RESEARCH PAPER

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Effects of hand dominance on myoelectric signal of non-fatigued lumbar multifidus muscle during single arm lifts

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Some evidence indicates that lower back muscles located at the non-dominant side of the body are more fatigue resistant than their opposite counterparts presumably due to preferential use of the dominant hand. The aim of the study was to determine if any distinction exists in the surface electromyographic activity of corresponding contralateral non-fatigued lumbar multifidus (LM) muscles as a function of hand dominance. The relative to maximum root mean square, the median frequency (MdF) and spike shape parameters were computed from the surface myoelectric signals of ipsilateral and contralateral lumbar multifidus muscle of 46 adult healthy subjects (27 right-handed, 19 left-handed) during voluntary contractions evoked by the single arm lifts in prone position. Activation of LM as a contralateral muscle to lifted arm was greater than as ipsilateral muscle, independently of handedness. Regardless if LM performed ipsi- or contralateral action to the lifted arm, the mean spike amplitude, slope, number of peaks per spike and spike duration were greater and mean spike frequency as well as MdF were smaller in the muscle of dominant than non-dominant side. Combined changes of spike shape measures indicate increased recruitment, lower firing rates and higher synchronization of motor units in the LM of dominant side as compared to its counterpart.

Key words: surface electromyography, low back, asymmetry, handedness, spike shape analysis, fast Fourier transform

INTRODUCTION

Lumbar paraspinal muscles play an important role in providing stability of the lumbosacral complex during dynamic functional movements. The lumbar multifidus (LM) muscle is particularly relevant as it seems to provide segmental stability in about two-thirds of lower lumbar vertebral column (Zhang et al., 2018). Recently it was reported that various muscle fibers of LM present different activity during single and repetitive movements of the upper limb, supporting the hypothesis that the superficial multifidus contributes to the control of spine orientation, and that the deep multifidus has a role in controlling intersegmental motion (Moseley et al., 2002).

The way of use of a particular muscle affects its physiological response (Faulkner & White, 1990). The human motor system adapts to functional requirements with considerable plasticity. The long-term preferential use of selected muscles, related to side dominance, can be viewed as a moderate form of training. It results in changes in muscle fibre composition, with higher prevalence of slow twitch type I fibers in the muscle of dominant limb (Fugl-Meyer et al., 1982). The more frequent daily use of the dominant hand seems not only to increase proportion of slow type I muscle fibers but also weight of type I muscle fibers and mass of co-contracting postural muscle (Fugl-Meyer et al., 1982). Such findings are very interesting, as action potential amplitude is positively related with muscle

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fiber size, and with its parent motor units (MUs) recruitment threshold force (Norris & Gasteiger, 1955; Hakansson, 1956). It has been documented that handedness is accompanied by changes in MU control properties manifested by the reduced recruitment threshold and firing rates (initial and average) at the target level of force in muscles located in the dominant hand (Adam et al., 1988). In accordance with these results, some authors noticed differences in myoelectric manifestations of muscle fatigue between two sides, with the dominant one showing less fatigue. Up to date, most of the studies on the laterality were performed on muscles located in the distal parts of upper limbs (De Luca et al., 1986; Zijdewind et al., 1990; Williams et al., 2002). Only few studies examined proximal postural muscles. For example, the analysis of the rate of change in surface EMG spectral variable (indicating fatigue) revealed less fatigability of the upper trapezius muscle at the dominant than at the non-dominant side (Farina et al., 2003). Merletti et al. (1994) investigated muscle fatigue by electrical stimulation of the right and left longissimus dorsi at the L1 vertebral level, and shown that the muscle at the non-dominant side was more fatigue resistant than at the dominant one. It was suggested that this is related to the fiber type modifications associated with the more frequent use of the dominant upper limb and the consequent activation of the non-dominant, contralateral side of the back. Within the context of described function of LM during upper limb movements it would be interesting to verify if there are any myoelectric manifestations that may distinguish its activity between the dominant and non-dominant side of the body. In particular, to evaluate, if increased fatigue resistance of lower back muscles and possible differences in muscle fiber composition between both body sides are manifested by alterations in electromyographic activity of the non-fatigued LM during upper limb movements.

When hand dominance was not accounted for, prior studies examining EMG signal amplitude expressed as root mean square (RMS) of the signal have reported varied asymmetry in LM activity with greater activity ipsilateral (Stevens et al., 2007) or contralateral to arm lift (Ekstrom et al., 2008). When hand dominance was accounted for, the contralateral low back muscle activation amplitude patterns were similar during asymmetrical tasks performed with the dominant and non-dominant hands (Butler et al., 2009a). For the purpose of this study, we used more advanced examination methods to look for possible differences in power spectrum frequency and spike shape variables (Gabriel et al., 2007) of the surface EMG signal in the ipsilateral and contralateral LM muscles activated by simple dominant and non-dominant arm lift in prone position. It is known that distinct high and low-frequency bands within the myoelectric spectra corresponds to activity of MU innervating slow and fast muscle fibers, respectively (Wakeling & Syme, 2002). The power spectrum frequency range is lower for muscle fibers innervated by slow than fast MU units (Wakeling & Syme, 2002). The mean power frequency correlates negatively with the type 1 fiber proportion (Gerdle et al., 1988; Elert et al., 1992) and median power frequency increases with greater proportion of activated fast muscle fibers during muscle contraction (Solomonow et al., 1990).

If due to long-term preferential use of the dominant arm, the LM at the non-dominant side has greater proportion and size of MUs innervating slow muscle fibers, its EMG signal should be characterized by lower median-power frequency as compared to the LM at the dominant side. Hypotheses related to spike shape parameters on alterations in MU firing, recruitment and synchronization were presented in the Table 1. Better understanding of function of LM with regard to hand dominance may improve study designs directed to uncover the true changes in the function of this muscle in sports disciplines requiring high asymmetric activation of trunk and back muscles as well as individuals at risk or already heaving low back pain.

METHODS

Design

It was the observational cross-sectional study conducted on volunteers from the local University community. Bioelectrical properties of the lumbar paraspinal musculature were determined at the University laboratory. The protocol of the study was granted approval from the Institutional Review Board at the Poznan University of Medical Sciences (decision no. 709.17), and written informed consent to participate was signed by each study participant at the time of enrolment to the study.

Participants selection

The study included 46 adults (23 women and 23 men). The inclusion criteria of the study were: age range 20-50 years; lack of low back and pelvis pain over past 6 months, no prior lifetime history of acute low back or pelvis pain. The exclusion criteria were: history of severe trauma; lumbar, abdominal or pelvic surgery, pregnancy within last 12 months; system-

Table 1. Hypothetical changes in surface EMG spike parameters (the lowest row of the table) in the lumbar multifidus muscle at the non-dominant and dominant side of the body during contralateral arm lift due to long-term preferential use of the dominant arm. These changes were assumed based on theoretical changes in particular spike measures that would take place if increase in motor unit firing, recruitment or synchronization appeared (Gabriel et al., 2007). In the last row of the table we proposed the hypothetical, resultant differences in spike variables between the lumbar multifidus of the non-dominant and dominant side of the body. We suppose that such changes might be seen, if due to a more intensive and frequent use of the dominant upper limb, the lumbar multifidus at the contralateral non-dominant side of the body would be composed of greater proportion of MUs innervating moderately enlarged slow motor units, characterized by lesser structural heterogeneity, increased recruitment and lower firing rates for a given level of force as compared to the muscle at the dominant side of the body. Potential structural and functional adaptations in motor units were taken into consideration.

Motor unit activity pattern	Theoretical SEMG spike measure behavior				
	MSA	MSF	MSD	MSS	MNPSS
Increased motor unit firing frequency	–	↑	↓	–	–
Increased motor unit recruitment	↑	↑	↓	↑	↑
Increased motor unit synchronization	↑	↓	↑	↑	↓
Resultant hypothetical differences in the lumbar multifidus SEMG spike measures for weak synergistic contraction of lumbar multifidus					
Non-dominant vs. dominant side	↑	↓	↑	↑	↑
Empirically verified differences in the lumbar multifidus SEMG spike measures for weak synergistic contraction of lumbar multifidus					
Non-dominant vs. dominant side	↓	↑	↓	↓	↓

SEMG: surface electromyography, MSA: mean spike amplitude, MSF: mean spike frequency, MSD: mean spike duration, MSS: mean spike slope, MNPPS: mean number of peaks per spike in motor unit firing and recruitment.

ic disease, skin disease at the area of measurements, participation in physical training directly involving back and abdominal muscle workout within the last three months; body mass index (BMI) > 25 kg/m2. A group was recruited from students and staff employed by Poznan University of Physical Education. An invitation to participate in this study was issued by means of an advertisement posted on the social media and *via* an email sent to individual internal staff email accounts.

Procedure

Handedness determination

The handedness of the subjects was determined at baseline using a Short Form of Edinburgh Handedness Scale (EHS-SF) (Veale, 2014).

Preparation

Prior to measurements participants were asked to lay in the prone position on a plinth with the head in the midline and placed in a breathing hole. One pillow was placed under the pelvis in order to minimize the lumbar lordosis. Upper limbs were abducted in the shoulder joint to 120º and flexed in the elbow joint to 90º (Hides et al., 1992). The lumbar spinous processes were palpated, using the iliac crests as a reference point to determine the L4-L5 lumbar vertebral level. The electrodes placement points were marked on both sides of the body 2 cm from the center of L5 spinous process on the line running between the posterior superior iliac spine and the L1/L2 interspinous space (Kuriyama & Ito, 2005). To ensure that measurements points are marked above facet joint of L5/S1 the ultrasound imaging was used according to previously described methodology (Kiesel et al., 2007). Before positioning the electrodes (22 x 28 mm Ag/AgCl self-adhesive electrodes, 20 mm center to center interelectrode distance) the skin was shaved, cleaned with alcohol and abraded. The reference electrode was positioned at the radial styloid process of the right extremity.

Single arm lift testing

Electromyography data acquisition was performed during relaxation and contraction of lumbar multifidus muscle. The contraction of LM was achieved with single arm lift (SAL). The SAL is capable to increase levels of LM activation and was commonly used previously (Kiesel et al., 2007). To standardize the height of arm lifting, the horizontal bar was placed 5 cm above the surface of plinth. Subjects were instructed

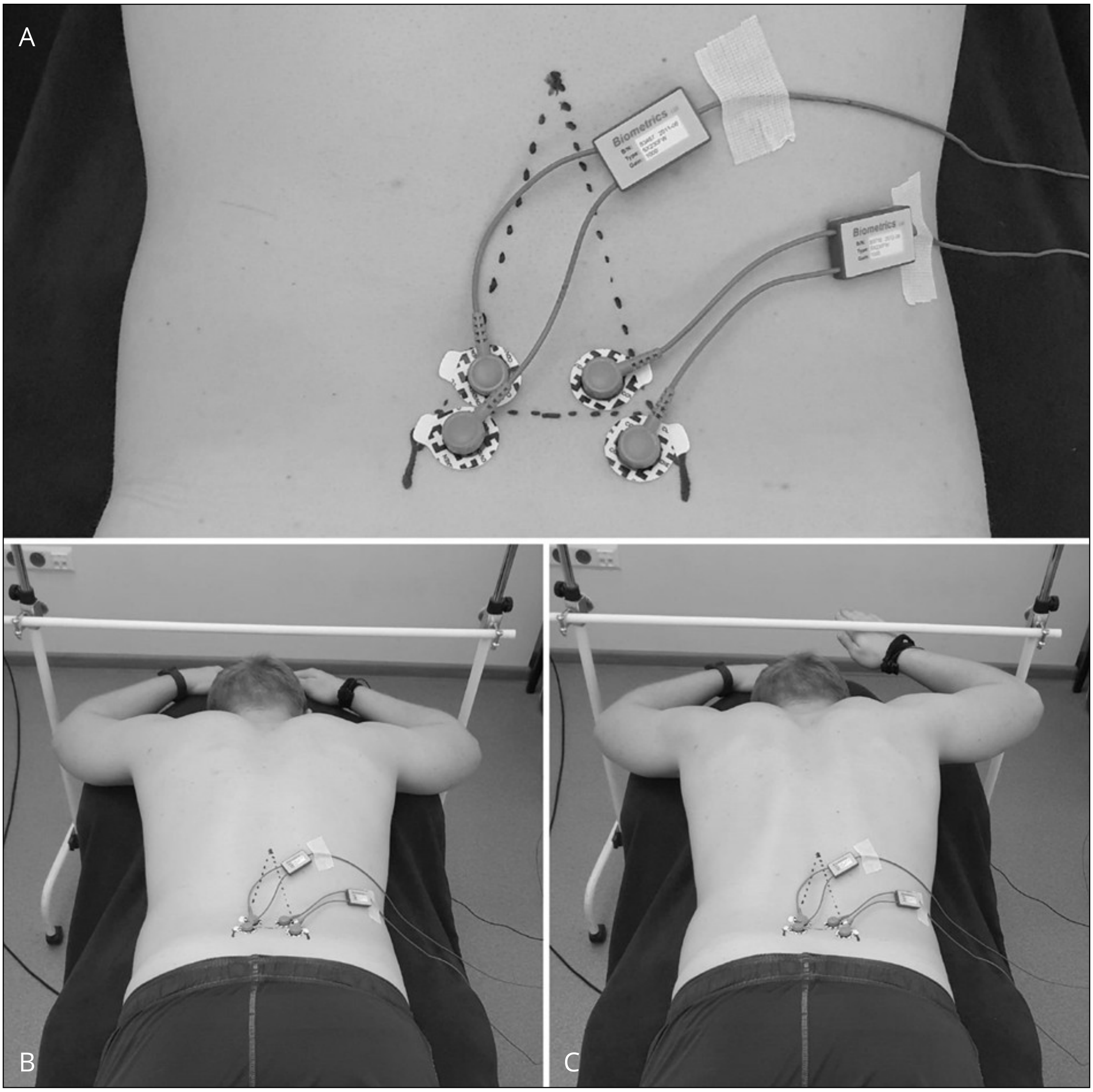

Fig. 1. Experimental setup: EMG electrodes placement (A) and subject position before (B) and during the single arm lift (C).

to lift their extremity straight up off of the table till the dorsal surface of the hand touched the bar. During performing the SAL subjects were verbally led by examiner to stay relaxed in prone position (Phase-1), lift one upper extremity (Phase-2), hold it in this new position (Phase-3), return to starting position (Phase-4), and stay relaxed in prone position (Phase-5). Then, all phases were repeated with second upper extremity. Prior to testing the contraction of lumbar multifidus, all subjects received an initial explanation about procedure. Each phase lasted 3 seconds. The rhythm was controlled by audible feedback generated by an electronic metronome. Prior to measurements subjects performed practice trials to become familiarized with the procedure which were followed by 3 testing trials separated by 1-minute rest intervals. The sequence of which arm will be performed SAL as first was randomly chosen separately for all 3 trials.

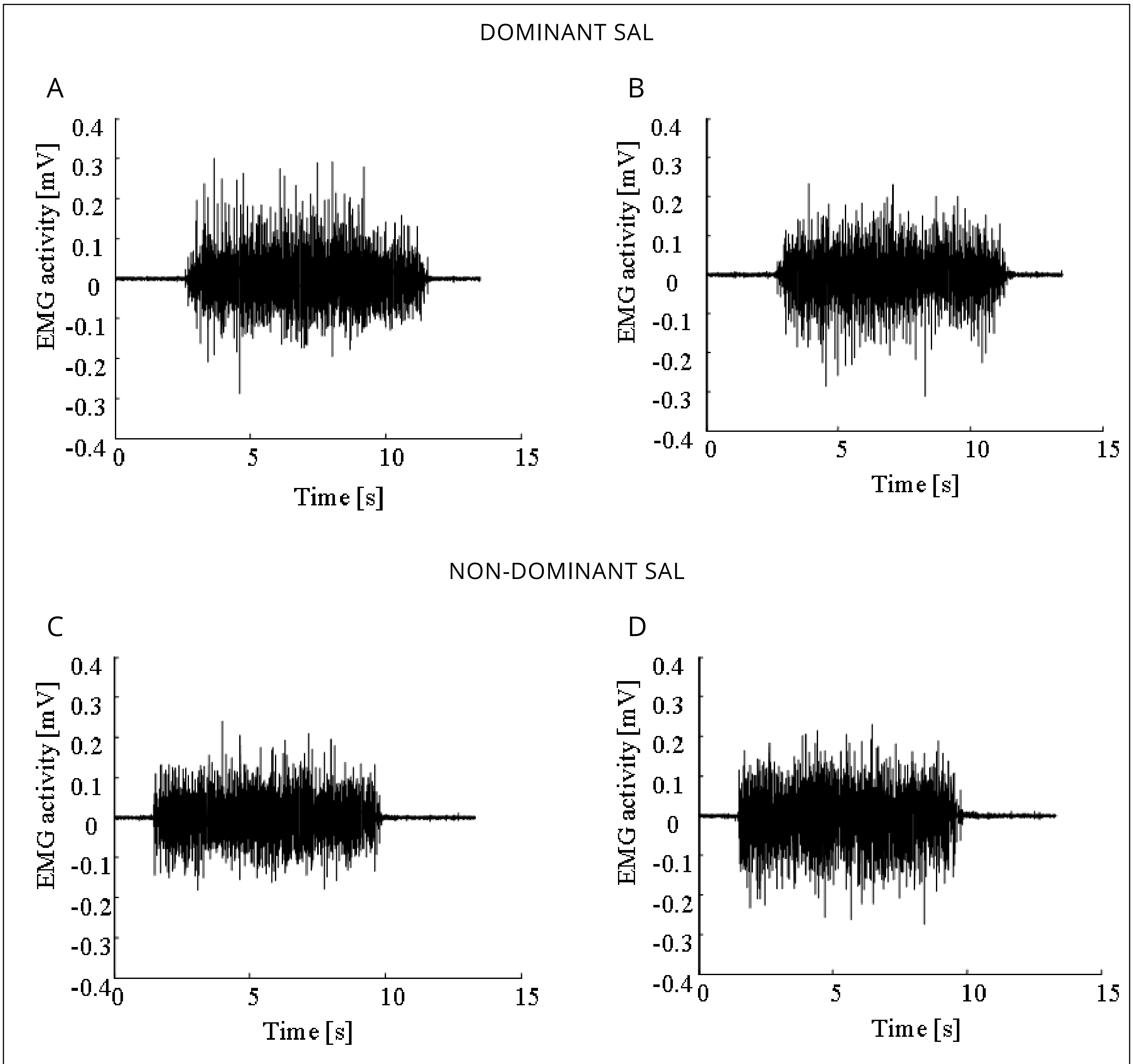

Fig. 2. Raw EMG signals for ipsilateral (A and C) and contralateral (B and D) lumbar multifidus of one of the subjects during the single arm lift.

Maximum voluntary isometric contraction testing

For testing the maximum voluntary isometric contraction (MVIC) force during upper trunk extension motion (Ekstrom et al., 2008; Okubo et al., 2010), subjects were positioned in the same prone lying position but with upper limbs parallel to the trunk. Therapeutic roller was placed under the distal part of shins and lower limbs were strapped over the ankles, knees and hips (Durmus et al., 2010). MVICs were performed 3 times under audible control of the metronome (3-seconds contraction, maintaining, and relaxation phases). Verbal encouragement was provided by the experimenter. During back extension MVIC force was measured with the force sensor strapped at the Th3 spinous process. Prior to measurements several submaximal trials were performed for familiarization.

Data management and analysis

Surface EMG signals were amplified (1000x, SX-230FW preamplifier, Biometrics LTD, Newport, UK), band-pass filtered between 20 and 450 Hz, transformed into digital integers (12 bit analogue-to-digital conversion) at a sampling frequency of 1 kHz (DLK900, Biometrics LTD, Newport, UK), and stored on PC in text format for off-line processing. In the middle of the SAL task which lasted 3 seconds, a 1-second window of surface EMG data of the right and left multifidus was identified in the middle of 3-second period of Phase-3 during SAL. Then software processing was performed by self-made algorithms written in MATLAB (the MathWorks Inc., Natick, MA) by applying low-pass (cut-off frequency 450 Hz) and high-pass (cut-off frequency 20 Hz) 4th order Butterworth filter. To remove QRS complex the 4th order Butterworth high-pass filter and cut-off frequency 60 Hz was applied in the segments of the signal (usually with duration of 1 s) where the ratio between the mean value of the signal and the peak of QRS was bigger than a given coefficient (usually chosen to be 2) (Raikova et al., 2011). The average root mean square (RMS) of rectified surface EMG signal was calculated within the above indicated 1-second time span and normalized to the mean RMS obtained during a 1-second time frame set at the middle portion of the maintaining phase of the highest- force MVIC trial. The clusters of 1024 points of rectified surface EMG data were then used to perform power spectral analysis using Fast Fourier Transform (FFT) and to calculate the five spike shape analysis (SSA) parameters. Power/frequency function was generated to calculate median power frequencies (MPF) according to Phinyomark et al. (2012) and spectral high-to- low ratio frequency domains for 20-100 Hz and 100-250 Hz ranges (Bradl et al., 2005). The parameter called high-to-low-ratio (HTLR) was derived by dividing the value of the upper range by the value of the lower range. Higher values of HTLR indicate shifting of frequencies towards higher power spectrum frequency ranges, whereas lower values of HTLR indicate lower frequency ranges in the spectrum. To perform spike shape analysis initially 100 ms duration period of resting muscle surface EMG data was manually chosen to minimize the noise in the signal (Gabriel et al., 2007) (Fig. 1). Then, five surface EMG spike shape analysis measures: MSA, MSF, MSD, MSS and MNPPS expressing MUs recruitment and rate coding were calculated in MATLAB using computer algorithms according to Gabriel et al. (2007).

Statistical analysis

The Shapiro-Wilk test was used to check the distribution of data. Variables of RMS, HTLR, MSA, MSF, MSD, MSS and MNPPS had data distributions different than normal. Therefore, all within and between the sides comparisons of dependent variables were first tested with the Friedman test and then using the Wilcoxon test. The variables of MdF were compared using the two-way ANOVA with the SAL side (dominant *vs.* non-dominant) and LM muscle (ipsilateral *vs.* contralateral) as factors. Significance level was set at $p<0.05$.

RESULTS

The enrolled subjects age was 29.19±7.08 years, height was 1.75±0.10 m, and BMI was 22.7±2.36 kg/m2. 27 of subjects were right-handed, and 19 were left-handed.

RMS EMG amplitude

A Friedman ANOVA test showed a significant effect of side of SAL on normalized RMS amplitude [$\chi^{2(3)}=13.96$, $p=0.003$]. When the dominant arm was lifted, the normalized RMS amplitude of the ipsilateral and contralateral LM did not differ (Table 2, horizontal comparisons). When the SAL was performed with the non-dominant arm the normalized RMS amplitude of the contralateral LM (dominant side) was greater than the ipsilateral LM (non-dominant side). Furthermore, the normalized RMS amplitude of LM at the dominant as well as at the non-dominant side was greater when it was activated contralaterally than ipsilaterally with respect to the lifted arm (Table 2, diagonal comparisons). No differences were noted in the surface EMG amplitudes between the contralateral as well as ipsilateral actions of LM muscles when SAL was performed with the dominant and non-dominant upper limb (Table 2, vertical comparisons).

Power frequency spectrum

The two-way ANOVA revealed a significant interaction for LM median frequency between upper limb sides and muscle [$F_{(1,180)}=46.54$, $p<0.001$] with no main effect of the side of SAL [$F_{(1,180)}=0.001$, $p<0.982$] and muscle [$F_{(1,180)}=0.001$, $p=0.981$]. A Friedman test indicated no effect of the side of SAL on LM HTLR [$\chi^{2(3)}=3.49$, $p=0.321$]. In the dominant LM the MdF values were lower than in the non-dominant LM either between the SAL sides (dominant *vs.* non-dominant) and muscles (contralateral *vs.* ipsilateral). In the non-dominant LM the HTLR values were not different than in the dominant LM either for comparisons made between the SAL sides (dominant *vs.* non-dominant) and muscles (contralateral *vs.* ipsilateral) (Table 2). HTLR values indicate that there was no shift of frequencies towards lower or upper power spectrum ranges.

Table 2. EMG amplitude and power spectrum measures of lumbar multifidus during single arm movements.

	RMS (%)			MdF (Hz)		HTLR	
	Ips-LM	Con-LM	*p*	Ips-LM	Con-LM	Ips-LM	Con-LM
n	46	46		46	46	46	46
			<0.001^{a}				
d-SAL	17.1±6.8^{d}	18.4±9.2nd	0.164	131.6±23.1^{d}	155.6±22.1nd	2.39±0.38^{d}	2.44±0.26nd
nd-SAL	15.4±8.1nd	20.0±11.8^{d}	0.000	155.5±25.3nd	131.7±24.3^{d}	2.51±0.35nd	2.40±0.29^{d}
p	0.080	0.596	0.028^{b}				

Data are presented as means ± standard deviations. The most upper and lower p values are for comparisons made diagonally for the same LM muscle actions, i.e. dominant or non-dominant. RMS: root mean square (% of maximum voluntary isometric contraction), MdF: median frequency, HTLR: high-to-low-ratio, Con-LM: contralateral lumbar multifidus, Ips-LM: ipsilateral lumbar multifidus, nd-SAL: non-dominant single arm lift; d-SAL: dominant single arm lift, ^{a}: comparison between the non-dominant LM during different SAL, ^{b}: comparison between the dominant LM. ^{d}: dominant side, nd: non-dominant side. Wilcoxon paired test was used for the statistical comparisons of RMS values. For the MdF two-way ANOVA did show the effect of interaction between the SAL (dominant *vs.* non-dominant) and LM muscles (ips *vs.* con).

Spike shape parameters

A Friedman ANOVA test revealed a significant effect of side of SAL on LM MSA [$\chi^{2(3)}$=62.24, p<0.001], MSF [$\chi^{2(3)}$=58.71, p<0.001], MSD [$\chi^{2(3)}$=71.64, p<0.001], MSS [$\chi^{2(3)}$=35.32, p<0.001] and MNPPS [$\chi^{2(3)}$=46.20, p<0.001] values. The MSA and MSS as well as MSD and MNPPS values where greater while MSF were lower for the dominant than non-dominant LM action irrespectively the arm lifted (dominant or non-dominant, Table 3, horizontal and vertical comparisons). Moreover, the values of MSA and MSS for LM at the dominant as well as at non-dominant side where greater when it was activated contralaterally than ipsilaterally with respect to the lifted arm (Table 3, diagonal comparisons).

Table 3. Spike shape measures of lumbar multifidus during single arm movements.

Activity	MSA (mV)			MSF (Hz)			MSD (ms)			MSS (mV/ms)			MNPPS		
	Ips-LM	Con-LM	*p*	Ips-LM	Con-LM	*p*	Ips-LM	Con-LM	*p*	Ips-LM	Con-LM	*p*	Ips-LM	Con-LM	*p*
n	46	46		46	46		46	46		46	46		46	46	
			0.013^{a}			0.266^{a}			0.666^{a}			0.023^{a}			0.142^{a}
d-SAL	0.053±0.033^{d}	0.040±0.029nd	<0.001	140.2±24.2^{d}	162.4±24.5nd	<0.001	5.8±.0.7^{d}	4.9±0.8nd	<0.001	21.5±13.4^{d}	19.2±13.0nd	0.027	1.4±0.1^{d}	1.3±0.1nd	<0.001
nd-SAL	0.036±0.029nd	0.063±0.047^{d}	<0.001	159.7±27.1nd	140.4±22.1^{d}	<0.001	4.9±0.8nd	5.8±0.8^{d}	<0.001	17.3±13.9nd	25.5±18.8^{d}	<0.001	1.3±0.1nd	1.4±0.1^{d}	<0.001
p	<0.001	<0.001	0.023^{b}	<0.001	<0.001	0.883^{b}	<0.001	<0.001	0.502^{b}	<0.001	<0.001	0.019^{b}	<0.001	<0.001	0.952^{b}

Data are presented as means ± standard deviations. The most upper and lower *p* values are for comparisons made diagonally for the same LM muscle actions, i.e., dominant or non-dominant. MSA: mean spike amplitude, MSF: mean spike frequency, MSD: mean spike duration, MSS: mean spike slope, MNPPS: mean number of peaks per spike in motor unit firing and recruitment, Con-LM: contralateral lumbar multifidus, Ips-LM: ipsilateral lumbar multifidus, nd-SAL: non-dominant single arm lift; d-SAL: dominant single arm lift, ^{a}: comparison between the non-dominant LM during different SAL, ^{b}: comparison between the dominant LM, ^{d}: dominant side, nd: non-dominant side. Wilcoxon paired test was used for the statistical comparisons.

DISCUSSION

The aim of the study was to verify if there are any changes in surface LM EMG signal between the sides of the body grouped according to handedness. Oppositely to what was expected, it was found (Table 1, lowest row) that based on the combined direction of changes in various spike shape measures, the LM of the dominant side is characterized by increased recruitment, lower firing rates and higher synchronization of motor units as compared to its counterpart.

Lumbar multifidus functional behavior during a single arm lift

The conventional measure of the normalized EMG amplitude (RMS) indicated, that when non-dominant arm was lifted, the LM muscles at both sides were co-activated, but the muscle at the contralateral side to the lifted arm exhibited higher EMG amplitudes than the muscle at the ipsilateral side. The MSA and MSS values, as the EMG amplitudes were always higher in the LM of the dominant and non-dominant side when these muscles performed contralateral than ipsilateral actions with respect to the lifted arm. The MdF and MSF values were higher in the contralateral LM when the dominant arm was lifted, whereas the reverse order was present when the non-dominant arm was lifted. However, no differences in these measures were found when the LM muscles of dominant and non-dominant sides performed contralateral or ipsilateral actions. Butler et al. (2009a) have observed higher EMG amplitudes in the LM contralateral as compared to the ipsilateral muscle for different variants of asymmetric lifting activities with dominant and dominant hands. Such pattern also very well reflects the cortical control of upper limb movements. For instance it has been shown that during unimanual actions, the drive from one primary sensorimotor cortex to the other is greater during movement of the contralateral as opposed to ipsilateral hand (Daneels et al., 2001; Serrien et al., 2003). On the other hand, the conventional RMS values were the same for both LM muscles when the dominant arm was lifted, although the spike shape amplitude measures did show the contralateral asymmetry in LM activation. Accordingly, no asymmetries in the activity of LM during lifting and lowering movements of dominant and non-dominant upper limbs were found based on the conventional EMG amplitude measurements in the other study on handedness (Daneels et al., 2001). Nevertheless, the RMS and median power frequency of the surface EMG signal do not well express MU control properties such as recruitment or firing rates across the muscle contraction (Christie et al., 2009). Conversely, the MSA and MSS values are more sensitive to changes in EMG amplitude than RMS at submaximal (<50% MVC) force levels (Green et al., 2017) and MSF spike variable is more sensitive to changes in force than mean power frequency (Gabriel et al., 2011). The MSS is a measure that has been supposed to reflect the recruitment of higher-threshold MUs as their action potentials have greater amplitudes and slopes than lower-threshold MUs (Komi & Vitasalo, 1976). During weak voluntary muscle contractions MU recruitment is the dominant process but change in MU rate-coding also take place continuously with the gradation of muscle force (De Luca & Hostage, 2010). Therefore, it has been proposed that to distinguish MU activity patterns changes in all five spike shape parameters must be taken together into account (Gabriel et al., 2007) (see Table 1). In the present study subjects had to lift the upper limb from the plinth and hence were subjected to control the force output related to limb heaviness. To match the target force, control mechanisms of muscle contraction are designed to optimize the relationship between force production and duration of MU activity (De Luca et al., 1982; De Luca & Contessa, 2015). Our results seem to confirm previous findings which showed, that recruitment of new MUs from inactivity to tonic discharge during LM contractions proceed without changes in discharge rate in already active MUs (Lothe et al., 2015). Therefore, as the contralateral muscle, LM was presumably activated more intensively than as the ipsilateral muscle due to recruitment of greater number of MUs rather than a relevant increase in firing frequency of initially activated units during SAL.

Life-long functional adjustments of LM due to handedness

The measured spike amplitudes (MSA), slopes (MSS) and number of peaks per spike (MNPPS) EMG values were always greater in the muscle of the dominant as compared to the non-dominant side of the body for the same LM actions (contralateral and ipsilateral) during SAL. Surface EMG is able to detect the activity of enlarged MUs (Roeleveld et al., 1998) and action potential amplitude is positively related to muscle fiber size of parent MUs (Norris & Gasteiger, 1955; Hakansson, 1956). We suppose that greater spike amplitudes and slopes indicate that MUs recruited in LM of the dominant side generated action potentials which had higher amplitudes that in the muscle of the non-dominant side. Different types of increased physical activity induce different structural and functional adjustments in the neuromuscular system. For example long-term resistance training increases muscle size, due to increase in muscle fiber diameter, and this is accompanied by the increase in motor unit action potential (Jenkins et al., 2021) and absolute EMG amplitudes (Škarabot et al., 2021). On the other hand, muscle fiber diameter decreases with very long-term endurance training (Trappe et al., 1995; 2006). We suppose that LM of the dominant side possesses larger muscle fibers, at least in slow MUs, as these were probably activated during low intensity contractions evoked by SAL, than the muscle of non-dominant side. It is known, that asymptomatic subjects have asymmetries in LM CSA at L5–S1 with a larger muscle at the dominant side in the majority of people (Fortin et al., 2013). Moreover, among other studied factors, handedness is the only one relevantly associated with this LM size asymmetry (Fortin et al., 2013). This is in line with what was found in the past in limb muscles (Fugl-Meyer et al., 1982).

The MdF and MSF were significantly lower and MSD longer in LM of the dominant as compared to the non-dominant side during the same muscle actions. The frequency content of the surface EMG signal and median frequency increase linearly with progressive recruitment of higher-threshold MUs with faster conduction velocities of their muscle fibers (Moritani & Muro, 1987; Solomonow et al., 1990; Sbriccoli et al., 2003). This occurs regardless of firing frequency of action potential in MU, as with increase in discharge rate the median frequency is nearly constant (Solomonow et al., 1990). This presumably transfers to the observation that during SAL slower MUs were activated in LM of the dominant side while faster in muscle of the non-dominant side. The power spectrum frequency range is lower for muscle fibers innervated by slow than fast MUs (Wakeling & Syme, 2002), and median power frequency decreases with increase in proportion of type I muscle fibers within the muscle (Solomonow et al., 1990).

The chosen SAL task produced relatively low average activation (root mean square EMG amplitude) in the contralateral (18-20%) and ipsilateral (15-17%) LM with respect to the MVIC. Our physiological data suggest, that in the LM muscle of dominant side greater proportion of slower MUs with enlarged muscle fibers was activated with SAL than in the muscle of non- dominant side. Unfortunately, there is no single study in which muscle type content and size would be verified in the LM of dominant and non-dominant sides (Cagnie et al., 2015) to support our assumption based on the detected differences in spike measures. Based on the changes in each of the five measures, which were detected in the present study (Table 1 – theoretical SEMG spike measure behavior), it looks like in LM of the dominant side the recruitment of MUs was increased (changes in 3 out of 5 spike measures were as predicted theoretically), MUs exhibited higher rates of synchronization (changes in 4 out of 5 spike measures were as predicted theoretically) and worked at lower firing rates (all changes in spike measures were as predicted theoretically) as compared to the LM of the non-dominant side. Accordingly, similar MU control properties manifested by the reduced recruitment threshold and firing rates (initial and average) at the target level of force were previously reported in muscles located in the dominant hand (Adam et al., 1988).

Function of LM

The anatomical uniqueness of the LM, which includes attachments and architecture of different layers, also supports the significant role of LM in control and stabilization of the lumbar spine in multiple planes (Lonnemann et al., 2008). However, it seems that specific everyday activities performed with the preferred and non-preferred upper and lower limbs induce differential and body side specific anatomic and physiological responses in back muscle structure and function (Merletti et al., 1994). Although in the symmetrical lower limb postures, the asymmetrical movements of upper limbs result in higher activation of contralateral muscles of the lower back (Butler, 2009a), it is not known how exactly forces resulting from the upper and lower limb use are transferred to the lumbar spine during wide spectrum of daily, recreational and labor activities. The recruited participants were living in urban areas and were generally involved in desk jobs (students and university office workers). In able bodied humans, the periods of use of the dominant arm are longer than the non-dominant arm during standing and sitting postures but not walking, with the former 15-25% more active than the latter (Coley et al., 2008). Data show that the dominant upper-limb is used about 19% more in the daily activities at the waist to head range than the non-dominant upper-limb, while the greatest activity period is spent in the waist to chest range (Vega-Gonzales & Granat, 2003). However, how the activity of the dominant upper limb, which is optimized to precisely control the hand movements, and the non- dominant limb which is optimized to control steady state postures affect LM activity transfers to the activity of both LMs is unknown (Przybyła et al., 2012). Furthermore, it is not known what are the differences in physical activity volumes related to handedness. Dominant limb may exert large, brief forces while non-dominant may act isometrically spanning longer periods to maintain loads in the hand either during work, recreational or daily activities. This is important as motor unit control strategies are changed differently with specific types of increased activity. For instance in the resistance trained individuals the firing rates of MUs are increased but too much lesser extent than in the endurance trained athletes, and there are differences in motor unit excitability (Herda et al., 2015) and synchronization (Milner-Brown et al., 1975). Finally, nothing is known how the activity and postures (symmetrical or in contra post) of lower limbs, directional frequency of trunk rotations, and dynamic asymmetries in lumbar and pelvic skeleton during various activities, which are presumably related to one side dominance affect structure and function of LM muscles.

Limitations

The results of the present study must be interpreted with the regard of limitations of surface EMG signal recordings. First, it is known for some time that accurate measurement of multifidus muscle activity requires intra-muscular electrodes, because surface electrodes placed over the LM muscle at L2-L4 vertebral level may be more sensitive to the adjacent longissimus muscle than LM itself (Stokes et al., 2003). It should be born in mind that there is possibility that the recorded signal over LM might be contaminated with electrical activity from adjacent muscles. However, in this study we applied the electrodes with low interelectrode distance, 2 cm laterally to the level of L5 spinous process and used SAL to record low activation levels of the muscle. This assured that the cross talk from adjacent erector spinae was negligible (Hofste et al., 2020). Moreover, it seems that spike shape measures may be less prone to noise signal coming from other simultaneously active muscles than the conventional EMG measures and more sensitive in detection of specific differences in structural and functional adjustments induced in response to altered physical activity. Second, in the present study we used only the weight of upper limb without gradually increasing resistance to activate the muscle, since we were focused on assessing the task, which is more functionally related to movements performed during daily activities. It seems that right-handed individuals have larger right than left hands, while left-handers have hands nearly symmetrical (Purves et al., 1994). However, the total arm masses of the dominant and non-dominant upper limbs are not significantly different in men and women (Gutnik et al., 2015). Therefore, we do not suppose that relative loads were different during SAL performed with either arm. Furthermore, we did not measure muscle cross- sectional area. Therefore, we are unable to indicate if there were any differences in size of both studied muscles. This could potentially facilitate better understanding of the present study findings. Finally, critique may come due to the method of MVIC assessment, which could underestimate true maximum voluntary muscle activation and overestimate muscle activation. However, this method has been frequently used (Ekstrom et al., 2008; Okubo et al., 2010), we obtained similar values as previously (Kiesel et al., 2007), and there is no single optimal method to assess trunk extensor muscle performance using more advanced tools (Demoulin et al., 2012).

CONCLUSION

It can be hypothesized that handedness is accompanied by changes in MU control properties manifested by increased recruitment, lower firing rates and higher synchronization of motor units in the LM of dominant as compared to the non-dominant side. Asymmetry in LM size has been linked with the chronic low back pain (Hides et al., 2008), however a causative relationship between both these factors is still unclear. It may be that to unravel potential changes in asymmetry in LM structure and function, grouping of pain with the assignment to the dominant or non-dominant side of the body could potentially provide novel information in subjects with chronic low back pain. Spike shape analysis of surface EMG seems to be more sensitive and precise in analysis of motor control strategies of skeletal muscles than conventional amplitude and frequency measures. This can useful in detecting neuromuscular adjustments in response to various forms of therapeutic exercises and physical training.

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