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## DIAGNOSTICS

# Intramuscular EMG Versus Surface EMG of Lumbar Multifidus and Erector Spinae in Healthy Participants

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**Study Design.** Cross-sectional design.

**Objective.** The aim of this study was to investigate the correlation between intramuscular EMG (iEMG) and surface EMG (sEMG) from lumbar multifidus and erector spinae muscles during (submaximal) voluntary contraction tests in healthy participants.

**Summary of Background Data.** Low back muscle function is a key component in the stability of the lumbar spine in which an important role is attributed to the lumbar multifidus (LM). Impairments in this stabilization system are held responsible for (chronic) low back pain. LM function can be measured by iEMG and sEMG; however, in earlier studies, results from iEMG and sEMG were inconsistent.

**Methods.** Fifteen healthy adults were included. The intervention consisted of five clinical tests: resting, submaximal contraction tests of the lower back, abdominal contraction, and a biofeedback test in which LM and erector spinae (ES) activities were compared

by iEMG and sEMG. Correlations were calculated with regard to original signal, co-contraction ratio, and cross-talk ratio. Correlation coefficients for each combination of iEMG and sEMG signals were calculated, to identify original signal (i.e., activity of only the targeted muscle) and possible cross-talk. Correlations  $>0.75$  were considered as good concurrent validity.

**Results.** The original signals of LM showed fair to high correlation coefficients ( $r$ : 0.3–0.8). Co-contraction of LM and ES was observed during all tests, but iEMG shows more variation in the correlations ( $r$ : 0.1–0.8) compared to sEMG ( $r$ : 0.3–0.8). Significant cross-talk was observed in all tests, particularly during the biofeedback test of iEMG<sub>ES</sub> versus sEMG<sub>LM</sub> and iEMG<sub>LM</sub> versus sEMG<sub>ES</sub> ( $r = 0.8$ ).

**Conclusion.** Surface EMG of ES and LM are no adequate representation of LM and ES activity measured by iEMG because of moderate/high cross-talk and co-contractions. Clinical tests that aim to assess LM activity do not represent isolated LM activity. This should be taken into account in future clinical studies.

**Key words:** electromyography, erector spinae, healthy participants, intramuscular electromyography, low back muscles, low back pain, lumbosacral region, multifidus, paraspinal muscles, surface electromyography.

**Level of Evidence:** 3

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Low back pain (LBP) is a common disorder worldwide and occurs in all age groups.<sup>1</sup> Worldwide, LBP is the highest ranking impairment on the “years lived with disability” list of 289 included impairments.<sup>2</sup> LBP results in significant levels of disability and restrictions in daily life activities, such as the inability to work.<sup>1,3</sup> In 85% of LBP the cause can be considered as nonspecific LBP (nLBP).<sup>4,5</sup> Theoretically, low back muscle function is a key component in the stability of the lumbar spine, and LBP has been described as an effect of impairments in this stabilization system.<sup>6</sup> An important muscle of this stabilizing system is considered to be the lumbar multifidus (LM), which contribution of LM has been debated previously.<sup>7–9</sup> Several

methods (*i.e.*, magnetic resonance imaging, computed tomography, ultrasound, electromyography (EMG) and 3D kinematics) have been applied to measure the LM function in individual LBP patients.<sup>10–16</sup> The knowledge of functionality and morphology of low back muscles gave rise to clinical tests to separately measure LM and erector spinae (ES) activity in nLBP patients.<sup>14,17,18</sup>

To validate the placement of the surface electrodes, the surface EMG (sEMG) signal should be compared with intramuscular EMG (iEMG) signal. In earlier studies, in which iEMG and sEMG of the LM were compared, results were nonequivocal.<sup>19,20</sup> To standardize sEMG research protocols, it is important to know to what extent LM and ES EMG is reflected by the surface electrodes. In this way, the original signal, that is, activity of only the targeted muscle, cross-talk (*i.e.*, recording EMG activity of nontargeted muscles) and co-contraction (*i.e.*, simultaneous contraction of adjacent muscles) can be quantified.<sup>21,22</sup> In 1999, European recommendations for sEMG (SENIAM; Surface ElectroMyoGraphy for the Non-Invasive Assessment of Muscle) were published, that attempted to standardize sensor placement properties and the authors published a practical guideline for the proper use of sEMG.<sup>23</sup> These sEMG sensor locations are validated by a literature scan of a large number of European publications on sEMG.<sup>23</sup> However, these recommendations and guideline have not been validated using iEMG. Up to now, validity and reliability of clinical tests for measuring selective low back muscles (without cross-talk) are unclear due to lack of sEMG sensor standardization. Therefore, the first step is to investigate iEMG and sEMG from LM and ES during different (submaximal) voluntary contraction tests in healthy participants.

Within this context, the research questions in this article are:

1. What are the correlations between iEMG and sEMG from LM and ES during different (submaximal) voluntary contraction tests to determine: the correlation between iEMG and sEMG from LM and ES to measure original signal; co-contraction and; cross-talk?
2. Is it possible to activate LM and ES selectively?

## MATERIALS AND METHODS

### Design

Cross-sectional design.

### Participants

Healthy subjects were recruited from social networks in the Northern and Eastern part of the Netherlands. Motivated subjects between 18 and 65 years were included. Exclusion criteria were nLBP, presence of red flags, lumbosacral radicular syndrome, pregnancy, previous back surgery, psychiatric diagnosis, insufficient knowledge of the Dutch language, and a body mass index >30. The participants were informed about the purpose and protocol of the study before they were

asked to sign informed consent. After participation, the participants got a €15 voucher. The study was approved by the Medical Ethics Committee of the University Medical Center Groningen in the Netherlands (NL58616.042.16).

### Procedure

After enrolment all patients were invited at the department of clinical neurophysiology of the University Medical Center Groningen to perform the measurements. Participants were instructed to take a prone position over a small pillow that was applied during all tests to decrease lordosis and increase comfort. Frequently used clinical tests were used to demonstrate the concept of creating LM muscle activity only (“abdominal muscle test” [ABD-test] and “biofeedback test” [BIOFEEDBACK-test]), combined ES and LM muscle activity (“contralateral arm lift test” [CAL-test] and “contralateral arm lift and ipsilateral leg lift test” [CALIL-test]) and no activity (resting [REST-test]).

Participants performed five tests during the EMG measurements:

- REST-test: A resting recording was obtained. The participant had to relax for 15 seconds and was not allowed to talk.
- CAL-test: A submaximal contraction task involving a contralateral arm lift (regarding to the iEMG and sEMG electrodes) was performed. The participant had to flex the arm to approximately 120° and flex the elbow to approximately 90°, the participant was instructed to raise the contralateral arm toward the ceiling approximately 5 cm.<sup>15</sup> The participant had to keep this position for 15 seconds.
- FEEDBACK-test: A biofeedback test was performed, to try to demonstrate a voluntary contraction of LM to create more differences in muscle contraction between LM and ES. During the test, the participant had to focus at the 2 iEMG signals that were live presented at the screen in front of the patient. The participant was instructed to perform a voluntary movement with arms, pelvic, legs, and/or head while he/she had to lie in prone position. In addition, the participant was instructed that the goal of these movements is to create higher amplitudes at signal one (iEMG LM) and create as low as possible amplitude at signal two (iEMG ES) to create an individual LM contraction. The participant got direct visual feedback to influence the signal and of the amount of muscle contraction from the screen in the front. In addition, the participant was not instructed which signal was connected with LM or ES. This test had a duration of 60 seconds.
- ABD-test: Participants contracted their abdominal muscles by pulling back their navel in prone position. The participant was asked to hold this contraction for 15 seconds.<sup>24</sup>
- CALIL-test: A submaximal contraction task involving a CAL-test with an ipsilateral leg lift (regarding to the electrodes) was instructed. The participant was

asked to stay in prone position and to keep this contraction for 15 seconds.<sup>25</sup>

When the surface and needle electrodes were positioned and fixed, the participants were allowed to practice the tests, until they performed as intended before EMG signals were recorded. Each test was performed once, if EMG signals were recorded correctly. Participants were allowed to take rest, for which they asked, between the tests.

## Measurements

### Intramuscular EMG

The locations of the needle electrodes were determined with the use of ultrasound imaging (Figure 1). Monopolar needle electrodes were used to measure iEMG (Ambu Neuroline Monopolar 38 × 0.36 mm; 1.5" × 28G). Under ultrasound guidance, the needle electrodes were inserted ± 2 cm lateral to L1 spinous process into the ES and ± 2 cm lateral to L5-S1 spinous process into the LM (Figure 1).

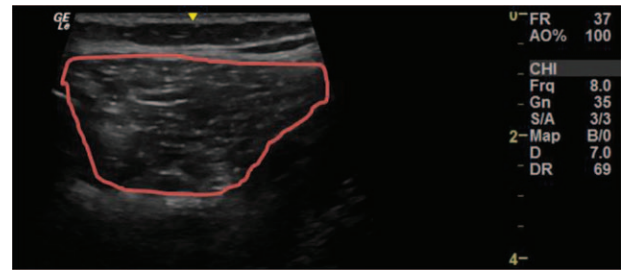
### Surface EMG

Surface electrodes were attached to the skin after the skin was shaved and cleaned (alcohol 70%) and were used to measure bipolar sEMG (3.2 × 2.2 cm Ag/AgCl 3 M Red Dot™ ECG electrodes, 3 M Health Care Infection Prevention Division at St. Paul in USA). Pairs of surface electrodes were attached to the skin above ES and LM muscle and parallel to the muscle fibres. Placement of the sEMG electrode for ES (sEMG<sub>ES</sub>, Figure 2A and B) was done according to the Seniam guidelines.<sup>23</sup> For measuring LM activity, 2 sEMG positions were used (Figure 2): sEMG<sub>LM-1</sub> (according to the Seniam guidelines)<sup>23</sup> and sEMG<sub>LM-2</sub> (mediocaudal to the Seniam LM location, ± 2 cm lateral to L5-S1 spinous process). sEMG<sub>LM-2</sub> was added, since at level L5-S1 LM has its widest diameter and most superficial location.<sup>26</sup> A ground electrode was placed over the ilium. All electrodes were placed at one side of the participants (Figure 2).

## Data Analysis

### EMG Data Analysis

The intramuscular (independent variable) and surface (dependent variable) electrodes were connected to a Natus Nicolet AT2+6 amplifier (Natus Medical Incorporated at Pleasanton in USA), where all signals were amplified. The



**Figure 1.** Ultrasound image of the lumbar multifidus, to determine location of lumbar multifidus. Red line showed cross-sectional area of lumbar multifidus.

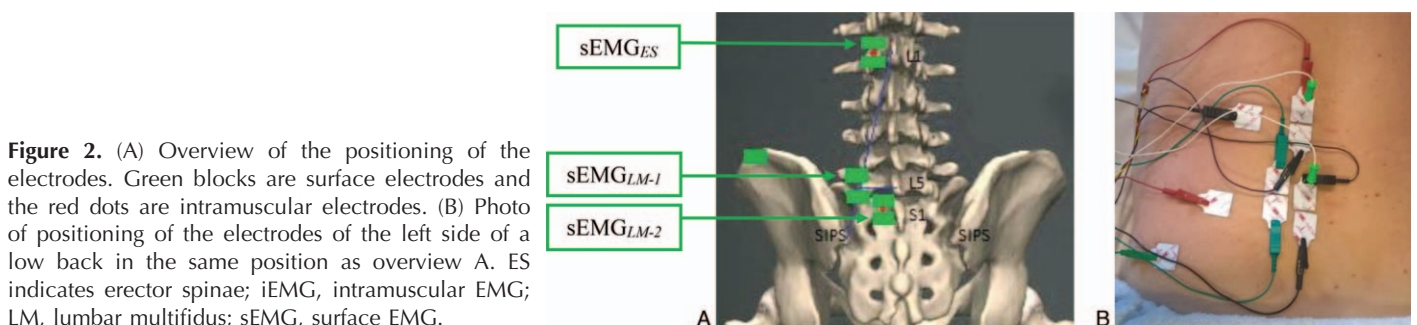
needle and surface EMG signals were processed with Synergy On Nicolet EDX System software (Middleton in USA), with a sample frequency of 44.1 kHz.

The root-mean square (RMS) value is calculated for each signal before the normalization step. Only the cross-correlation of electrodes that have high RMS (RMS > 10) values was used for the analysis. To compare the data from the different sources, the following preprocessing steps were performed. To prevent aliasing effects for the downsampled signal, the signal was first filtered using a low pass filter of 400 Hz. Next, the raw data were down sampled to 1000 Hz. Then, a notch filter of 50 Hz was applied to counteract influences from the power network. Next, all signals were normalized to unit variance and zero mean. Finally, the signal envelopes were calculated using window size of 293 milliseconds.<sup>23</sup> The cross-correlations of signals were calculated using the resulting envelopes. These data analysis steps were applied for all measured signals of all tests in this study.

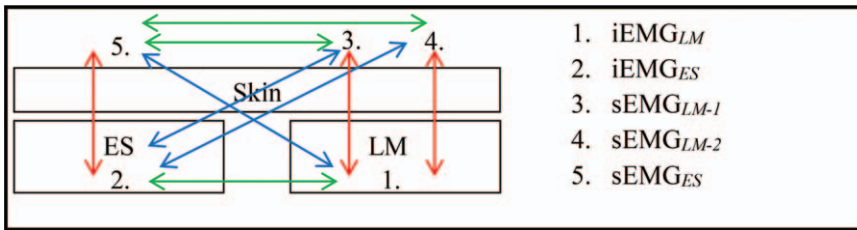
### Data Correlation Analysis

Correlation coefficients for each combination of intramuscular and surface electrode signals were calculated to identify original signal, cross-talk, and co-contraction (Figure 3). In Figure 3, a schematic overview of each combination of iEMG and sEMG signals is shown. Three groups of comparisons could be done: original signals (red arrows); cross-talk (green arrows); and co-contraction (blue arrows). These signals were calculated during the whole tests.

To test whether it is possible to activate LM and ES selectively in an attempt to minimize co-contraction, the biofeedback test (test 4) was performed. Therefore, we isolated these periods of LM activity with as low as possible



**Figure 2.** (A) Overview of the positioning of the electrodes. Green blocks are surface electrodes and the red dots are intramuscular electrodes. (B) Photo of positioning of the electrodes of the left side of a low back in the same position as overview A. ES indicates erector spinae; iEMG, intramuscular EMG; LM, lumbar multifidus; sEMG, surface EMG.



**Figure 3.** Schematic overview of the different options to compare EMG signals. Red arrows (original signals):  $iEMG_{LM}$  vs.  $sEMG_{LM-1}$ ,  $iEMG_{LM}$  vs.  $sEMG_{LM-2}$ ,  $iEMG_{ES}$  vs.  $sEMG_{ES}$ . Blue arrows (co-contraction):  $iEMG_{ES}$  vs.  $iEMG_{LM}$ ,  $sEMG_{ES}$  vs.  $sEMG_{LM-1}$ ,  $sEMG_{ES}$  vs.  $sEMG_{LM-2}$ . Green arrows (cross-talk):  $iEMG_{LM}$  vs.  $sEMG_{ES}$ ,  $iEMG_{ES}$  vs.  $sEMG_{LM-1}$ ,  $iEMG_{ES}$  vs.  $sEMG_{LM-2}$ . ES indicates erector spinae; iEMG, intramuscular EMG; LM, lumbar multifidus; sEMG, surface EMG.

ES activity (correlation of co-contraction lower than 0.20), in which we found higher LM RMS values compared to ES RMS values.

Correlation coefficients between EMG signals were interpreted as follows:<sup>27</sup>  $r \leq 0.25$ , low or no correlation;  $0.25 \leq r < 0.50$ , fair correlation;  $0.50 \leq r \leq 0.75$ , moderate to high correlation;  $r > 0.75$ , high to very high correlation.<sup>27</sup> A good test would mean correlations of direct signal  $>0.75$  and low to fair correlations  $<0.50$  of cross-talk and co-contraction.

**RESULTS**

**Participants**

In total, 15 healthy participants (11 women and 4 men) were included between 23 and 59 years’ old. Personal characteristics are presented in Table 1.

For each test and each electrode-comparison a correlation coefficient is calculated. Table 2 shows the correlation coefficients of original signals, co-contraction, and cross-talk.

**Original Signal**

Original signal is when intramuscular and surface EMG is measured of one muscle without measuring muscle activity from other muscles. The original signal had a large variation

between tests. During all tests, LM can be measured from fair to very good by surface electrodes ( $r$ : 0.3–0.8). ES can be measured from fair to very good by surface electrodes ( $r$ : 0.4–0.9). In the FEEDBACK-test, the surface electrodes of ES and LM showed the best representation of the intramuscular signals of the muscles ( $r$ : 0.6–0.9).

**Co-contraction**

Co-contraction is when two adjacent muscles are contracting similarly. In each test both the ES and LM are contracted at the same time ( $r \geq 0.1$ ); however, how often co-contraction took place varied between tests ( $r$ : 0.1–0.8). Intramuscular electrodes ( $r$ : 0.1–0.8) showed slightly more variation compared to the variation derived from surface electrodes ( $r$ : 0.3–0.8) over all tests for the lower values. Intramuscular electrodes’ comparison of LM and ES showed most co-contraction in the FEEDBACK-test ( $r = 0.8$ ). In the other tests, most co-contraction is found between surface electrodes LM method-1 and ES (CAL-test:  $r = 0.4$ ; ABD-test:  $r = 0.6$ ; CALILL-test:  $r = 0.3$ ) compared to intramuscular electrodes (CAL-test:  $r = 0.2$ ; ABD-test:  $r = 0.5$ ; CALILL-test:  $r = 0.1$ ).

**Cross-talk**

Cross-talk is a signal which may be erroneously interpreted as generated by muscle fibres near the detection electrode.

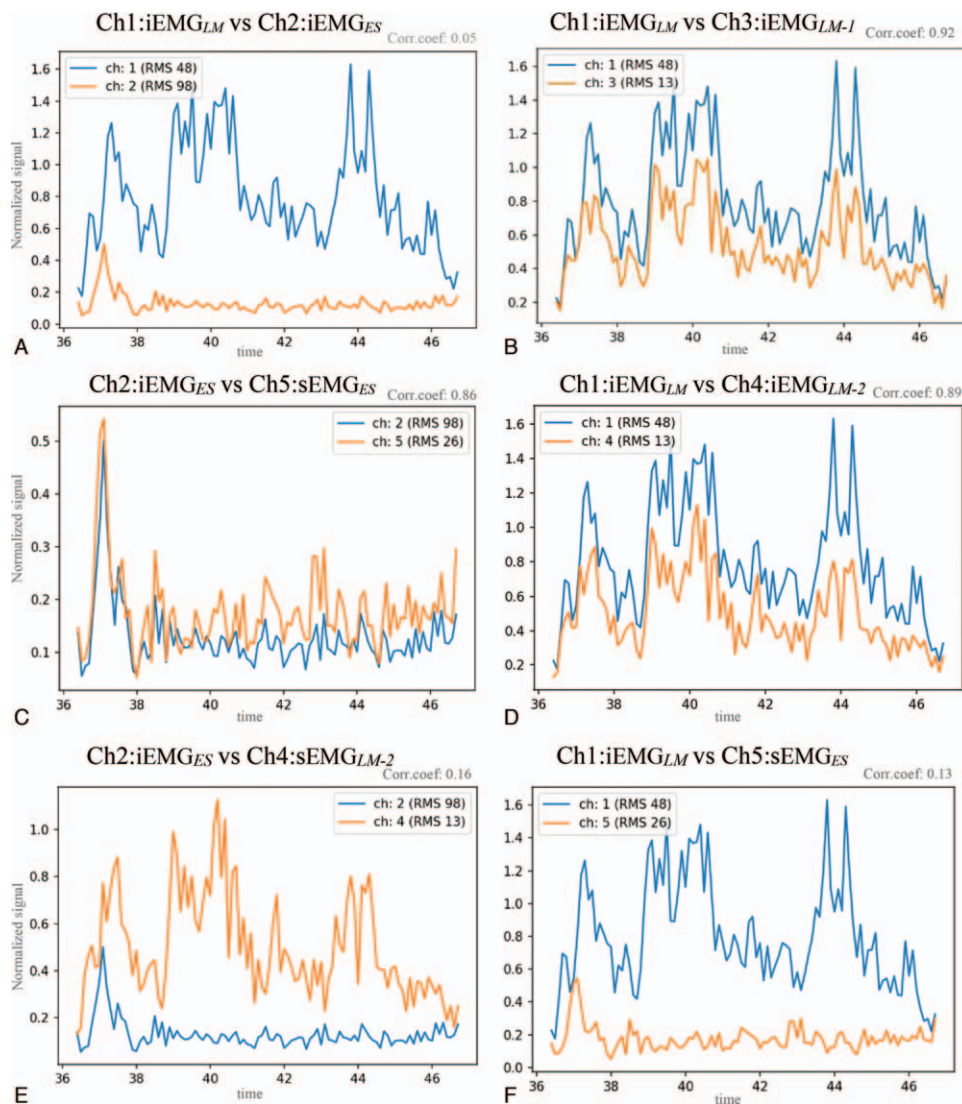
**TABLE 1. Descriptive Statistics of Included Participants (n=15).**

	Mean	Std. Deviation	Minimum	Maximum
Age, years	34	14	23	59
Height, cm	176	11	160	200
Weight, kg	74	16	55	105
Waist circumference, cm	90	8	75	105

**TABLE 2. Average Correlation Coefficient of 2 EMG Signals (x – x) (n = 15).**

Test	Original Signal ES (2–5)	Original Signal LM (1–4)	Original Signal LM (1–3)	Co-contraction (3–5)	Co-contraction (4–5)	Co-contraction (1–2)	Cross-talk (2–4)	Cross-talk (2–3)	Cross-talk (1–5)
CAL	0.4	0.4	0.3	0.4	0.3	0.2	0.2	0.4	0.2
FEEDBACK	0.9	0.8	0.6	0.6	0.8	0.8	0.8	0.6	0.8
ABD	0.6	0.6	0.6	0.6	0.6	0.5	0.6	0.6	0.4
CALILL	0.6	0.4	0.3	0.3	0.3	0.1	0.4	0.3	0.1

1 indicates intramuscular  $EMG_{LM}$ ; 2, intramuscular  $EMG_{ES}$ ; 3, surface  $EMG_{LM-1}$ ; 4, surface  $EMG_{LM-2}$ ; 5, surface  $EMG_{ES}$ ; ABD, abdominal contraction; CAL, contralateral arm lift; CALILL, ipsilateral leg and contralateral arm lift test; FEEDBACK, Biofeedback; LM, m. lumbar multifidus; ES, m. erector spinae.



**Figure 4.** Examples of EMG data of RMS values from original EMG signals comparing iEMGs of LM vs. ES (A), iEMG vs. sEMG of LM and ES (B-D) and iEMG of ES of LM (E), and iEMG of LM vs. sEMG of ES (F). The correlation coefficient is calculated for each comparison and noted in the sub-figures A–F. Ch indicates channel; Corr. coef, correlation coefficient; ES, erector spinae; LM, lumbar multifidus; RMS, root mean square.

The amount of cross-talk varied between tests, ranging from  $r = 0.1$  in the CALILL-test to  $r = 0.8$  in the FEEDBACK-test. The differences in correlation between the 2 surface electrodes of LM method-1 and method-2 had a maximum of  $r = 0.2$  in all test. In the ABD-test, a fair to moderate correlation was found for cross-talk (ES;  $r = 0.4$  and LM;  $r = 0.6$ ).

To test the second research question, original signal and cross-talk were measured when co-contraction was as low as possible ( $r < 0.2$ ) during the FEEDBACK-test. The criteria (intramuscular comparison between LM and ES:  $r < 0.20$  and higher LM RMS value compared to ES RMS value) are applied to all the 15 participants. A participant can have more than one time frame meeting the criteria with a duration of at least 1 second. Just 16 time frames of  $>1$  second recorded during the FEEDBACK-test could be selected meeting these criteria, see Appendix 1, <http://links.lww.com/BRS/B589>. In six of these 16 events, the RMS value of iEMG<sub>LM</sub> and iEMG<sub>ES</sub> was  $>10$ , which indicates a sufficient voltage of the signal. In addition to these six events, two events (Appendix 1, <http://links.lww.com/>

BRS/B589, C5 and C6) showed correlation coefficients of original signals (iEMG<sub>LM</sub> vs. sEMG<sub>LM</sub> and iEMG<sub>ES</sub> vs. sEMG<sub>ES</sub>)  $>0.6$  ( $r = 0.6–0.9$ ) and  $r < 0.4$  for cross-talk combinations ( $r = -0.1$  to  $0.4$ ).

One of the two events (the second event; E6 in Appendix 1, <http://links.lww.com/BRS/B589>) is shown in Figure 4 in which co-contraction was low ( $r = 0.05$ , Figure 4A. Ch1: iEMG<sub>LM</sub> vs. Ch2: iEMG<sub>ES</sub>) and LM showed more muscle activity compared to ES (see Appendix 1, <http://links.lww.com/BRS/B589>, E6: RMS values). In this event, the normalized intramuscular muscle activity of LM showed more activity compared to intramuscular ES muscle activity. Original signals of LM and ES are high to very high correlated ( $r > 0.75$ , Figure 4B–D). In addition, correlations of cross-talk combinations were low to absent ( $r = -0.13$ , Figure 4E and  $r = 0.16$ , Figure 4F). This example indicated more valid results to measure original signal and cross-talk without co-contraction in LM and ES; however, just two events of all the 15 included participants met all the criteria. Therefore, it is very uncommon to contract LM and ES muscle isolated.

## DISCUSSION

With this study, LM and ES muscle activity were measured by intramuscular and surface electrodes in healthy participant, to determine whether sEMG is a valid method for measuring LM and ES muscle activity during (submaximal) voluntary contraction tests. Overall, results of frequency and RMS values show that sEMG electrodes of LM and ES do not accurately represent iEMG signals of LM and ES when both muscles are active, as identified in all clinical tests. Results indicate that co-contraction and cross-talk are present in sEMG signals and give a considerable amount of confusion in the interpretation of the recorded sEMG signals in this sample of healthy participants.

The second research aim was to identify cross-talk and original signal in isolated contraction of the LM, to study how correlations would be. The results show that it is very uncommon to contract LM and ES muscle isolated in healthy volunteers, because just two events in all the 15 included participants met the criteria. Except from these two events, it means that during functioning, both the LM and ES are active at the same time. This also leads to large co-contraction correlations, because as soon as one of the low back muscles contracts other low back muscles co-contrast. The biofeedback test in this study was introduced to minimize these effects; however, in most participants LM and ES muscle activation was observed at the same time.

In all tests, original signal correlations were  $>0.4$  for iEMG and sEMG of the ES. However, the results of original signal correlations of LM were equal or lower compared to the ES original signal correlations. For example, in the contralateral arm lift test original signal correlations of ES was  $r=0.6$  and of LM were  $r=0.4$  and  $r=0.3$ . Okubo *et al* and Stokes *et al* also compared iEMG and sEMG in low back muscles.<sup>19,20</sup> In both studies, iEMG and sEMG of the LM results differed.<sup>19,20</sup> According to Okubo *et al*, iEMG and sEMG activity measurements were strongly correlated in the LM<sup>19</sup>; however, in the present study, the range of original signal correlation coefficients varied between  $r=0.38$  and  $r=0.84$ . Original signal correlations were higher in every test for LM method-2 compared to LM method-1, but the differences were small. The difference between both studies may well be explained in differences in the placement of electrodes; L2 and L4 in the study of Stokes *et al* compared to L5 and L5-S1 in the present study. However, in the study of Okubo *et al*, the placement of electrodes of LM was also at the level of L5. From an anatomical point of view, one might expect that on the higher lumbar levels, the LM and ES are overlapping, which leads to difficulties in precise location and placement of electrodes, hence in larger cross-talk signals and higher co-contraction signals.

None of the applied clinical tests appeared to be able to activate isolated LM activity. However, for example, the clinical CAL-test should elicit LM muscle activity.<sup>15</sup> According to Hebert *et al* 2015, their results support the reliability and validity of the multifidus lift test (*i.e.*, in this

present study it was called CAL-test) to assess LM function at the L4–L5 spinal level. However, their results did not show any information about ES contraction during the multifidus lift test. The current results demonstrate that healthy participants activate not only LM during contralateral arm lift test, but also contract ES muscle during this test. Therefore, it is questionable whether multifidus lift test measures isolated LM contraction.

A particular strength of this study is the use of multiple validated clinical tests that were used to test the hypothesis of voluntary individual contraction of the LM compared to ES. Additionally, the number of participants ( $n=15$ ) was considerably higher compared to other iEMG/sEMG studies ( $n=8$  or  $n=3$ ).<sup>19,20</sup> There appeared no problems with the stability and quality of our recordings. A well understanding of low back morphology is deemed necessary to correctly identify LM muscle activity. We used new perspectives on LM muscle location in addition to application of the Seniam guideline<sup>23</sup> because LM muscle is the widest and most superficial at the level of L5-S1 based on the cross-sections of LM muscle.<sup>26</sup> A limitation of this study is that comparisons of sEMG was made to iEMG, which can be regarded as a good representation of the level of muscle activation, but it cannot be regarded as a “criterion standard,” since placement of intramuscular electrodes cannot be done in a perfect reproducible way.<sup>28</sup> We optimized the reliability of the placement of the needle position to the best of our possibilities by using ultrasound guidance of the needle to position the iEMG. Future studies may focus on inclusion of LBP patients to test whether the construct measured with healthy participants are also valid in patient samples.

It can be concluded that in all the clinical tests in this study sEMG LM and sEMG ES represent iEMG LM and iEMG ES signals insufficiently. In all the clinical tests and FEEDBACK-test low to high co-contraction and cross-talk is measured in the surface electrodes. None of the applied clinical tests appeared to be able to activate isolated LM activity. LM and ES were active simultaneously in healthy participants in all clinical tests.

### ➤ Key Points

- ❑ Surface EMG electrodes of LM and ES do not accurately represent intramuscular EMG signals of LM and ES when both muscles are active, as identified in all used clinical tests.
- ❑ Co-contraction and cross-talk are present in surface EMG signals and give a considerable amount of confusion in the interpretation of the recorded surface EMG signals
- ❑ Healthy participants activate not only LM during contralateral arm lift test, but also contract ES muscle during this test.
- ❑ None of the applied clinical tests appeared to be able to activate isolated LM activity.

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