Research Paper: Test-retest Reliability of EMG β-Band Intermuscular Coherence of Non-specific Chronic Low Back Pain During Flexion-extension Task

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ABSTRACT

Introduction: This study aimed to investigate the reliability and agreement of the Beta-band Intermuscular Coherence (Bb-IMC) as a clinical assessment tool for Non-Specific Chronic Low Back Pain (NS-CLBP) patients and healthy subjects by studying four phases of the Flexion-Extension Task (F-ET): standing, flexion, relaxation, and extension phases.

Materials and Methods: Twenty-four men with NS-CLBP and 20 healthy subjects voluntarily participated in this study. All subjects performed three trials of F-ET while the surface electromyography was recorded from the lumbar erector spinal, gluteus maximus, and hamstring muscles of both sides. Beta-band intermuscular coherence analysis was used to calculate the pool coherence and the pairwise coherence for all mentioned muscles. Afterward, the Intra-class Correlation Coefficient (ICC), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC) for four phases of F-ET were used to analyze the intra-rater reliability and agreement of the measurements.

Results: The investigation of ICC, SEM, and MDC showed that the reliability was moderate to a high level for pool and pairwise coherence of Bb-IMC in all mentioned muscles for four phases of the flexion-extension task in NS-CLBP patients and healthy subjects. Yet, the agreement was low because the measurement error was relatively large.

Conclusion: So far, no studies have used the Bb-IMC method to study low back pain, which is carried out in our research to check the reliability of this new method. Our findings revealed that pool and pairwise coherence obtained during F-ET have moderate to a high level of reliability for using Bb-IMC and could be considered a tool for the NS-CLBP patients' assessment. Despite the small sample size investigated, in clinical practice the using Bb-IMC measure can help to study the interaction of corticospinal in NS-CLBP and also in healthy subjects. This measure requires larger sample sizes in addition to studying other circumstances and functional movements such as lifting weight. Further, more research appears to be warranted by the observed effectiveness of a particular intervention in modulation mechanisms of corticospinal tract function by Bb-IMC in NS-CLBP.

Keywords: Non-specific chronic low back pain, Flexion-extension task, Beta-band intermuscular coherence, Pool coherence, Pairwise coherence

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1. Introduction

Low Back Pain (LBP) is one of the most common and demanding musculoskeletal pain syndromes worldwide [1, 2]. Over 85% of Chronic LBP (CLBP) complaints don't belong to a specific disease or anatomic abnormality and are simply classified as NonSpecific Chronic LBP (NS-CLBP) [3, 4]. NS-CLBP as a complicated condition is contributed to multiple pain-related and associated disability factors, including pathoanatomical, psychological, social factors, biophysical and cultural factors, environmental, genetic, comorbidities, and pain-processing mechanisms [5, 6].

Neuroimaging research had illustrated that chronic musculoskeletal pain was the cause of structural and functional cortical reorganization [7]. It is believed to be responsible for activity altering of the lumbopelvic area muscles with changes in the representation of the motor cortical for those muscles in NS-CLBP patients [6]. Consequently, this might lead to the development and conservation of chronic pain. So, the importance of abnormal cortical Central Nervous System (CNS) processes in patients with NS-CLBP has attracted some researchers [8]. Accordingly, different studies had come up with the conclusion that the effect of pain and avoidance behaviors (pain-related fear) could shift the different patterns of muscle activation such as Flexion Relaxation Phenomena (FRP) in the trunk forward flexion movement [9, 10] that involves in all physical and functional daily living activities and can be related to expected pain and fear of pain as a contributing factor to the motor control disorder [11, 12].

Intermuscular Coherence (IMC) is a helpful tool to study motor control in this context to have a better perception of the CNS strategies during the execution of motor tasks [13, 14]. IMC is characterized as a coherence analysis between the surface Electromyography (sEMG) signals from the synergistic muscles [13] and also defines the common oscillatory drive to a pair of muscles (intermuscular coherence) [15]. This mechanism might detect the existence of both shared inputs of neural presynaptic from the higher structures of the brain and specifically from the motor cortex [16] and the common spinal interneurons contributions [17]. It exclusively aims to define these neural mechanisms by studying peripheral information only.

Furthermore, it is shown that coherence at specific frequencies is mediated via distinct pathways, including delta (0-5 Hz), alpha (5-15 Hz), beta (15-30 Hz), and gamma (30-60 Hz). Thus, coherence analysis detected at different ranges of frequencies provides essential information on how the nervous system works to control the activity of muscles during various tasks [18, 19].

Accordingly, Beta-band Intermuscular Coherence (Bb-IMC) is assumed to originate mainly from the primary motor cortex and is a potential biomarker of corticospinal tract function. It is presumed to show the common corticospinal drive from the primary motor cortex to the muscles. It suggests that the Bb-IMC is suitable for dynamic tasks as well [18, 20]. On the other hand, other bands are suggested to be related to common input from the subcortical structures [19] and reflect the synchronization of multiple muscles during postural tasks, slow movements, and isometric contraction [20]. Studies have proved the great importance of Bb-IMC in many diseases, where a study conducted on cervical spinal cord injury patients to investigate the effect of spinal cord injury on the common neural drive adjusting the agonist and antagonist muscles activities [21]. Another study has also investigated the spasticity of stroke and possible mechanisms causing the abnormal motor overflow [22].

Besides, Bb-IMC was used to study impaired motor function accompanied by aging, and the results contributed to the design of new interventions to reinforce control of sensorimotor in elderly subjects [23]. Although Bb-IMC analysis is easy to apply and requires only the recording through sEMG, the derived variables reproducibility from Bb-IMC in NS-CLBP patients had not been investigated.

For clinical relevance, possible changes in corticospinal control of lumbopelvic muscles in NS-CLBP and comparing them with healthy subjects should be assessed longitudinally by Bb-IMC to detect, for example, NS-CLBP-related changes linked to corticospinal tract function or to evaluate the effects of interventions on corticospinal tract function. Therefore, this study aimed to determine the test-retest reliability and agreement of Bb-IMC variables recorded during 4 phases of the Flexion-Extension Task (F-ET) of standing, flexion, relaxation, and extension in NS-CLBP and healthy subjects.

2. Materials and Methods

Study subject

Twenty-four men with NS-CLBP and 20 healthy subjects voluntarily participated in this study (Biomechanics Laboratory, School of Rehabilitation, Tehran University of Medical Sciences). The patients were included if they were 20-40 years old, suffered from NS-CLBP for at least three consecutive months, had at least 30 out of 100 in the numerical rating scale [24], and 8 out of 50 in the Oswestry questionnaire [25]. The patients were excluded if they had any history of neurological, rheumatoid, and psychological diseases, had received physiotherapy during the last three months, or used opioid and analgesic drugs in the last 72 hours before the test. The patients were also excluded from the study if they suffered from disk herniation, spondylolisthesis, spinal canal stenosis, sciatica, and previous lumbar surgery. Besides, the patients were excluded if they were reluctant to carry out the study at any stage. Healthy subjects were included in the study, provided that they had no history of LBP or they had not received previous postural training exercises [26]. Also, all participants signed an informed consent form according to a protocol approved by the Tehran University of Medical Sciences Ethics Committee with the assurance number IR.TUMS.VCR.REC.1398.675. Also, this study obtained the approval of the Iranian Registry of Clinical Trials (IRCT20090301001722N22).

Measures/Instruments

The skin surface of the muscles was shaved and cleaned with alcohol wipes. All sEMG signal recordings were made using the Datalog, Biometrics Ltd England. Then, the bipolar active electrodes with a recording diameter of 10-mm and a 20 mm fixed center to center interelectrode distance were mounted on the relevant muscle, built-in differential amplifier, and the ground electrodes were located on the right wrist. The electrode positions and orientations were chosen according to EMG sensor locations defined in SENIAM guidelines [27] on the following muscles: the right lumbar erector spinal (1), left lumbar erector spinae (2), right gluteus maximus muscle (3), left gluteus maximus muscle (4), right hamstring muscle (5), and left hamstring muscle (6). Muscles 1, 4, and 6 were considered the first group, and muscles 2, 3, and 5 were the second group.

Study procedure

To carry out the study, the subjects were familiarized with the procedure before starting the test to reduce stress and fear of testing. All subjects stood inside a square marked on the floor while their hands hanged by their sides and their feet were hip-width apart [28]. Besides, a paper was on the experiment site to ensure a standardized foot placement for each trial. There was a visual target placed at 3 meters' distance, and their eyes were focused on it (Figure 1). After that, the subjects were asked by verbal commands to perform three trials of F-ET while the sEMG was recording. Each trial included recording data for 20 seconds (i.e., 5 seconds at upright standing phase, 5 seconds during flexion phase, 5 seconds at relaxation or full flexion phase, 5 seconds during the extension phase) (Figure 2). A metronome was simultaneously monitoring the consequences of all the above-mentioned phases with sEMG recording as an auditory signal (beep) every second during the whole task. The subjects were asked to bend forward as far as possible with the knees at extension three times. They were allowed to rest for two minutes between trials to reduce the probability of discomfort, fatigue, and back injury [29, 30].

Beta-band intermuscular coherence analysis

sEMG signals from all three trials were concatenated for each subject to make a series of a longer single time and increase the coherence reliability estimations. In the following steps, to provide a visual representation of the coherence dependence on frequency, the spectra for a mentioned muscle pair were averaged in all participants within a group. Coherence values were calculated between 0 and 350 Hz. Then, frequency spectrum analysis for each phase of F-R T tasks was measured by MATLAB software 7.11 (the Math Works Inc., Natick, MA, USA), and spectrums of 15-30 Hz moved to coherence software. We could guess the mean coherence distribution in a specific frequency band across the participants and provide a group summary [19].

We measured the Pool Coherence (PC) [31] across each of two muscle groups (i.e., first group, 1, 4, and 6 against the second group, 2, 3, and 5) and the Pairwise Coherence (PWC) among each pair of muscles as well [32] to highlight the contributions of coherence that were common or unique to each pair of muscles or all synergist muscles. Three muscles were estimated using the pooled coherence function [33] to determine the common neural coupling between each of the two muscle groups. The definition is as following [33]:

$$Cpool=\frac{|\Sigma_{j=1}^{p} P_{xy_j}(f) L_j|^2}{(\Sigma_{j=1}^{p} P_{xxj} L_j)(\Sigma_{j=1}^{p} P_{yyj} L_j)}$$

where p denoted all the possible muscles pairs 1, 4, 6 then 2, 3, 5 in our case, namely 1 with 4, 1 with 6, and 4 with 6, then 2 with 3, 2 with 5 and 3 with 5, j stood for the j pair, Pxy(f) was the density of power cross-spectral, Pxx(f) and Pyy(f) represented the densities of the auto spectral of the two muscles forming the couple, and Lj was the number of segments used for the auto-spectral and cross-spectrum estimation. Pxx(f), Pxy(f),

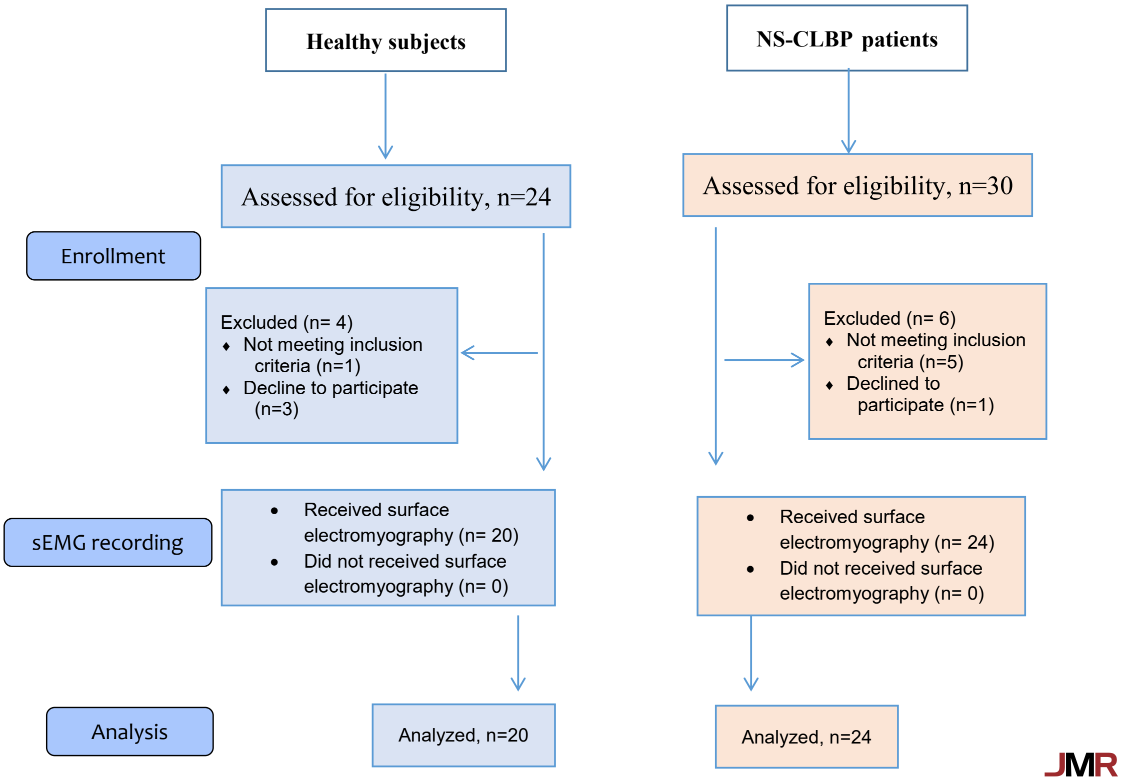

Figure 1. Flow-chart of the study participants

and Pyy(f) were estimated with 50% overlap directing to a spectral resolution of 2 Hz according to the signals lasting 500 ms (i.e., a window using a Hanning function) [34] and to improve the estimation, the number of available signals was the doubled. Besides, to estimate the contribution of coherence between two muscles, the analysis of pairwise coherence was performed. The following standard coherence formulation was the basis of this analysis [33]:

$$Cxy(f)=\frac{|P_{xy}(f)|^2}{P_{xx}(f)P_{yy}(f)}$$

, where Cxy was the coherence between sEMG signals x and y, the f was the frequency. Pyy and Pxx denoted autospectra for signal y and x, while Pxy stood for signal x and y cross-spectrum.

Coherence was defined as the frequency-domain of the Pearson correlation coefficient extension and expressed the linear correlation degree between the signals at every frequency on a scale ranged from 0 to 1, where 1 represented perfect correlation and 0 represented no correlation [35]. The raw EMG signal was detruded before EMG-EMG coherence calculation to remove the offset.

When intramuscular coherence exceeded a Confidence Limit (CL) with a probability of 95%, it was distinguished at a specific frequency to be significantly larger than zero. CL was determined as [36]:

$$CL=1-a^{1/(N-1)}$$

, where α is the desired significance level.

The inverse Fourier transform of the coherence spectrum was defined as the cumulate density function. The inverse Fourier transform was calculated as a time-domain measure of association between signals sEMG. Cumulate density function and coherence spectra were calculated for all muscle groups and every phase of F-ET, and the result was a set of 24 coherence spectra per subject.

The cumulate density function is defined by the inverse Fourier transform of the cross-spectrum fx1(λ) as a following [36]:

$$q\times 1(u)=\int_{-x}^{x} f_{x1}(\lambda)e^{i\lambda u}d\lambda$$

Descriptive statistics

This study aimed to assess the test-retest reliability and agreement of coherence variables calculated from muscular activity measured during F-ET in NS-CLBP patients and healthy subjects.

Figure 2. Standing position

Reliability is determined by the Intra-class Correlation Coefficient (ICC) and is defined as the ability of the measurement to distinguish between subjects. The agreement is quantified by the Standard Error of Measurement (SEM) and the Smallest Real Difference (SRD). It can be defined as the degree to which repeated measurements match [37, 38]. The agreement should specifically be large in intervention studies to find a well-suited measure indicating that small effects can be shown [37]. The SEM expresses how repeated measurements of a subject on the same test tend to be distributed around the "true" value, considering no systematic errors. SRD stands for the Minimal Detectable Change (MDC) and represents the smallest change necessary to exceed the measurement error of two repeated measures at a specified Confidence Interval (CI) [39, 40]. The MDC can be signified as the magnitude of change below which there is more than a 95% chance that no real change has occurred (Tables 1, 2, 3 & 4).

Data analysis

The Kolmogorov-Smirnov showed the normal distribution of age, weight, height, and Body Mass Index (BMI) in both groups (P>0.05).

Reliability and agreement

The ICC with corresponding 95% confidence intervals in each group of all subjects was performed on the reliability analysis for all data to check the distribution of sampling. In statistical analysis, to determine the reliability measures, the three trials mean of assessing the coherence (1, 4, and 6) and coherence (2, 3, and 5) in each phase of F-ET was used. Then, the coherence (1, 4, and 6) and coherence (2, 3, and 5) were measured by mixed model ANOVAs for each phase of the four phases of the F-ET.

ICC values were interpreted based on Munro's reliability classification as follows: a low correlation (0.26 to 0.49), moderate correlation (0.50 to 0.69), high correlation (0.70 to 0.89), and very high correlation (0.90 to 1.00) [38]. Afterward, a paired t test was utilized to assess the differences in coherence (1, 4, and 6) and coherence (2, 3, and 5) in each phase of F-ET between NS-CLBP patients and healthy subjects.

SEM was calculated as SEM=SD of first test×square root of 1 – ICC; on the other hand, MDC was calculated for the 95% CI as MDC=SEM×1.96×square root of 2 for all variables. An alpha level of 0.05 was applied for all statistical tests with a Bonferroni adjustment.

3. Results

The Mean±SD age, height, weight, and BMI of the NS-CLBP patients of this study were 39.917±10.346 years, 177.250±8.045 cm, 85.083±11.334 kg, and 27.036±2.998 kg/m^2, respectively. Whereas in healthy subjects, these values were 34.250±10.172 years, 174.850±6.385 cm, 79.620±8.127 kg, 26.049±2.391kg/m^2, respectively. Our findings showed that between the groups, there were no significant differences in demographic data (P>0.05).

The first coherence (1, 4, 6) and the second coherence (2, 3, 5) were measured as the Pool Coherence (PC) and also the Pairwise Coherence (PWE) for all the above-mentioned muscles. Then, the Intra-class Correlation Coefficient (ICC), Standard Error of Measurement (SEM), and Minimal Detectable Change (MDC) were utilized for four phases of F-ET to analyze the intra-rater reliability and agreement of the measurements.

Statistical tests of ICC, SEM, and MDC in the four phases of F-ET for NS-CLBP patients and healthy subjects indicated a moderate to high correlation for the first coherence (1, 4, and 6) and the second coherence (2, 3, and 5). The following illustrates each phase of F-ET will be presented separately (Tables 1, 2, 3 & 4).

4. Discussion

This study assessed the test-retest reliability and agreement of variables calculated from Bb-IMC coherence during F-ET. As far as we know, this is the first research to investigate the inter-rater reliability of the Bb-IMC as-

Table 1. Reliability, agreement, and descriptive data of pairwise and pool coherence (1, 4, and 6) and (2, 3, and 5) in non-specific chronic low back pain patients (n=24) and healthy subjects (n=20) during the standing phase

Variables	Healthy (n=20)			Non-Specific Chronic Low Back Pain (n=24)		
	ICC (95% CI) (Lower, Upper)	SEM	MDC	ICC (95% CI) (Lower, Upper)	SEM	MDC
PWC (1, 4)	0.552 (0.16, 0.79)	0.011	0.030	0.539 (0.18, 0.77)	0.013	0.037
PWC (1, 6)	0.669 (0.33, 0.85)	0.009	0.026	0.746 (0.50, 0.88)	0.010	0.028
PWC (4, 6)	0.613 (0.25, 0.83)	0.014	0.040	0.645(0.33, 0.83)	0.011	0.030
PWC (2, 3)	0.677 (0.35, 0.86)	0.012	0.033	0.656 (0.35, 0.84)	0.010	0.029
PWC (2, 5)	0.619 (0.25, 0.83)	0.014	0.040	0.683 (0.39, 0.85)	0.011	0.029
PWC (3, 5)	0.797 (0.56, 0.91)	0.007	0.018	0.664 (0.36, 0.84)	0.009	0.024
PC (1, 4, and 6)	0.697 (0.38, 0.87)	0.008	0.022	0.589 (0.25, 0.80)	0.011	0.032
PC (2, 3, and 5)	0.666 (0.33, 0.85)	0.009	0.025	0.744 (0.49, 0.88)	0.007	0.021

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ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; PWC: Pairwise Coherence; PC: Pool Coherence; 1: right lumbar erector spinal muscle; 2: left lumbar erector spinal muscle; 3: right gluteus maximus muscle; 4: left gluteus maximus muscle; 5: right hamstring muscle; 6: left hamstring muscle.

Table 2. Reliability, agreement, and descriptive data of pairwise and pool coherence (1, 4, and 6) and (2, 3, and 5) in non-specific chronic low back pain patients (n=24) and healthy subjects (n=20) during the flexion phase

Variables	Healthy (n=20)			Non-Specific Chronic Low Back Pain Patients (n=24)		
	ICC (95% CI) (Lower, Upper)	SEM	MDC	ICC (95% CI) (lower, upper)	SEM	MDC
PWC (1, 4)	0.650 (0.30, 0.85)	0.012	0.033	0.550 (0.20, 0.78)	0.013	0.035
PWC (1, 6)	0.628 (0.27, 0.83)	0.013	0.037	0.599 (0.27, 0.80)	0.011	0.031
PWC (4, 6)	0.592 (0.21, 0.82)	0.015	0.042	0.601 (0.27, 0.81)	0.013	0.036
PWC (2, 3)	0.561 (0.17, 0.80)	0.016	0.045	0.597 (0.26, 0.80)	0.012	0.034
PWC (2, 5)	0.533 (0.13, 0.78)	0.014	0.040	0.558 (0.21, 0.78)	0.011	0.032
PWC (3, 5)	0.587 (0.21, 0.81)	0.014	0.039	0.723 (0.46, 0.87)	0.010	0.027
PC (1, 4, and 6)	0.823 (0.61, 0.93)	0.006	0.017	0.508 (0.14, 0.75)	0.013	0.036
PC (2, 3, and 5)	0.700 (0.38, 0.87)	0.009	0.025	0.663 (0.36, 0.84)	0.012	0.034

JMR

ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; PWC: Pairwise Coherence; PC: Pool Coherence; 1: right lumbar erector spinal muscle; 2: left lumbar erector spinal muscle; 3: right gluteus maximus muscle; 4: left gluteus maximus muscle; 5: right hamstring muscle; 6: left hamstring muscle.

sessment in NS-CLBP patients. Our study demonstrated a moderate to a high level of reliability for using Bb-IMC in NS-CLBP patients and healthy subjects regarding our sample size (e.g., 24 patients; 20 healthy subjects). Since values of ICC do not detect the differences of the absolute between the measurements [41]; therefore, the SEM and MDC are often studied to evaluate the error of the measurements and help in separating actual change from the error of measurement as well [42]. However, Atkinson et al. suggested considering the MDC instead of SEM since they had argued that SEM could underestimate the actual change [43, 44]. Regarding the literature review, no previous study had considered the SEM and

Table 3. Reliability, agreement, and descriptive data of pairwise and pool coherence (1, 4, and 6) and (2, 3, and 5) in non-specific chronic low back pain patients (n=24) and healthy subjects (n=20) during the relaxation phase

Variables	Healthy (n=20)			Non-Specific Chronic Low Back Pain Patients (n=24)		
	ICC (95% CI) (Lower, Upper)	SEM	MDC	ICC (95% CI) (Lower, Upper)	SEM	MDC
PWC (1, 4)	0.587 (0.21, 0.81)	0.015	0.040	0.616 (0.29, 0.81)	0.011	0.030
PWC (1, 6)	0.573 (0.19, 0.81)	0.014	0.039	0.613 (0.29, 0.81)	0.011	0.030
PWC (4, 6)	0.514 (0.10, 0.77)	0.018	0.051	0.635 (0.32, 0.82)	0.012	0.034
PWC (2, 3)	0.519 (0.11, 0.78)	0.016	0.044	0.659 (0.36, 0.84)	0.012	0.032
PWC (2, 5)	0.532 (0.13, 0.78)	0.014	0.040	0.614 (0.29, 0.81)	0.010	0.027
PWC (3, 5)	0.565 (0.17, 0.80)	0.011	0.030	0.619 (0.30, 0.82)	0.012	0.032
PC (1, 4, and 6)	0.787 (0.54, 0.91)	0.005	0.014	0.559 (0.21, 0.78)	0.015	0.040
PC (2, 3, and 5)	0.647 (0.30, 0.84)	0.009	0.024	0.717 (0.45, 0.87)	0.009	0.026

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ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; PWC: Pairwise Coherence; PC: Pool Coherence; 1: right lumbar erector spinal muscle; 2: left lumbar erector spinal muscle; 3: right gluteus maximus muscle; 4: left gluteus maximus muscle; 5: right hamstring muscle; 6: left hamstring muscle.

Table 4. Reliability, agreement, and descriptive data of pairwise and pool coherence (1.4.6) and (2.3.5) in non-specific chronic low back pain patients (n=24) and healthy subjects (n=20) during the extension phase

Variables	Healthy (n=20)			Non-Specific Chronic Low Back Pain Patients (n=24)		
	ICC (95% CI) (Lower, Upper)	SEM	MDC	ICC (95% CI) (Lower, Upper)	SEM	MDC
PWC (1, 4)	0.580(0.20,0.81)	0.013	0.035	0.697 (0.42, 0.86)	0.009	0.026
PWC (1, 6)	0.573 (0.19,0.81)	0.013	0.035	0.701 (0.42, 0.86)	0.010	0.027
PWC (4, 6)	0.618 (0.25,0.83)	0.012	0.032	0.736 (0.48, 0.88)	0.007	0.020
PWC (2, 3)	0.540(0.14, 0.79)	0.014	0.038	0.608 (0.28, 0.81)	0.014	0.039
PWC (2, 5)	0.560 (0.17, 0.80)	0.015	0.040	0.738 (0.48, 0.88)	0.009	0.025
PWC (3, 5)	0.578 (0.19, 0.81)	0.013	0.037	0.747 (0.50, 0.88)	0.006	0.017
PC (1, 4, and 6)	0.799 (0.56,0.92)	0.008	0.022	0.731 (0.47, 0.87)	0.009	0.024
PC (2, 3, and 5)	0.552 (0.16, 0.80)	0.010	0.027	0.744 (0.49, 0.88)	0.007	0.021

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ICC: Intra-class Correlation Coefficient; SEM: Standard Error of Measurement; MDC: Minimal Detectable Change; PWC: Pairwise Coherence; PC: Pool Coherence; 1: right lumbar erector spinal muscle; 2: left lumbar erector spinal muscle; 3: right gluteus maximus muscle; 4: left gluteus maximus muscle; 5: right hamstring muscle; 6: left hamstring muscle.

MDC values for the reliability of Bb-IMC; consequently, a comparison study was not feasible.

Our findings revealed that intramuscular coherence variables obtained during F-ET are moderate to a high level of reliability for using Bb-IMC for Bb-IMC in NS-CLBP patients and healthy subjects and could be considered as a tool for the NS-CLBP patients' assessment. Yet, the agreement, was low as the measurement error was relatively large. Compared with other previous studies, as far as we know, there is only one pilot study that conducted by F. Gennaro to determine the test-retest reliability of Cortico-muscular (CMC) and intramuscular (intraMC) coherence variables in the gathered beta and lower gamma frequencies during walking in young and old adults. intraMC had a moderate reliability in younger adults whereas CMC had low reliability in younger and older subjects [45]. Edwin H et al considered, in settings of EMG-processing and specific conditions, that variables of derived coherence can be considered to be reliable measures [27].

The signal processing for the coherence calculation includes a different option even though the EMG acquisition is relatively easy. Bearing this in mind, previous studies indicated that the reliability and agreement of intramuscular coherence variables depended on settings of signal processing particularly rectification of EMG signals and to some extent the task speed [32].

Those studies had proposed that the common drive nature like amplitude or frequency modulation [46], the active motor units number or force product [47], and the common drive amount that motor units receive [46] must be considered during the coherence study. Experimental conditions make it difficult to control the complex interaction across all previous factors. Hence, it is not easy to determine the most corticospinal drive and accurate quantification during EMG processing. Please delete this sentence and add (this research did not receive any specific grant from funding agencies in the public, commercial, or not-profit sectors). The necessity of this processing stage is discussed in recent studies [46, 48]. Besides, rectification had been recommended to promote the firing rate of motor unit information [48, 49]. Anyway, some studies had drawn more emphasis on rectification as a non-linear process with an inconsistent influence on the power spectrum. Therefore, it may detect a drive of the common oscillatory to the muscle(s) [23, 49].

5. Conclusion

The current study has investigated the reliability of Bb-IMC for NS-CLBP patients for the first time. Our findings revealed that intraMC coherence variables obtained during F-ET have a moderate to a high level of reliability for using Bb-IMC and could be considered a tool for the NS-CLBP patients' assessment. Despite the small investigated sample size, using this measure to conclude the interaction of corticospinal in NS-CLBP and healthy subjects should help improve the analysis in clinical practice. This limitation requires larger sample sizes in addition to studying other circumstances and functional movements such as lifting weight. Furthermore, more research appears to be warranted by the observed effectiveness of a particular intervention in modulation mechanisms of corticospinal tract function by Bb-IMC in NS-CLBP.

Limitations and strengths

We used the flexion-extension task in our study to research Bb-IMC between the following muscles: the right lumbar erector spinal left lumbar erector spinal, right gluteus maximus muscle, left gluteus maximus muscle, right hamstring muscle, and left hamstring muscle. Thus, these results cannot be generalized to other tasks and muscles. Accordingly, additional studies should be carried out to determine the reliability of Bb-IMC in NS-CLBP patients in other circumstances, such as functional movements. Doing similar research on both genders can be another option as well.

Ethical Considerations

Compliance with ethical guidelines

The research supervisor complied with all ethical guidelines.

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Authors contributions

All authors contributed equally in preparing all parts of the research.

Conflict of interest

The authors had no conflict of interest.

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