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B. Data acquisition

The subjects stood upright in their neutral position before each trial started. Before the electrode array was placed, alcohol pads were used to clean the skin in the lumbar area, in order to improve electrode-skin contact. One 8×8 high-density electromyogram (HD-EMG) electrode array (OT Bioelettronica) was placed on each side of subject's lumbar area (Fig. 1 (C)). In order to observe the activity of lumbar muscles during trunk movements, each electrode array was placed between T12-L4 horizontally aligned to the spine and 4 cm away from the spine. The electrode array has a 10 mm inter-electrode distance and 3 mm electrode diameter. The amplifier EMG-USB2+ (OT Bioelettronica) sampled the monopolar EMG signals at 2048 Hz and band-pass filtered at 10-900 Hz.

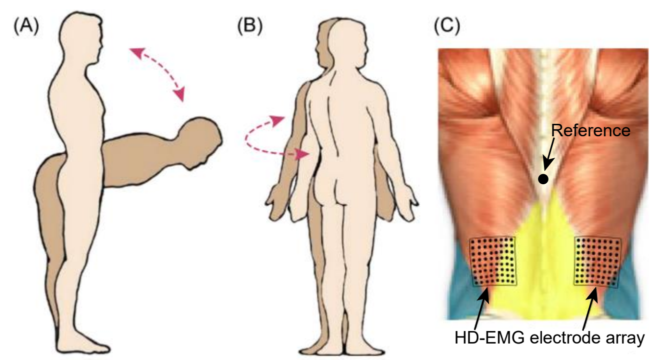

Fig. 1. Experimental setup for the data acquisition. (A) Lumbar flexion (hold or oscillation tasks). (B) Trunk left/right twisting. (C) The placement of the HD-EMG electrode array.

Three tasks were performed by the subjects under the guidance of the experimenter. For all three tasks, a 5-second neutral-standing rest was given before and after the movement in each trial to obtain the baseline EMG activity. In those tests, the subjects stood with two arms resting in neutral position. The three trunk movement tasks were sustained forward flexion oscillation, and twisting movements. During the flexion-holding task, the subjects performed lumbar flexion at their preferred speeds, reached their arms forward horizontally, and the lumbar position was held at the maximum of the range of motion for 10 seconds before they extended back to the upright posture (Fig. 1(A)). In the oscillation task, the subjects performed lumbar flexion and extended back to the upright posture as soon as they have reached the maximum range of motion. In each trial, five lumbar flexion movements were performed with 1-second rest between each movement. The twisting task was performed by rotating the trunk to the left and right to the range of motion at the subjects' preferred speed (Fig. 1(B)). Each rotation included twisting to the left, coming back to neutral, twisting to the right, with 1-second rest between five repetitions. The purpose of the design of the three tasks was to simulate common occupational activities involving these muscle groups. Each task was repeated over five trials, leading to 15 trials for each subject. The order of the three tasks were randomized across subjects.

C. Data processing

EMG preprocessing: The HD-EMG signals were first processed using an independent component analysis (ICA)-based method [15] to remove motion artifact. Lumbar EMG signals are often convolved with electrocardiogram (ECG) interference. To remove ECG interference, we implemented a moving-median filtering method that thresholds the signals with three local standard deviations away from the local median within a 1-second window.

Data analyses: To quantify the level of muscle activation over time in each task, we first calculated the root mean square (RMS) values of individual channels using a 0.5-second sliding window with a step size of 0.05 second. The average RMS across 64 channels from each electrode array was then calculated. Since the movement frequency was lower than 0.5 Hz, we further low-pass filtered the average RMS with a cutoff frequency of 0.5 Hz.

We then quantified the spatial distribution of the muscle activation in each task. We constructed the 2D EMG amplitude heatmaps by calculating the RMS of individual channels using a 0.5-second window. This procedure resulted in 64 RMS values corresponding to 64 electrode channels on each side. For better illustrations, the 8×8 matrix was interpolated by the bicubic interpolation method into a 449×449 matrix. The 2D heatmaps at different time points of the tasks were calculated to quantify the different phases of movements. The range of the color bar was fixed at different time points for each side, such that the heatmaps were comparable across different time points during a trial.

III. Results

Examples of the average RMS time series and the 2D heatmaps at different time points are shown in Fig. 2-Fig. 4. The blue traces represented the average RMS across 64 channels on the left lumbar side, while the orange traces represented the average RMS across 64 channels on the right lumbar side. Four movement phases were selected to illustrate the heatmaps in both the flexion-holding task and the oscillation task. Five phases were selected to visualize the lumbar muscle activity in the twisting task due to one more distinct posture in the task.

As shown in Fig. 2, the RMS increased from the resting state to 0.08 mV during the flexion-holding period, and the most activated areas during the flexion-holding task were the triangular-shaped areas over the ES muscle. In the first phase, the subject was in upright standing, and the heatmaps of both sides showed minimal activity. In the second phase, the subject initiated the forward flexion movement. The average RMS and heatmaps started to increase. From the first phase to the second phase, the heatmap showed an increase muscle activity across electrodes from 0.02 mV to approximately 0.04 mV. The increase of activity was larger and reached 0.06 mV in the area over the ES muscle. In the third phase, the flexion position was maintained, and the heatmaps showed a high level of symmetric, triangular-shaped activation over the ES muscle. Among the four phases, the last phase showed the strongest average RMS and heatmap activation level.

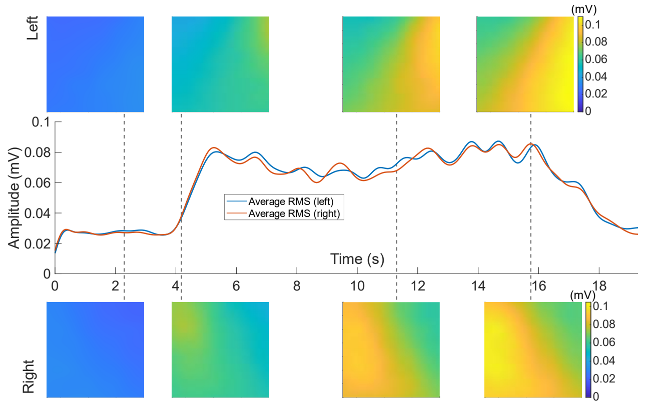

Fig. 2. Average RMS and heatmaps during the flexion-holding task of Subject I. The orientations of the heatmaps match the orientations of the electrode grids in Fig. 1(C). The color coding of the four heatmaps of each grid is fixed.

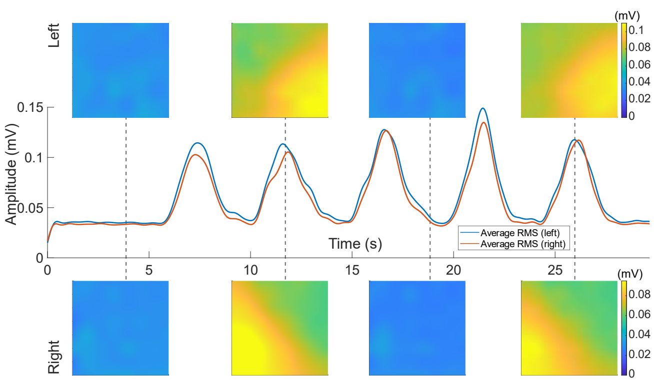

Fig. 3. Average RMS and heatmaps during the oscillation task of Subject II.

The oscillation task (Fig. 3) shows a similar pattern of activation as in the flexion-holding task. We observed the symmetric activation of the ES muscle between the left and right sides of the lumbar for both the RMS time series and 2D heatmaps. Although the subjects flexed forward and moved back at the same speed, it took slightly longer for the EMG activity to descent to the resting level than the ascent phase.

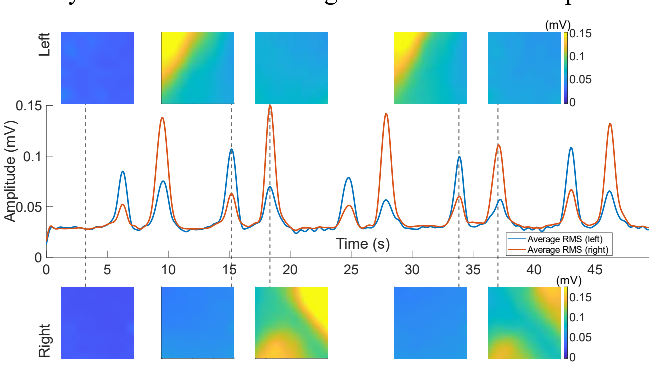

Fig. 4. Average RMS and heatmaps during the twisting task of Subject III.

For the twisting task, the average RMS showed an asymmetric pattern between the left and right twists (Fig. 4). The most activated areas were inverted triangles on the lateral sides of the array, which corresponded to a different lumbar muscle (potentially the latissimus dorsi (LD) muscle based on the anatomical location of this muscle) during the twisting movement. In contrast, the ES muscle showed less activation since the trunk did not incline forward and the ES muscle undertook less tension. The average RMS peak was higher on the ipsilateral side of the LD muscle than the contralateral side of the LD muscle.

Lastly, the peak of the average RMS during left and right twists from both sides is summarized in Fig. 5. We observed substantial bilateral co-activation of both sides of the LD muscle for both twisting directions. However, it showed that the average RMS peak was higher on the ipsilateral side than the contralateral side by averaging across three subjects.

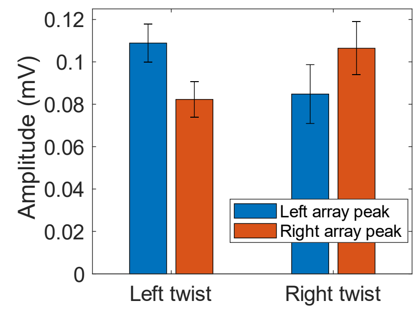

Fig. 5. Peaks reached by the averaged RMS of the left/right electrode array when twisting to the left/right direction. The error bars represent standard error.

IV. Discussion

In this preliminary study, we used HD-EMG recordings to capture lumbar muscle activities when participants performed different trunk movement tasks, including lumbar flexion-holding, lumbar flexion and upright oscillation, and left-right twisting movements. We quantified the overall amplitude and 2D spatial distribution of the lumbar muscle activity at different phases of different trunk movement tasks. We observed symmetric and coordinated activation of the erector spinae muscles during the flexion-hold or oscillation tasks. We also found alternating, asymmetrical coactivation patterns in the latissimus dorsi during the trunk twisting task. These preliminary results demonstrated that HD-EMG recording arrays may be used as a research/clinical tool to quantify activation patterns of the lumbar muscles during dynamic trunk movements. The overall amplitude and spatial distribution of lumbar muscle activation can be used to classify common occupational movement patterns and may be helpful in the assessment or prevention of low back injuries. This method can be further developed to assess lumber muscle dysfunction in individuals with low back pain.

As shown in the overall amplitude and activation heatmaps, the most activated muscle was the ES during lumbar flexion in the flexion-holding task and the oscillation task. In the last phase of the flexion-holding task, we observed an increase in the average RMS and the heatmap activation level. The increased muscle activation could be due to the required torque to sustain the flexion posture. The average RMS also fluctuated substantially when the flexion position was maintained after 10 s, even though the trunk remained relatively stable. These two preliminary observations could be due to initial muscle fatigue after sustained activation. With longer muscle contractions trials, it is possible that the average RMS may become smaller due to inactivity of the large fatigable MUs. Another possible reason for the EMG fluctuation could be associated with recruitment-derecruitment cycles (termed motor unit rotation) in motor unit pool to avoid overloading [16]–[19]. Alternatively, the inability to rotate the activation of different MUs (thus variability in EMG amplitude) of the lumbar muscles was found in the chronic low back pain patients [20], which could be a mechanism for the muscle injury and a physiological factor that hinders functional recovery.

In the trunk twisting task, the level of activation in the LD muscle (the average RMS) showed an alternation between the left and right twist movements, where the ipsilateral side showed a higher level of activation than the contralateral side. However, we also observed a high level of co-activation on both sides of the LD muscle for both twisting directions, which was consistent across the three participants.

One limitation of this preliminary study is that the recorded muscle activation patterns were truncated at the edge of the electrode array, largely because each electrode array only covered an 80×80 mm^2 area. In future studies, we will use a larger HD-EMG electrode array with higher recording areas. In addition, we plan to use ultrasound imaging to capture muscle contractions at different depths, in order to validate the muscle activation patterns observed by the HD-EMG recordings. Finally, only three healthy subjects were recruited in the study. We plan to recruit more subjects, including individuals with low back pain, in order to systematically evaluate the feasibility of this muscle activity recording approach.

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