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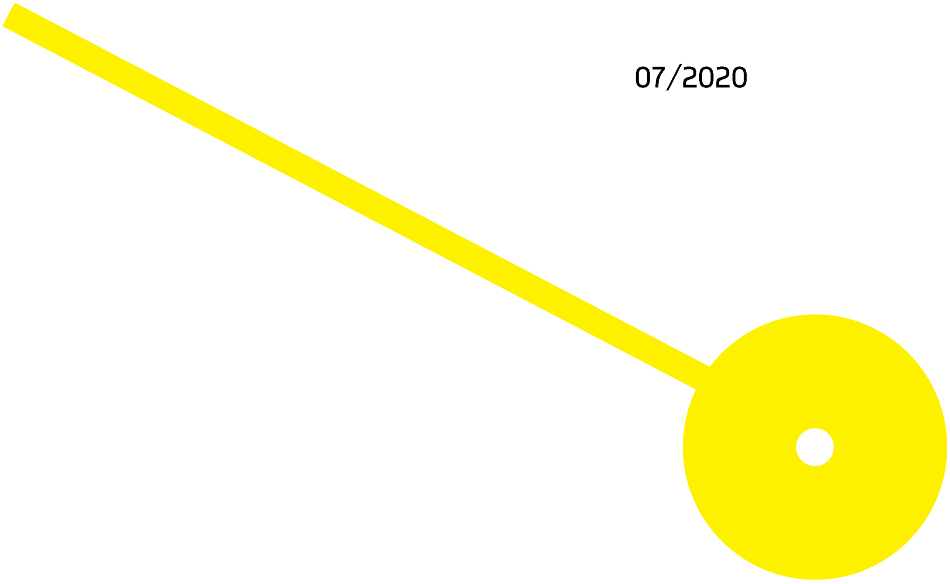
Analysis of different activation patterns used during prone hip extension between subjects with and without chronic low back pain

Tiago Sousa



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Analysis of different activation patterns used during prone hip extension between subjects with and without chronic low back pain

Autor
Tiago Sousa[1,2]
Orientador
Paulo Carvalho[1]
[1] *Área técnico-científica de fisioterapia da Escola Superior de Saúde/Instituto Politécnico do Porto*
[2] *Futebol Clube do Porto- Departamento de Saúde*

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Resumo

Introdução: O padrão de movimento pode alterar devido a um atraso no tempo de início e/ou na sequência de ativação muscular, predispondo o indivíduo a desordens do controlo motor, incluindo dor lombar (LBP). A eletromiografia de superfície (sEMG) pode avaliar estes parâmetros. **Objetivo:** Descrever e comparar o tempo de início e a sequência de ativação muscular de Glúteo Máximo ipsilateral (GM_Ipsi), Bíceps Femoral ipsilateral (BF_Ipsi) e dos músculos Eretores da Espinha ipsilateral (ES_Ipsi) e contralateral (ES_Contra), durante o movimento de extensão da anca do membro inferior dominante, em indivíduos com e sem dor lombar crónica. Esta investigação também pretende procurar a presença da sequência de ativação muscular considerada "ideal" e a relação entre o *tilt* pélvico e a sequência de ativação muscular, em ambos os grupos. **Métodos:** Foi realizado um estudo transversal, com uma amostra composta por 64 estudantes universitários voluntários divididos em dois grupos: 31 sem dor lombar (grupo NLBP) e 33 com dor lombar (grupo LBP). O sinal eletromiográfico dos músculos GM_Ipsi, BF_Ipsi, ES_Ipsi e ES_Contra foi recolhido através de sEMG. O tempo de início e as respetivas ordens de ativação muscular foram analisados. Em ambos os grupos o *tilt* pélvico foi medido, com o auxílio de um medidor palpação-PALM. Os dados estatísticos foram processados no software SPSS, versão 20.0 para MAC OS, com um grau de significância de 0,005. **Resultados:** O grupo LBP apresentou um atraso no tempo de início de GM_Ipsi ($t = -3{,}171$; $p = 0{,}002$) e BF_Ipsi ($t = -2{,}092$; $p = 0{,}041$) relativamente ao grupo NLBP. As cincos ordens mais frequentes de sequência de ativação muscular apresentaram associação com a presença de dor lombar ($xf2 = 11{,}54$; $p = 0{,}015$). A ordem "ideal" de sequência de ativação muscular (GM_Ipsi> BF_Ipsi> ES_Contra> ES_Ipsi) nunca foi utilizada. Verificou-se que o BF_Ipsi foi maioritariamente o primeiro a ser ativado e o GM_Ipsi o último em ambos os grupos. Os indivíduos que ativam primeiro o BF_Ipsi apresentam um *tilt* pélvico significativamente superior (grupo LBP: $U = 51$; $p = 0{,}001$ e grupo NLBP: $U = 41$; $p = 0{,}001$). **Conclusão:** Em cada grupo verificou-se um padrão consistente de ativação, não sendo possível suportar ou refutar a teoria de que um atraso na ativação do Glúteo Máximo está relacionado com a dor lombar, uma vez que este foi o último a ser ativado em ambos os grupos, embora tenha sido observado um maior atraso no grupo LBP. Este estudo apresenta informações importantes para investigadores/clínicos que usam o teste como uma ferramenta de avaliação e/ou como um exercício de reabilitação.

Palavras-chave: EMG; Dor Lombar; Extensão da Anca; *Tilt* Pélvico

Abstract

Background: The movement pattern may change due to a delay in the onset timing and/or muscle activation sequence, predisposing the individual to motor control disorders, including low back pain (LBP). The surface electromyography (sEMG) can assess these parameters. **Objective:** To describe and compare the onset timing and muscle activation sequence of ipsilateral Gluteus Maximus (GM_Ipsi), ipsilateral Biceps Femoris (BF_Ipsi) and ipsilateral (ES_Ipsi) and contralateral (ES_Contra) Erector Spinae muscles, during the hip extension movement of the dominant lower limb, in subjects with and without chronic low back pain. This investigation also intends to look for the presence of muscle activation sequence considered "ideal" and the relation between the pelvic tilt and the muscle activation sequence, in both groups. **Methods:** A cross sectional study was performed, with a sample composed by 64 volunteer college students, divided in two groups: 31 without low back pain (NLBP group) and 33 with low back pain (LBP group). Through sEMG it was collected the electromyographic signal of the GM_Ipsi, BF_Ipsi, ES_Ipsi and ES_Contra muscles. It was analyzed the onset timing and respective orders of activation. Additionally, pelvic tilt was measured, with palpation meter-PALM, in both groups. Statistical data was processed in the SPSS software, version 20.0 for MAC OS, with a significance degree of 0.005. **Results:** The LBP group presented a delay in the onset timing of GM_Ipsi (t=-3.171; p=0.002) and BF_Ipsi (t=-2.092; p=0.041) compared with the NLBP group. There was an association between the 5 most frequent orders of muscle activation sequence and the presence of low back pain (xf2=11.54; p=0.015). The "ideal" order of muscle activation sequence (GM_Ipsi>BF_Ipsi>ES_Contra>ES_Ipsi) was never used. It was found that the BF_Ipsi was mostly the first to be activated and the GM_Ipsi was the last in both groups. The subjects that activate first the BF_Ipsi have a significantly higher pelvic tilt (LBP group: U=51; p=0.001 and NLBP group: U=41; p=0.001). **Conclusion:** It was found a consistent pattern of activation in each group. It was not possible to support or refute the theory that a delay in activation of the Gluteus Maximus is associated with low back pain, since it was the last to be activated in both groups, although it was found a higher delay in the LBP group. These informations are important to the investigators/clinicians who use the test as an assessment tool and/or as a rehabilitation exercise.

Keywords: EMG, Low Back Pain, Prone Hip Extension, Pelvic Tilt.

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1. Introduction

Low back pain (LBP) is one of the most common musculoskeletal disorders. Approximately 60% to 80% of adults will experience LBP at some point in their lives. Ten percent of these cases will develop chronic low back pain (Meucci et al., 2015).

The National Institutes of Health Research Task Force recommend "chronic low back pain" to be defined as a back pain problem that has persisted at least 3 months, resulted in pain for at least half the days in the past 6 months (Deyo et al., 2015). This condition is the leading cause of physical activity limitation before age 45 and the second between 45 and 65 years (Bruno & Bagust, 2006; Ponte, 2005). Represents the second cause of consultation in general practice and the first in rheumatology, implying high health and social systems costs with high rates of absenteeism and inability to work (Arab et al., 2011; Bruno et al., 2008; Bruno & Bagust, 2006; Hoy et al., 2010; Mansell et al., 2014; Ponte, 2005).

Despite the high incidence and adverse effects on daily activities, the exact causes are not fully understood and there is a reportedly effective approach to its diagnosis and treatment (Amirdelfan et al., 2014; Arab et al., 2011; Hayden et al., 2014). However, there has been recent evidence in the rehabilitation of low back muscles to intervene in this region motor control (Arab et al., 2011; Bruno & Bagust, 2006; Lederman, 2010; Russo et al., 2018).

Motor control refers to the use of correct onset timing, muscle activation sequence and intensity of activation, to achieve specific movement patterns, resulted from the coordinated activity between the synergistic, agonistic and antagonistic muscles (Arab et al., 2011; Bruno et al., 2008; Bruno & Bagust, 2006; Jouffroy & Médina, 2006; Lederman, 2010; Lieberman et al., 2006; Sakamoto et al., 2009). However, the Gluteus Maximus (GM) muscle is primarily active in activities involving lumbopelvic stabilization and tasks like climbing stairs and running (Barker et al., 2014; Jouffroy & Médina, 2006; Kang et al., 2013; Lieberman et al., 2006; Row et al., 2012; Ward et al., 2010; Wilson et al., 2005).

Therefore, analysing muscle and his synergists activity is important to observe their role in lumbopelvic stabilization during daily living activities. This muscle activity assessment can be accomplished by some clinical tests as the prone hip extension test (Arab et al., 2011; Lewis & Sahrmann, 2009; Tateuchi et al., 2012). This test, developed by Vladimir Janda, in 1987, is a valid test, specially in clinical practice, simulating hip extension in the standing position and defining the lumbopelvic muscle activation pattern (Bruno et al., 2008; Chance-Larsen et al., 2010; Lehman et al., 2004; Page et al., 2010; Takasaki et al., 2009).

An "ideal" pattern of muscle activation sequence during this test was theorized: Gluteus Maximus ipsilateral (GM_Ipsi) > Biceps Femoris ipsilateral (BF_Ipsi) > Erector Spinae contralateral (ES_Contra)

> Erector Spinae ipsilateral (ES_Ipsi) (Bruno et al., 2008; Bruno & Bagust, 2007; Lehman et al., 2004; Sahrmann, 2002). This theory holds that changes in lumbopelvic motion patterns, due to muscle activation timing and intensity changes, may result from repetitive movements and long term abnormal postures, which alter muscle tissue characteristics and can cause dysfunction (Lewis & Sahrmann, 2009; Sahrmann, 2002; Van Dieën et al., 2017).

One of the most common disorders occurs when the hamstrings and erector spinae (ES) activate first during the movement to compensate the gluteus maximus activation delay, promoting anterior pelvic tilt and excessive lumbar extension, resulting in increased compressive and anterior shear forces on the lumbar spine and lumbosacral joint (Choi et al., 2015; Evcik & Yücel, 2003; Guimarães et al., 2010; Kang et al., 2013; Lee & Yoo, 2011; Oh et al., 2007; Tateuchi et al., 2012). Therefore, LBP may arise or be perpetuated by nociceptive mechanical stress and surrounding tissues tension, due to pelvic girdle asymmetry, making the lumbopelvic stabilizing muscles to develop a vicious cycle (Lee & Yoo, 2011; Sarikaya et al., 2007).

Studies to address motor control and lumbopelvic postural asymmetries are needed to facilitate the implementation of preventive measures and effective interventions, allowing to differentiate activation patterns in individuals with and without LBP (Herrington, 2011; Juhl et al., 2004; Sahrmann, 2002). Evidence is also scarce regarding the association between muscle activation sequence and postural deficits in motor control (Bruno & Bagust, 2006; Lehman et al., 2004; Takasaki et al., 2009).

Therefore, the aim of this study was to investigate the onset timing and muscle activation sequence of GM_Ipsi, BF_Ipsi, ES_Ipsi and ES_Contra muscles, during the hip extension movement, of the dominant limb, in individuals with and without LBP. It is also intended to observe the existence of the muscle activation sequence considered "ideal" and the relationship between the muscle activation sequence and the pelvic tilt, in both individuals.

2. Methods

2.1 Sample

The study design was observational, analytical and cross-sectional.

The sample consisted of 64 female volunteers, aged between 18 and 35 years, divided in two groups, one without low back pain (NLBP group) – 31 subjects, and other with low back pain (LBP group) – 33 subjects.

The LBP group inclusion criteria were recurrent episodes of LBP for a period longer than three months. (Arab et al., 2011; Deyo et al., 2015; Silfies et al., 2005). The NLBP group included individuals who did not have history of LBP that prevented normal activities for at least one day in the past three months (Bruno et al., 2008; Jacobs et al., 2011).

For both groups, exclusion criteria were: history of hip joint injury or trauma, history of lumbar spine surgery, history of spondyloarthropathies diagnosed, history of brain injury or neuromuscular disease; pain during the hip extension test, history of pregnancy; individuals who were receiving physiotherapy treatment to resolve LBP (Bruno et al., 2008; Jacobs et al., 2011; Lehman et al., 2004; Tateuchi et al., 2012).

2.2 Instruments

Sample selection and characterization was conducted through a questionnaire, to ascertain the inclusion and exclusion participation criteria and information about the individuals sociodemographic data.

Anthropometric measurements were assessed using a force platform Bertec® FP4060-10 (Bertec® – Bertec corporation, Columbus, OH, USA) to record body mass and a stadiometer Seca® 222 (Seca® – Medical Scales and Measuring Systems, Birmingham, United Kingdom) to record height.

Surface electromyography (sEMG) was collected through the BioPLUX® research device (Plux wireless biosignals SA, 2630-369 Arruda dos Vinhos, Portugal), with 8 channels and a sampling frequency of 1000Hz, using double differential electrode leads (CMRR-110db) (Hermens et al., 2000; Kamen & Gabriel, 2009; Merletti, 1999).

The electrodes sensors were connected to the BioPLUX® research device using wireless connectivity, by Bluetooth on a range of 100m, with a gain of 1000 and an analogue filter at 25 to 500Hz.

Self-adhesive Ag/AgCl dual snap Noraxon® disposable electrodes for surface EMG were attached to BioPLUX sensors. The electrodes characteristics were: 4cm x 2.2cm of adhesive area; 1 cm diameter of each of the two circular conductive areas and 2 cm inter-electrode distance. For reference electrode, self-adhesive disposable electrodes Ag/AgCl snap Noraxon® for sEMG were used, with: 3.8 cm diameter of the circular adhesive area and 1 cm diameter of the circular conductive area.

To visualize and acquire the electromyographic signal the MonitorPlux® software version 2.0 was used.

To check the skin impedance level an electrode impedance checker was used (Noraxon®, Scottsdale, Arizona, USA) (Hermens et al., 2000; Kamen & Gabriel, 2009).

The beginning of motion was allowed by a Light-Emitting Diode (LED) and detected by two pressure transducer TSD111® (Biopac® Systems, Inc., California, USA), one placed at the anterior proximal third of the thigh and another at the anterior distal third of the tibia. The range of motion was measured using a Biopac® electrogoniometer (model - TSD130B). This data were acquired using a Biopac® MP150WSW Data Acquisition System (Biopac® Systems, Inc., California, USA) with a sampling frequency of 100Hz and the data collected through the Acqknowledge® software version 4.0 (Biopac® Systems Inc., California, USA). To synchronize the two acquisition and research systems a cable was used to connect the BioPLUX® and the Biopac® MP150WSW Data Acquisition Systems. To provide individuals final range feedback (20º measured by electrogoniometer), photovoltaic cells sensors Brower Timing Systems® IRD-T175 were used (Brower Timing Systems®, Utah, USA).

Sagital plane pelvis position was measured with a palpation meter PALM (Performance Attainment Associates®, Minnesota, USA). This instrument was used in other studies and is useful to measure the angle between the anterior upper iliac spine (ASIS) and posterior superior iliac spine (PSIS) (Gnat et al., 2009; Krawiec et al., 2003).

To evaluate pain intensity of LBP group, in the last pain episode, the Visual Analogue Scale (VAS) was used (Ferreira-Valente et al., 2011; Ponte, 2005).

2.3 Procedures

This study's procedures took place in a biomechanics laboratory and were performed in a controlled environment.

Initially, a musculoskeletal examination was performed throughout motion tests (namely, active hip flexion with knee extension and passive hip flexion with active and passive hip adduction and medial rotation) (Lewis & Sahrmann, 2009). During these tests, individuals rated their pain using VAS and were excluded in the presence of pain (Lewis & Sahrmann, 2009).

The skin was prepared, reducing the skin impedance by less than 5KΩ. Therefore, the hair was removed, an abrasive pad was used and the skin was clean with isopropyl alcohol (70%), removing the skin oiliness and the remaining dead cells (Bruno & Bagust, 2007; Hermens et al., 2000; Kamen & Gabriel, 2009; Lewis & Sahrmann, 2009).

After skin preparation, adhesive electrodes were placed in the testing position to prevent the skin movement. The individuals were positioned in prone position on a table, with their arms along the body, feet aligned with the shoulders and ankle in neutral position (Bruno & Bagust, 2006; Bruno & Murphy, 2011; Page et al., 2010). A stabilize band was used to stabilize the pelvis and limit movement only at the hip joint (Lewis & Sahrmann, 2009). Data were collected in the dominant lower limb, identified by the preference in the activity of "kicking a ball" (Boren et al., 2011; Chance-Larsen et al., 2010).

The electrodes were placed according to Criswell (2011) guidelines: for GM_Ipsi were placed at the midpoint of the line drawn from the last sacral vertebrae to the greater trochanter; in ES_Contra and ES_Ipsi were placed bilaterally about 2 cm to the level of the spinous process of L3, parallel to the spine on the muscle; and in BF_Ipsi were placed at the midpoint of the line between the ischium tuberosity and the lateral epicondyle of the tibia. The reference electrode was placed on the lateral malleolus of the non-dominant side (Arab et al., 2011; Boren et al., 2011; Criswell, 2011; Tateuchi et al., 2012).

A time lag of 5 minutes was estabilished between electrodes placement and the beginning of EMG signal collection. All electrodes placement locations were confirmed by palpation and their activity was confirmed by viewing a signal while manual resistance was applied to each muscle (Arab et al., 2011; Boren et al., 2011; Chance-Larsen et al., 2010; Tateuchi et al., 2012).

Individuals were instructed to perform the hip extension movement, after seeing the LED activation, up to 20°, keeping the knee extension, ankle in neutral position and hip without rotation (Tateuchi et al., 2012). To maintain knee extension during movement, tape was placed at the level of the anterior tibial tuberosity, crossing the knee joint, acting as a tactile feedback (Arab et al., 2011; Lewis & Sahrmann, 2009). Individuals were trained to perform this movement smoothly. Subsequently, three repetitions were recorded for subsequent analysis and calculation of the mean onset timing (Arab et al., 2011; Bruno & Bagust, 2006; Tateuchi et al., 2012).

After collecting EMG data, pelvic tilt was evaluated. Subjects were in an upright posture, with arms crossed over their chest, weight distributed and feet 30 cm apart, looking at the skyline to control the postural sway (Herrington, 2011; Lee & Yoo, 2011). Subsequently, investigator palpated and marked the reference points of ipsilateral ASIS and PSIS of the dominant lower limb and placed the PALM to measure pelvic tilt angle (Gnat et al., 2009; Herrington, 2011; Krawiec et al., 2003; Stovall & Kumar, 2010).

2.4 Data processing

For each motion test repetition, the data was submitted to the same procedure, aiming to determine the onset timing and muscle activation sequence. Device synchronization and EMG signal processing was performed using a routine developed in MatLab® student version software and its analysis was accomplished in software Acqknowlegde® version 4.0.

Thus, a 2nd order digital filter Infinite Impulse Response – Butterworth was applied to the EMG signal, one of 10Hz (high pass) and another of 450 Hz (low pass), to remove electrical noise and/or cable movement. Then, the mean root square (RMS), a 10 samples, was calculated (Criswell, 2011; Kamen & Gabriel, 2009).

Through the MatLab® routine was identified the point at wich the pressure registered in the transducer derived from baseline. Muscle activation timing was defined as the time interval between this point and the EMG onset activity of each recorded muscle (Bruno et al., 2008; Chance-Larsen et al., 2010; Lewis & Sahrmann, 2009).

EMG onset timing was considered as the time when 30 consecutive frames mean RMS (30 ms) exceeded baseline for 2 standard deviations. Baseline EMG activity was determined over a 50 ms period, 500 ms before the point (-500 to -450 msec) in which EMG activity clearly derived from baseline. All traces were visually inspected in software Acqknowlegde® version 4.0, to ensure that onset was not obscured by movement artifact or an electrocardiogram (<7% of trials) (Bruno et al., 2008; Bruno & Bagust, 2007; Hodges & Bui, 1996). Then, the average muscle activation timings of the three repetitions of movement test were determined (Park et al., 2011).

Pelvic tilt is defined as the angle formed by a horizontal line drawn between ASIS and PSIS. The mean of three measurements was determined (Gnat et al., 2009; Herrington, 2011).

2.5 Ethics

The study was conducted in accordance with the declaration of Helsinki and approved by the Institutional Research Ethics Committee. Each individual provided written informed consent before participation.

2.6 Statistics

Descriptive and inferential statistics analysis was done by IBM SPSS Statistics® version 20.0 (IBM Corp.®, New York, United States), for Mac OS X (64-bit), with a 95% confidence interval (significance level 0.05).

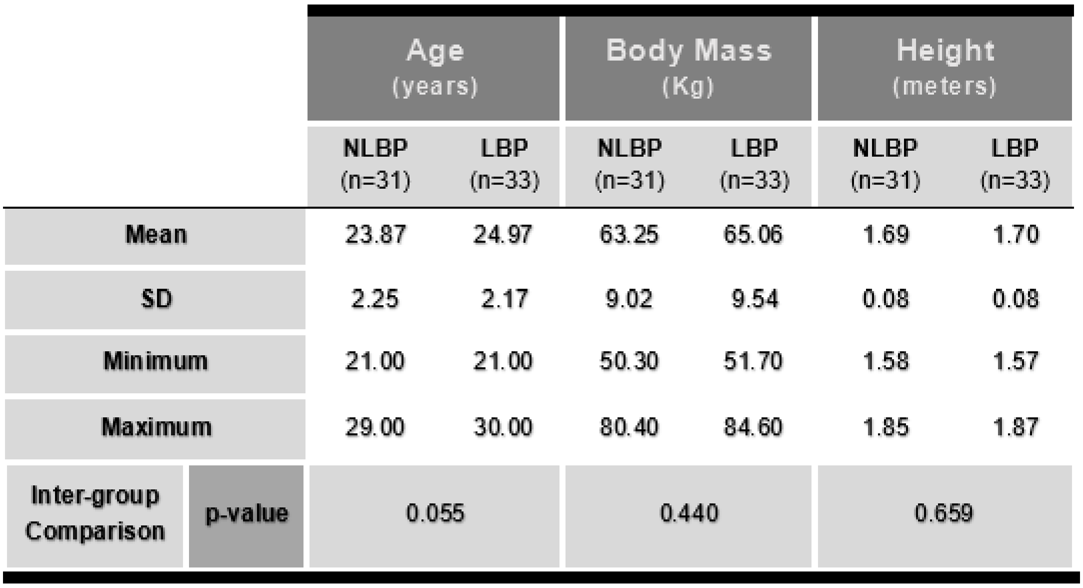
A descriptive statistic analisys was performed for sample characterization, calculating the mean, standard deviation, maximum and minimum (Marôco, 2011). To compare groups (pelvic tilt and muscles onset timings) the t-test was used for two independent samples. The assumptions of t-tests were guaranteed by the central limit theorem, since each group had more than 30 subjects (Marôco, 2011). The order and muscle activation sequence analysis was performed using a comparison of absolute and relative frequencies of each group. The Fisher exact test was performed to verify the association between the 5 most used muscle activation sequences and their respective group (chi-square assumptions were not insured) (Marôco, 2011). Also, Mann-Whitney-U nonparametric test attested how certain muscle activation sequences influence pelvic tilt, due to low sample size in each sequence. In this last comparison, the variables were characterized by median and interquartile deviation (Marôco, 2011).

3. Results

3.1 Sample

The NLBP group comprised 31 individuals and the LBP group 33. The LBP group presented an average pain intensity of 50.6 ± 0.86 mm (VAS scale) and a mean duration of 6.94 ± 1.90 years. Demographic and anthropometric data (Table 1) showed no significant differences between groups (p>0,05), therefore, the groups were comparable.

Table 1. Characteristics of demographic and anthropometric data of the sample with the respective mean, standard deviation (SD), minimum and maximum values. NLBP – Group without low back pain; LBP – Group with low back pain.



		Age (years)		Body Mass (Kg)		Height (meters)	
		NLBP (n=31)	LBP (n=33)	NLBP (n=31)	LBP (n=33)	NLBP (n=31)	LBP (n=33)
Mean		23.87	24.97	63.25	65.06	1.69	1.70
SD		2.25	2.17	9.02	9.54	0.08	0.08
Minimum		21.00	21.00	50.30	51.70	1.58	1.57
Maximum		29.00	30.00	80.40	84.60	1.85	1.87
Inter-group Comparison	**p-value**	0.055		0.440		0.659	

3.2 Study results

In Figure 1 are presented the mean onset timings and standard deviation values. In the LBP group, the GM_Ipsi (t=-3.171, p=0.002) and BF_Ipsi (t=-2.092, p=0.041) muscles activated significantly later, compared with the NLBP. No significant differences were seen between both groups in the ES_Ipsi and ES_Contra muscles (p>0.05). Additionally, the onset timing of most muscles occurred before movement initiation, excepting the GM_Ipsi muscle, where the NLBP group onset timing occurred almost simultaneously with the movement initiation, contrasting with the LBP group delay. Regarding muscle activation sequence (Table 2), there was a great variability in both groups (NLBP group: 10 of 24 possible sequences; LBP group: 9 of 24 possible sequences). Despite this, there was a significant association between the 5 most frequent muscle activation sequences used and the presence of LBP (Xf2=11.54, p=0.015).

Therefore, the only difference in the common activation sequences in both groups is the activation order of the ES muscles. Also, the "ideal" sequence (GM_Ipsi>BF_Ipsi>ES_Contra >ES_Ipsi) was not used in any group.

Based on the activation sequences, was analyzed which muscles activated first and last. Observing Table 3, the BF_Ipsi was usually the first muscle activated in both groups and GM_Ipsi the last.

In Table 4 was observed the comparison of the onset timing of the first and last muscle sequence and the period between them. Thus, in the LBP group, the last muscle was activated significantly later, compared to the NLBP group. The same tendency occurred with the first muscle being activated, however it was not significant.

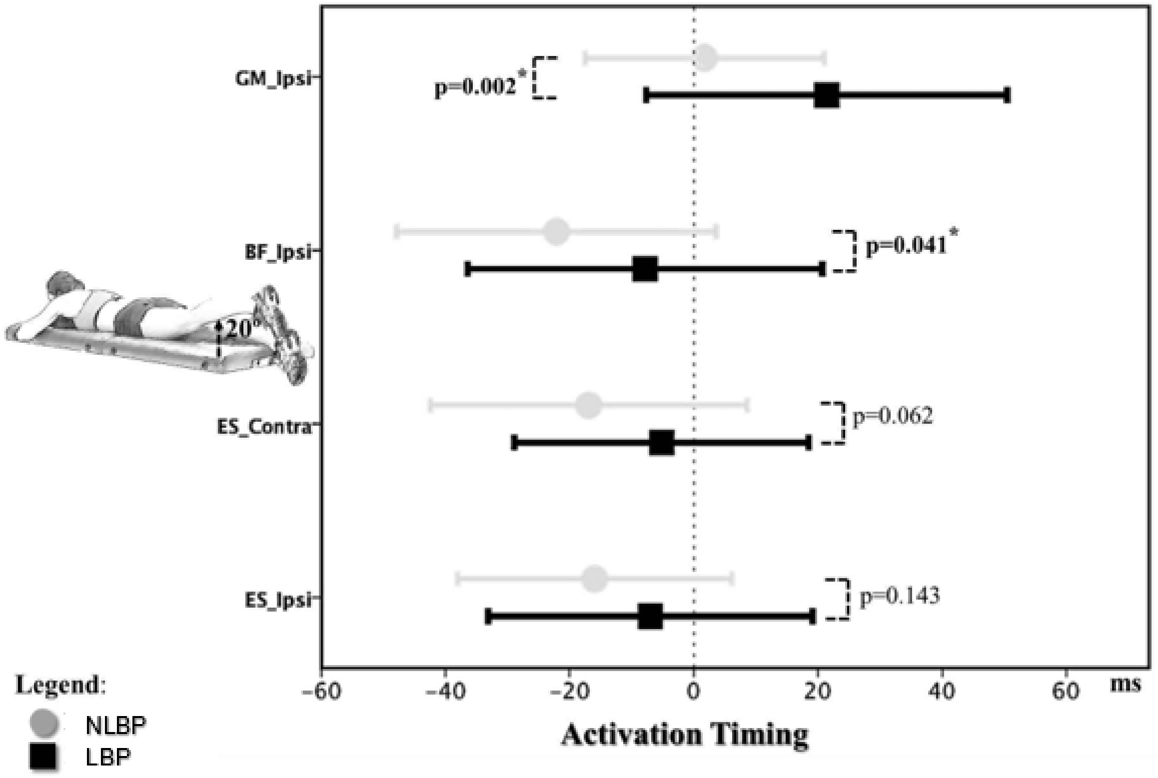
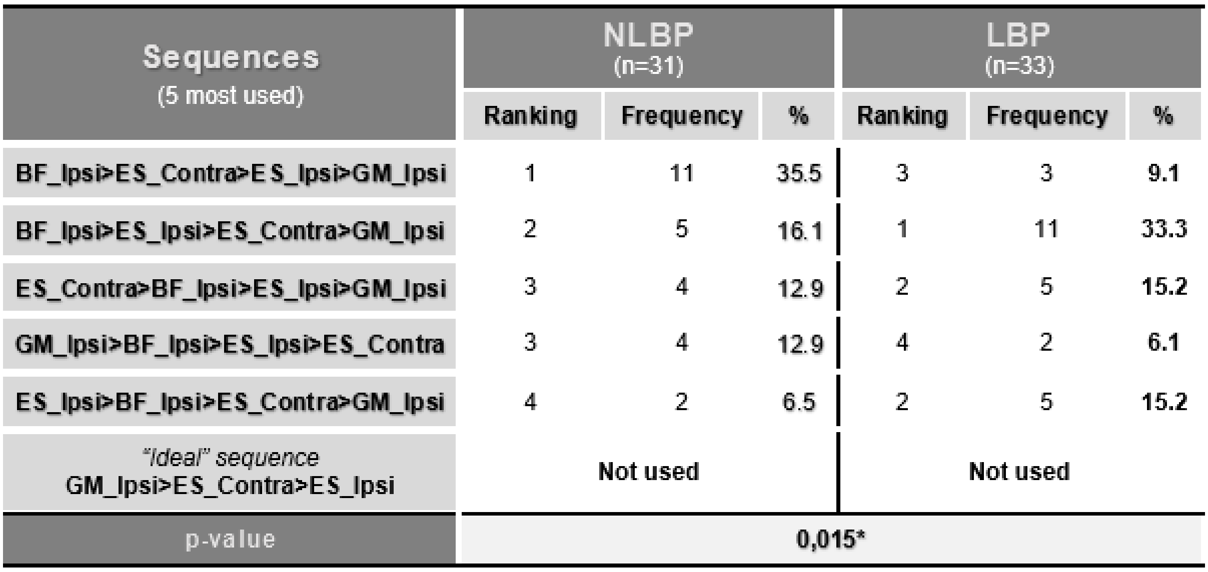


Figure 1. Comparison the onset timings of the Gluteus Maximus Ipsilateral (GM_Ipsi), Biceps Femoris Ipsilateral (BF_Ipsi), Erector Spinae Ipsilateral (ES_Ipsi) and Contralateral (ES_Contra) between the two groups. NLBP – Group without low back pain; LPP – Group with low back pain. *Significant difference (p<0.05).

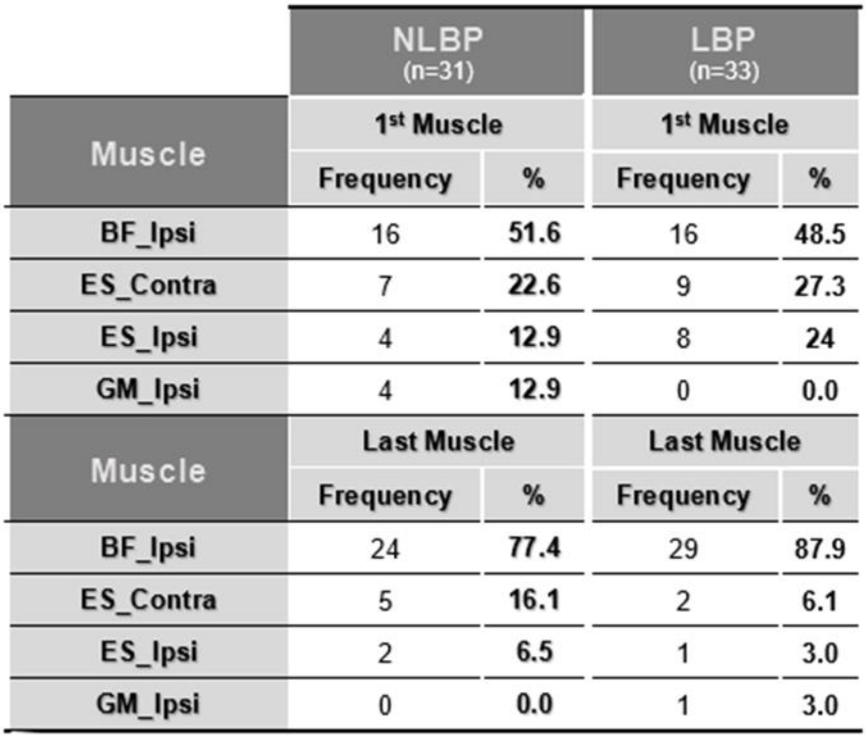
Table 2. The 5 most common muscles activating sequences in each group (NLBP – Group without low back pain; LPP – Group with low back pain) and their respective ranking. The results are presented as relative and absolute frequencies. BF_Ipsi – Biceps Femoris Ipsilateral; ES_Contra Erector Spinae Contralateral; ES_Ipsi - Erector Spinae Ipsilateral; GM_Ipsi – Gluteus Maximus Ipsilateral.



Sequences (5 most used)	NLBP (n=31)			LBP (n=33)		
	Ranking	Frequency	%	Ranking	Frequency	%
BF_Ipsi>ES_Contra>ES_Ipsi>GM_Ipsi	1	11	35.5	3	3	9.1
BF_Ipsi>ES_Ipsi>ES_Contra>GM_Ipsi	2	5	16.1	1	11	33.3
ES_Contra>BF_Ipsi>ES_Ipsi>GM_Ipsi	3	4	12.9	2	5	15.2
GM_Ipsi>BF_Ipsi>ES_Ipsi>ES_Contra	3	4	12.9	4	2	6.1
ES_Ipsi>BF_Ipsi>ES_Contra>GM_Ipsi	4	2	6.5	2	5	15.2
"Ideal" sequence GM_Ipsi>ES_Contra>ES_Ipsi	Not used			Not used		
p-value	0,015*					

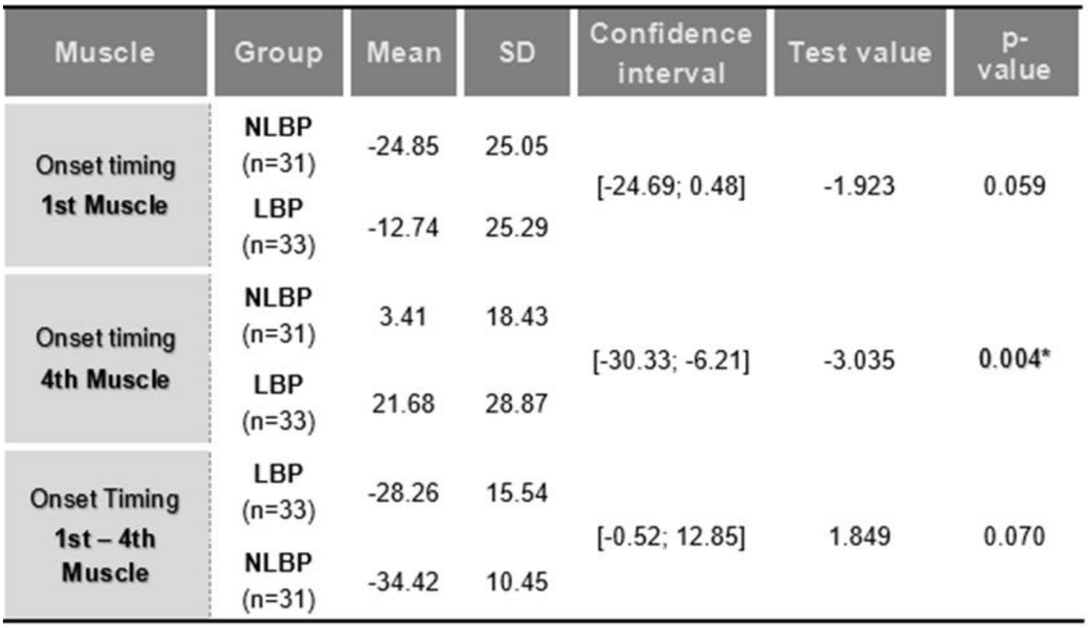
There were no significant differences between groups for pelvic tilt (Table 5). However, LBP group presented higher pelvic tilt values. Although, significant differences were found in individuals of both groups who activated BF_Ipsi first as they showed significantly greater pelvic tilt compared to individuals who used another muscle as first strategy.

Table 3. The muscles that had a higher frequency of activation in the first and last place in the activation sequence. The results are presented as relative and absolute frequencies. BF_Ipsi–Biceps Femoris Ipsilateral; ES_Contra–Erector Spinae Contralateral; ES_Ipsi–Erector Spinae Ipsilateral; GM_Ipsi–Gluteus Maximus Ipsilateral; NLBP–Group without low backpain; LBP–Group with low back pain.



Muscle	NLBP (n=31)		LBP (n=33)	
	1st Muscle		1st Muscle	
	Frequency	%	Frequency	%
BF_Ipsi	16	**51.6**	16	**48.5**
ES_Contra	7	**22.6**	9	**27.3**
ES_Ipsi	4	**12.9**	8	**24**
GM_Ipsi	4	**12.9**	0	**0.0**
Muscle	**Last Muscle**		**Last Muscle**	
	Frequency	**%**	**Frequency**	**%**
BF_Ipsi	24	**77.4**	29	**87.9**
ES_Contra	5	**16.1**	2	**6.1**
ES_Ipsi	2	**6.5**	1	**3.0**
GM_Ipsi	0	**0.0**	1	**3.0**

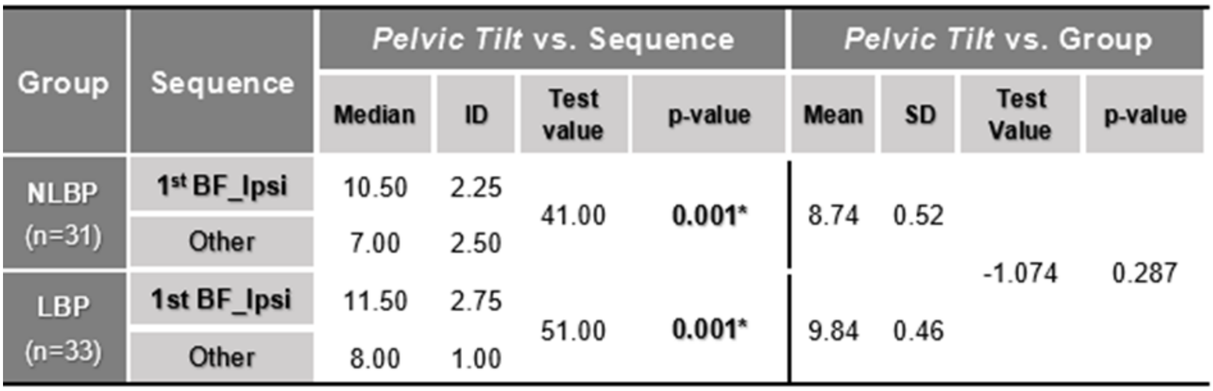
Table 4. The onset timing of the first and the last muscle in the sequence in both groups (NLBP – Group without low back pain; LBP – Group with low back pain). Presents the respective values of mean, standard deviation (SD), confidence interval, test value and p-value. *Significant differences (p<0.05).



Muscle	Group	Mean	SD	Confidence interval	Test value	p-value
Onset timing **1st Muscle**	**NLBP** (n=31)	-24.85	25.05	[-24.69; 0.48]	-1.923	0.059
	LBP (n=33)	-12.74	25.29			
Onset timing **4th Muscle**	**NLBP** (n=31)	3.41	18.43	[-30.33; -6.21]	-3.035	**0.004***
	LBP (n=33)	21.68	28.87			
Onset Timing **1st – 4th Muscle**	**LBP** (n=33)	-28.26	15.54	[-0.52; 12.85]	1.849	0.070
	NLBP (n=31)	-34.42	10.45			

Table 5. The pelvic tilt values in both groups (NLBP – Group without low back pain; LBP – Group with low back pain) relative to sequence of muscle activation and to the Group. Presents the respective

values of median, interquartile deviation (ID), mean, standard deviation (SD), test value and p-value. *Significant differences (p<0.05). BF_Ipsi – Biceps Femoris Ipsilateral.



Group	Sequence	*Pelvic Tilt* vs. Sequence				*Pelvic Tilt* vs. Group			
		Median	ID	Test value	p-value	Mean	SD	Test Value	p-value
NLBP (n=31)	1st BF_Ipsi	10.50	2.25	41.00	**0.001***	8.74	0.52	-1.074	0.287
	Other	7.00	2.50						
LBP (n=33)	1st BF_Ipsi	11.50	2.75	51.00	**0.001***	9.84	0.46		
	Other	8.00	1.00						

4. Discussion

According to the objectives of this study, it was observed that the LBP group showed an onset timing delay of biceps femoris and gluteus maximus. It was also observed that the "ideal" muscle activation sequence was never used. However, and despite some variability observed, the five most frequent muscle activation sequences used were common in both groups, and each group showed a predominant activation sequence. In both groups, the BF_Ipsi was the muscle activated mostly in first place and GM_Ipsi the last. Finally, it was observed that individuals who recruited BF_Ipsi muscle first had higher anterior pelvic tilt. These results seem important to understand how the muscular system may contribute to lumbopelvic stability. The muscles mechanical properties of this region provide joint structures the ability to resist deformation and that their stiffness changes dynamically due muscle activation (Lederman, 2010). However, motor control changes can cause an inappropriate recruitment, interfering with muscle activation sequences and with the ability to automatically perform an adequate movement pattern. These changes can impact the physiological joint load, changing the direction and magnitude of imposed forces, originating the onset of LBP (Lewis & Sahrmann, 2009; Sahrmann, 2002; Silfies et al., 2005; Van Dieën et al., 2017).

Thus, it is pertinent to evaluate the onset timing. In this study was observed significant differences in the onset timing of GM_Ipsi and BF_Ipsi muscles between both groups, with a delayed onset in the LBP group. Regarding the beginning of movement, it was observed that the onset timing of GM_Ipsi in LBP group occurred clearly after movement started, unlike the NLBP group in which occurred near the movement onset. The remaining muscles began their activity before motion occurs. Similar results were observed in the studies of Bruno et al. (2008), performed in 27 individuals without LBP, and Bruno & Bagust (2007), in 51 individuals (20 with LBP), both with a similar methodology as the present study. The study of Chance-Larsen et al., (2010), performed in 20 healthy subjects, revealed the same results, despite the different aim.

The onset timing delay verified in LBP group may stem from pain, by motor control changes (Brumagne et al., 2008; Bruno & Bagust, 2007; Bruno & Murphy, 2011; Hodges, 2001; Hodges et al., 2013; Tsao et al., 2011). The proposed theory is that pain causes reflex spasm of the deep muscles surrounding painful area, causing muscle imbalances and altered motor patterns. These patterns cause abnormal stress on joints and surrounding structures, which can cause injuries and repetitive traumas, further inhibiting these muscles and increasing the activity on superficial muscles, resulting in a vicious cycle until development and/or perpetuation of LBP (Hodges et al., 2003, 2013; Vogt et al., 2003).

To prevent these events, the muscle recruitment sequence throughout the movement must be studied. This study observed that individuals in the LBP group used 9 of 24 possible muscle activation sequences, and in the NLBP used 10 sequences. Despite the minimal difference between groups, less variability in LBP group may be a protective mechanism to restrict the available movement patterns and avoid further damage and pain intensity increase (Bruno & Bagust, 2007; Fritz & Steven, 2002; Hodges et al., 2013). The study of Bruno & Bagust (2007) found similar results, with a greater inconsistency in subjects without LBP.

The literature suggested a more efficient activation sequence to perform the hip extension movement (Bruno et al., 2008; Bruno & Bagust, 2007; Lehman et al., 2004; Page et al., 2010; Sahrmann, 2002). This theory argues that GM_Ipsi is the main muscle responsible for this movement and an important functional link between lumbopelvic region and lower limbs (Barker et al., 2014), being subsequently aided by the BF_Ipsi muscle. Immediately after these muscles contraction, ES_Contra activates and then the ES_Ipsi, to help stabilize the lumbopelvic region (Page et al., 2010; Panayi, 2010).

In this study, the "ideal" activation sequence was not used by any group. Similar results were found in a study of Bruno & Bagust (2006) conducted in healthy subjects, where the sequence was only used once in 300 repetitions. In another study conducted by the same authors, composed by individuals with and without LBP, this sequence was not used in 310 repetitions (Bruno & Bagust, 2007).

These LBP group changes in muscle activation patterns may be an adaptation to an underlying vertebral instability from osteoligamentar laxity, injury and/or muscle dysfunction and inefficient neuromuscular control (Arab et al., 2011; Ibarz et al., 2013; Silfies et al., 2009). Despite the NLBP group not showed symptoms, individuals may also have deficits in motor control (Silfies et al., 2005).

Despite the "ideal" sequence was not used in 192 repetitions, it was observed that each group presented a distinct muscle activation sequence, with a significant association between the five most frequent muscle activation sequences and the respective group. However, the muscle activation sequence closest to the "ideal" was used mainly by the NLBP group. The sequence of ES_Contra first and then the ES_Ipsi was correct, to stabilize the movement and protect the lumbopelvic region (Suehiro et al., 2015), as contrasted with the LBP group, where the ES activation sequence was inverted.

These results agree with the study of Vogt & Banzer (1997), composed by 15 healthy individuals, with methodology similar to this study, but with more muscles evaluated, and the study of Sakamoto et al. (2009), with 31 healthy volunteers, in which the EMG activity was evaluated for four modalities of therapeutic exercises. However, this was not observed in Bruno & Bagust (2006, 2007) and Lehman et al. (2004) studies. This results inconsistency may be related to methodological differences across studies, in sample size and specific set of muscles studied.

The muscle activation sequence analysis showed that BF_Ipsi, ES_Contra and ES_Ipsi muscles tend to become active before GM_Ipsi. Between these three muscles, BF_Ipsi activated predominantly first. The GM_Ipsi muscle, which should be the first activated, was mostly last in both groups, residing the exception of a small percentage of individuals of NLBP group.

These results are similar to Bruno & Bagust (2006) study which showed that BF_Ipsi was the first activated in 34.3% of 300 repetitions and GM_Ipsi was the last activated in 81.3% of those repetitions. A study by the same authors showed that BF_Ipsi was the first and GM_Ipsi the last to be activated, respectively, in 49.7% and 81.3% of 310 repetitions in healthy subjects. In individuals with LBP, BF_Ipsi activated first and GM_Ipsi the last, in 61.5% and 99.0% of repetitions, respectively (Bruno & Bagust, 2007).

Given these findings, it becomes pertinent to compare the muscle activation onset timings in relation to each other, reinforcing the idea of a significant activation delay of GM_Ipsi in the LBP group. Same results were observed in Bruno et al. (2008) study. These muscles may be activated early to stabilize the spine before the onset of the GM_Ipsi. If so, a GM_Ipsi onset delay may possibly lead to a compensatory strategy by other muscles, like first place activation or increased activity (Arab et al., 2011; Jung et al., 2015; Kahlaee et al., 2017; Kim et al., 2014; Suehiro et al., 2015). This strategy may increase loads and tensions transmitted to lumbar spine during everyday activities, indicating a possible mechanism to develop and/or perpetuate LBP (Bruno & Bagust, 2007; Lewis & Sahrmann, 2009; Tateuchi et al., 2012).

Therefore, GM_Ipsi was expected to be the last muscle activated in individuals with LBP, compared to individuals without it. However, this study does not support this assumption, since the GM_Ipsi in the NLBP group was also the last most activated muscle. The difference resides only in the lower onset timing in NLBP group. Thus, the delay appears to be a normal finding, consisting in a lumbopelvic stabilization strategy, changing the forces transferred through the pelvis (Arumugam et al., 2012; Chance-Larsen et al., 2010; Guimarães et al., 2010; Hungerford et al., 2003; Kang et al., 2013; Lewis & Sahrmann, 2009; Schuermans et al., 2017; Tateuchi et al., 2012).

The weakness or inhibition of GM_Ipsi may result from muscle injury or hyperactivity of antagonist and/or synergist muscles (Hossain & Nokes, 2005; Sahrmann, 2002; Ward et al., 2010). Also, this GM_Ipsi mechanical weakness or inhibition may be associated with a neurological inhibition due to changes in the muscle activation sequence (Sahrmann, 2002). The new sequence is stored in cerebellum, also contributing to GM_Ipsi inhibition (Sahrmann, 2002). This weakness or inhibition is usually associated with hip flexors stiffness (Malai et al., 2015; Mills et al., 2015), lack of motor control or dominant muscles activity of ES_Ipsi, ES_Contra and BF_Ipsi. This can induce excessive anterior pelvic tilt during hip extension and subsequent lumbar spine hyperextension (Choi et al., 2015; Kang et al., 2013; Oh et al., 2007; Page et al., 2010; Tateuchi et al., 2012). These changes can cause excessive stress in lumbar spine and sacroiliac joint during gait, due shock absorption mechanism deficiency (Kang et al., 2013; Sahrmann, 2002; Van Der Hulst et al., 2010).

This study confirmed this hypothesis since the individuals who activated BF_Ipsi first showed greater pelvic tilt and consequently greater pelvic anteversion and lumbar lordosis. The interaction between the synergistic dominant muscles, which act in force couple, like the GM and BF, may explain these results. These muscles have different characteristics depending on the muscle lever arm and the hip flexion-extension angle (Chance-Larsen et al., 2010; Choi et al., 2015; Kang et al., 2013; Tateuchi et al., 2012). The GM lever arm increases with higher hip extension angle and the opposite applies in BF (Tateuchi et al., 2012). Based on these observations, the GM may have relative advantage in providing extension force, although both muscles are shortened in hip extension. Consequently, BF tends to be recruited sooner, increasing pelvic tilt and lumbar spine extension (Hossain & Nokes, 2005; Hungerford et al., 2003; Kang et al., 2013; Tateuchi et al., 2012).

All these results conclude that the use of functional tests, with the aid of biofeedback units, can help physiotherapists to detect and understand the presence of muscle imbalances. Despite the controversial "ideal" muscle activation sequence, changes in these tests may be an indicator to initiate an intervention aimed in optimizing the motor control and restoring the lumbopelvic stability. Motor control changes may negatively impact lumbopelvic stabilization. This does not suggest that all individuals with muscle activation sequence changes exhibit the same motor control deficit and require the same level of intervention. Therefore, intervention programs must be compatible with the demands and requirements of each patient.

The innovation of this study compared to previous ones is that it investigates an association between the muscle activation sequence and pelvic tilt, allowing to verify how onset timing and muscle activation sequence influence pelvis position in the sagittal plane.

5. Conclusion

The present study observed that the LBP group showed a significant activation delay of GM_Ipsi and BF_Ipsi, and that a consistent muscle activation sequence was present in each group. However, the results seem to refute the "ideal" muscle activation sequence, since it was not observed in both groups.

It was found that GM_Ipsi muscle was the last activated in both groups. However, this finding does not allow to support or refute the prevailing theory that an activation delay of GM is associated with LBP, because it was observed in both groups. However, this delay in the onset timing was higher in the LBP group.

Also, it was observed that the BF_Ipsi muscle was the first activated, and the individuals who activated this muscle first, had a significantly higher pelvic tilt.

Although, future research is needed to confirm these findings in individuals with LBP, as this test seems to be a tool to determine if the GM can be a potential cause for motor control changes and be used as an indicator for the prescription of therapeutic programs that aim restoring the normal sequence of GM activation.

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