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Biomechanical analysis of the lumbar area using surface electromyography: Flexion–relaxation ratio in maintenance workers

Sara Cecilia Herrera-Espitia[1], Natali Olaya-Mira[2], Isabel Cristina Soto-Cardona[3], Jonathan Osorio-Vasco[4],

[1] Ingeniería Biomédica. Instituto Tecnológico Metropolitano. Colombia. saraherrera240136@correo.itm.edu.co

[2] Maestría en Ingeniería Mecánica. Instituto Tecnológico Metropolitano. Colombia. nataliolaya@itm.edu.co

[3] Maestría en Ingeniería Biomédica. Instituto Tecnológico Metropolitano. Colombia. isabelsoto@itm.edu.co

[4] Maestría en Seguridad y Salud en el Trabajo. Instituto Tecnológico Metropolitano. Colombia. jonathanosorio296299@correo.itm.edu.co

Abstract

Objective: This study analysed the presence and absence of electromyographic silence during the holding phase of the flexion-relaxation of the trunk.
Methodology: The electrical activity of two back muscles (i.e., longissimus and multifidus) of 10 male workers in the maintenance sector, all younger than 65, was recorded when they performed an unloaded anterior flexion of the trunk for 15 seconds. The risk of suffering from low back pain was evaluated based on the calculated flexion-relaxation ratios.
Results: In the sample, the average FRRs of the longissimus and multifidus muscles were 6.47 ± 4.21 and 7.99 ± 4.71, respectively. In addition, 20% of the subjects presented values under 2.98 in the longissimus; and 40%, values under 7.21 in the multifidus—which indicates an absence of silences and possible pain. The average flexion velocity was 103.67 ± 15.56°/s; the average relaxation velocity, 98.968 ± 19.11°/s; and the average flexion angle, 106.94 ± 12.60°.
Conclusion: The results of this study demonstrate that, in the long term, maintenance and general service workers may suffer from chronic low back discomfort or pain as a consequence of their daily duties.

---------*Keywords:* low back pain, lumbar region, occupational health, surface electromyography, biomechanical phenomena.

Análisis biomecánico de la zona lumbar mediante electromiografía de superficie: Relación flexión-relajación en trabajadores de mantenimiento

Objetivo: Este estudio analizó la presencia y ausencia de silencio electromiográfico durante la fase de mantenimiento de la flexión-relajación del tronco.
Metodología: Se registró la actividad eléctrica de dos músculos de la espalda (longissimus y multifidus) de 10 trabajadores varones del sector del mantenimiento, todos ellos menores de 65 años, cuando realizaban una flexión anterior del tronco sin carga durante 15 segundos. Se evaluó el riesgo de padecer lumbalgia en función de los coeficientes de flexión-relajación calculados.
Resultados: En la muestra, los FRR medios de los músculos longissimus y multifidus fueron 6,47 ± 4,21 y 7,99 ± 4,71, respectivamente. Además, el 20% de los sujetos presentaron valores inferiores a 2,98 en el longissimus; y el 40%, valores inferiores a 7,21 en el multifidus, lo que indica ausencia de silencios y posible dolor. La velocidad media de flexión fue de 103,67 ± 15,56°/s; la velocidad media de relajación, de 98,968 ± 19,11°/s; y el ángulo medio de flexión, de 106,94 ± 12,60°.
Conclusiones: Los resultados de este estudio demuestran que, a largo plazo, los trabajadores de mantenimiento y servicios generales pueden sufrir molestias o dolor lumbar crónico como consecuencia de sus tareas diarias.

---------*Palabras clave:* lumbalgia, región lumbar, salud laboral, electromiografía de superficie, fenómenos biomecánicos.

Análise biomecânica da área lombar usando eletromiografia de superfície: Relação flexão-relaxamento em trabalhadores de manutenção

Objetivo: Este estudo analisou a presença e a ausência de silêncio eletromiográfico durante a fase de retenção da flexão-relaxamento do tronco.
Metodologia: A atividade elétrica de dois músculos das costas (ou seja, longissimus e multifidus) de 10 trabalhadores do sexo masculino do setor de manutenção, todos com menos de 65 anos, foi registrada quando eles realizaram uma flexão anterior do tronco sem carga por 15 segundos. O risco de sofrer de dor lombar foi avaliado com base nos índices de flexão-relaxamento calculados
Resultados: Na amostra, os FRRs médios dos músculos longissimus e multifidus foram 6,47 ± 4,21 e 7,99 ± 4,71, respectivamente. Além disso, 20% dos indivíduos apresentaram valores abaixo de 2,98 no longissimus e 40%, valores abaixo de 7,21 no multifidus, o que indica ausência de silêncios e possível dor. A velocidade média de flexão foi de 103,67 ± 15,56°/s; a velocidade média de relaxamento, de 98,968 ± 19,11°/s; e o ângulo médio de flexão, de 106,94 ± 12,60°
Conclusão: Os resultados deste estudo demonstram que, a longo prazo, os trabalhadores de manutenção e serviços gerais podem sofrer de desconforto ou dor lombar crônica como consequência de suas tarefas diárias.

---------*Palavras-chave:* dor lombar, região lombar, saúde ocupacional, eletromiografia de superfície, fenômenos biomecânicos.

Introduction

The World Health Organization has estimated that there are 1.7 billion Musculoskeletal Disorders (MSDs) around the world (1). Low Back Pain (LBP) is the most prevalent MSD, with around 568 million affected individuals, and the biggest cause of disability in 160 countries (1).

LBP is an important problem in industrial societies and the MSD that causes most early retirements (1). It has been calculated that LBP affects 70–85% of all individuals at some point in their lives (2, 3). In the US in 2008, the direct and indirect health care costs of LBP were USD 12.2–90.6 and USD 7.4–28.2 billion, respectively (4). In Colombia, a health care provider reported that the total cost of LBP treatment between 2008 and 2011 was COP 59,070,371. According to their data, LBP caused 465 days of sick leave and an average cost of COP 2,169,625 per worker on sick leave between 91 and 180 days (3).

LBP commonly appears in maintenance, general services, and cleaning workers (5) due to poor posture during their work activities, such as when they move the trunk (6, 7). LBP caused by overexertion of the hips and trunk movements is a serious concern in occupational health and ergonomics (6-8).

Preventive occupational analysis and evaluation of physical effort and trunk movements in the workplace have been based on observational methods and self-reporting. These are two useful tools because they are low-cost and affordable for occupational safety professionals (9, 10). However, these methods can be inaccurate because they are based on the subjective interpretation of those who make the observations and self-report (10, 11). Other evaluation methods, such as Surface Electromyography (sEMG), can be used in the workplace and improve accuracy (9). More precisely, an ergonomic evaluation methodology based on sEMG can help to prevent work-related MSDs.

Some studies have employed sEMG to evaluate the function of the trunk muscles (12) and spinal compression in the industrial sector (13). As a non-invasive painless tool, sEMG can be used to analyse muscle activity while at rest or during movement. This evaluation technique is useful because it can efficiently and directly measure many variables accurately if implemented correctly (9). These variables can be compared in different periods of time. Therefore, sEMG can be used in biomechanical or ergonomic studies to investigate the effects of multiple risk factors in the workplace (13).

An application of sEMG is the study of the muscle electrical activity in the trunk to analyse an individual's predisposition to LBP. Studies have shown that there is a difference between the electrical activity of the anterior flexion and relaxation of the trunk (14, 15). They have demonstrated that, in healthy subjects, there should be a period of electrical silence in the low back muscles (Figure 1) when the trunk reaches an angular position between 40° and 70° in lumbopelvic flexion. This is known as the Flexion-Relaxation Phenomenon (FRP) (16).

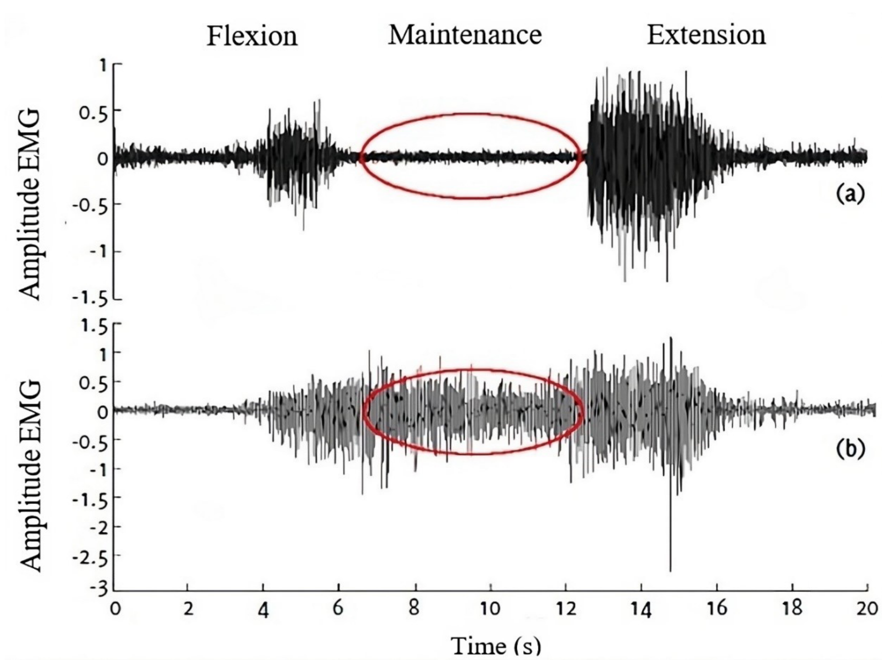

Figure 1. Presence (a) and absence (b) of electromyographic silence in lumbar flexion-relaxation test [17].

This period of electrical silence has been attributed to the completion of the lumbar flexion and the consequent relaxation of the paraspinal muscles. The anterior flexion is achieved with pelvic rotation, controlled by the muscles that act on the pelvis. During this period of electrical silence, the paraspinal muscles generate a considerable amount of elastic force through the thoracolumbar fascia, which contributes most of the force required to hold the body in this position (18).

Considering this silence, it is possible to calculate a ratio that relates muscle activity during forward flexion and totally relaxed positions. This is called the Flexion-Relaxation Ratio (FRR) (19).

The FRR is one of the phenomena studied in low back sEMG and a standard measurement to diagnose chronic LBP (20)–(24). Since diagnosing pain in this area is difficult and not very objective in the medical field, sEMG can be used to identify the presence or absence of the FRP and calculate the FRR. The FRP and the FRR should be support tools to establish an individual's predisposition to LBP so that it can be diagnosed and treated early.

This study investigated the FRP in a group of maintenance and general services workers at a university institution in Medellín (Colombia). These workers pick up and move furniture, equipment, and machinery; clean the facilities; and do general logistics activities at the institution. These work activities may be LBP triggers and these kinds of workers may exhibit an absence of electromyographic silences due to the activities they carry out daily. In Colombia, objective procedures have not been established to address this issue which would allow work-related LBP preventive assessment. Therefore, this study aimed to analyse the presence or absence of electromyographic silence during the holding phase of the flexion-relaxation of the trunk in maintenance and general services workers at a university institution in Medellín (Colombia).

Methodology

Type of study and population

This study adopted a non-randomized experimental design without a control group and followed the TREND guidelines. The electrical activity of two paraspinal muscles (i.e., longissimus and multifidus) in the low back area was recorded and analysed in 10 male workers according to the Surface Electromyography for the Non-Invasive Assessment of Muscles project recommendations (SENIAM) (25). At the time of the study, all the participants worked in general services at a university institution in Medellín (Colombia), reported no history of LPB, voluntarily signed the corresponding informed consent and their ages ranged between 28 and 65. Participant selection was based on convenience and was limited to the number of workers available at the institution on the day of the study.

Study design and experimental protocol

The muscle electrical activity of the participants was recorded using rectangular 3M 2228 electrodes (4 cm x 3.3 cm – Ag/AgCl) with FREEEMG 1000 wireless 4G probes (BTS Bioengineering Corp., Milan, Italy). A G-SENSOR inertial sensor (BTS Bioengineering Corp., Milan, Italy) was employed to analyze the posture of the unloaded anterior flexion for 15 seconds.

First, four wireless probes were positioned approximately between 2 and 3 cm from each other on the lumbar spine. Two of the probes were placed on the left and right longissimus muscles (erector spinae muscles), located between the L1 and L2 vertebrae, on the lowest floating ribs.

The other two probes were installed on the left and right multifidus muscles, located between the L4 and L5 vertebrae on top of the anterior superior iliac spines, where the lumbosacral passage or the lower lumbar tract can be found. Second, the inertial sensor was placed at the height of the inferior angle of the scapula. Figure 2 shows the location of the wireless probes and the inertial sensor on one of the participants.

The protocol was applied at the Biomechanics and Rehabilitation Laboratory of the Instituto Tecnológico Metropolitano in Medellín (Colombia). The room temperature in the laboratory was 25°C, and the humidity was controlled to collect the data from each subject. Each subject participated in three tests. Each test consisted of three phases, which can be observed in Figure 3.

Each phase lasted approximately five seconds. The first phase (contraction) is trunk flexion. During this phase, the electrical activity of the paraspinal muscles increases due to the eccentric control applied to perform the anterior flexion of the trunk. The second phase is the 'holding' or relaxation stage. During this phase, the muscle electrical activity stops because, when the trunk flexion is held, other muscles intervene, i.e., external oblique muscles, hip extensors (gluteus maximus), and knee flexor (hamstrings). This is the reason why there are electrical silences during the FRP. The third phase is trunk extension. During this phase, there should be increasing muscle electrical activity as the trunk is lifted due to the concentric contraction required to extend the trunk. The time of each phase was measured with a stopwatch. The muscle activity of each worker was recorded three times.

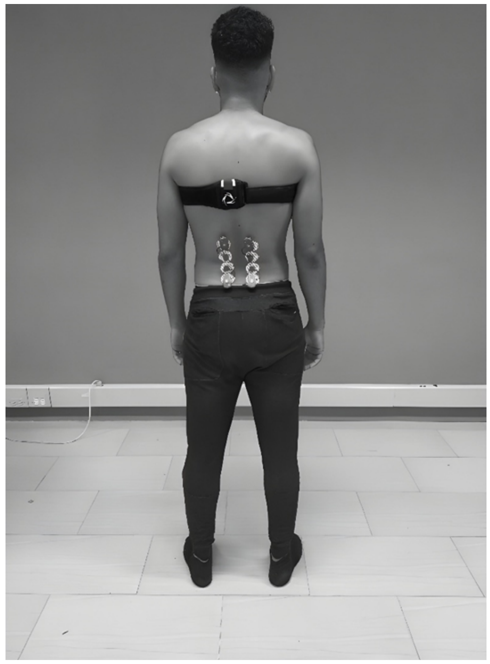

Figure 2. Placement of electromyographic probes and inertial sensor.

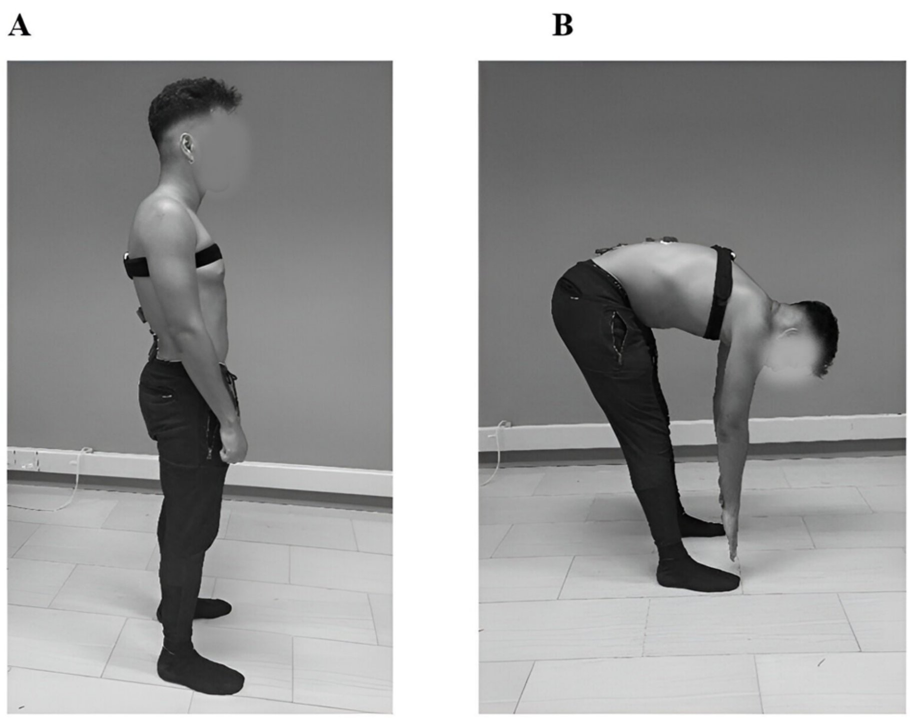

Figure 3. (A) Initial position before the flexion and (B) 'holding' phase before the extension.

Processing of electromyographic signals and statistical data

The signals were processed using BTS EMG-Analyzer V2.9.40.0 software (BTS Bioengineering Corp., Milan, Italy). The FRR was obtained by calculating the quotient of the energy (Root Mean Square value or RMS) delivered by the lumbar muscles during trunk flexion and the residual energy of the muscles (FRP) in the holding phase when the trunk is flexed. This calculation used Eq. (1) because low back pain can alter the normalization of the signals as it can induce maximum voluntary contraction.

$$FRR = \frac{\text{RMS of the trunk flexion}}{FRP} \qquad \text{Eq. (1)}$$

The average values for each worker and the overall average FRR, FRP, flexion velocity, extension velocity, and flexion angle were calculated for each muscle under evaluation. The overall average values were consolidated in a boxplot for descriptive statistical analysis of mean results and its standard deviation. BTS EMG-Analyzer v. 2.9.40.0 software from BTS Bioengineering was used for the electromyographic analysis.

Ethical considerations

This study adhered to the ethical principles outlined in the Declaration of Helsinki (DoH), as suggested by the World Medical Association (26). In addition, it followed the guidelines set forth in Article 6 of Resolution 8430 of 1993 by the Colombian Ministry of Health, which establishes the scientific, technical, and administrative standards for medical research involving human subjects.

Participants voluntarily signed an informed consent form to participate in the study. Participants requested that their personal data not be used in the data analysis. Ethical approval for the research was granted by the Research Ethics Committee at the Instituto Tecnológico Metropolitano (Medellín, Colombia) and recorded in Minutes 05 of the ordinary meeting held on September 24, 2020.

Results

Four sEMG signals per subject were collected during each test to measure the electrical activity of the longissimus and multifidus muscles. The FRP values for each muscle were necessary to calculate the FRR to assess presence/absence of electromyographic silence in maintenance workers. The overall average FRP value for each muscle is shown in Figure 4.

In turn, Figure 5 shows the average FRR for each subject. The longissimus and multifidus muscles were found to have an average FRR of 6.471 ± 4.210 and 7.994 ± 4.719, respectively. Out of the total sample, two subjects exhibited FRR values below the average in the longissimus and four in the multifidus. The reference values (longissimus FRR > 2.98; multifidus FRR > 7.21) were taken from Watson *et al.* (16).

The average flexion velocity was 103.666 ± 15.56°/s; the average extension velocity, 9.968 ± 19.11°/s; and the average flexion angle, 106.943 ± 12.60°, as illustrated in Figure 6.

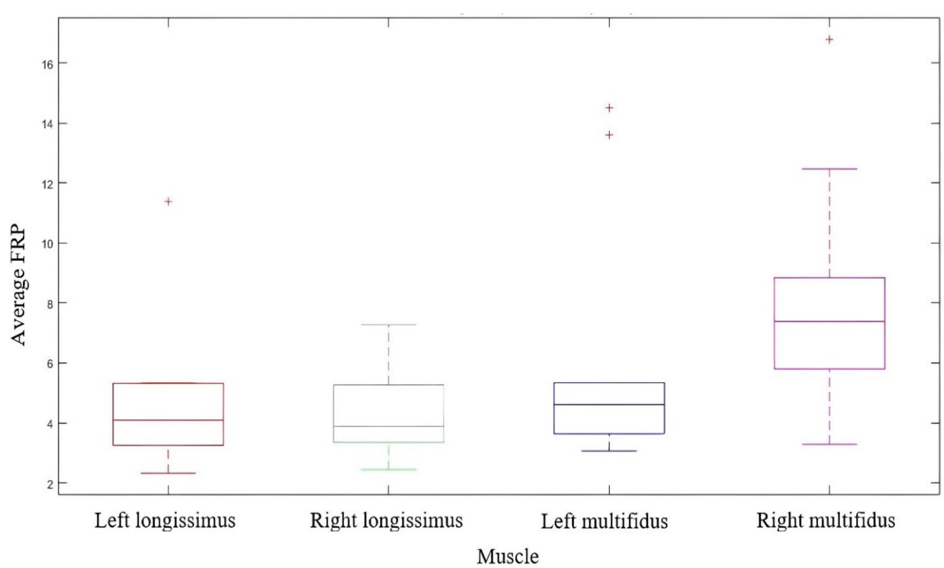

Figure 4. Overall average Flexion–Relaxation Phenomenon value for lumbar paraspinal muscles.

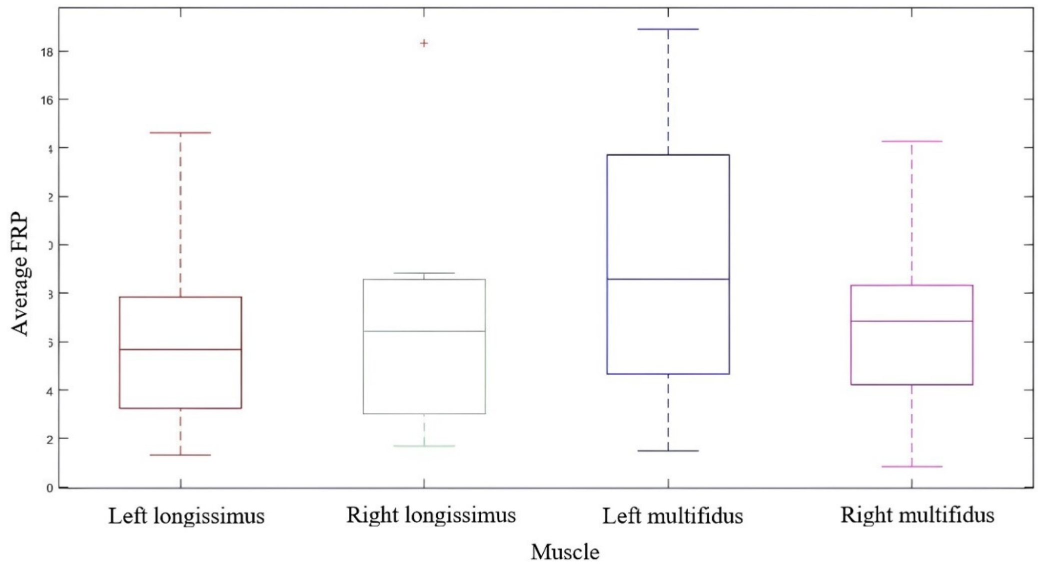

Figure 5. Average Flexion–Relaxation Rate of lumbar paraspinal muscles.

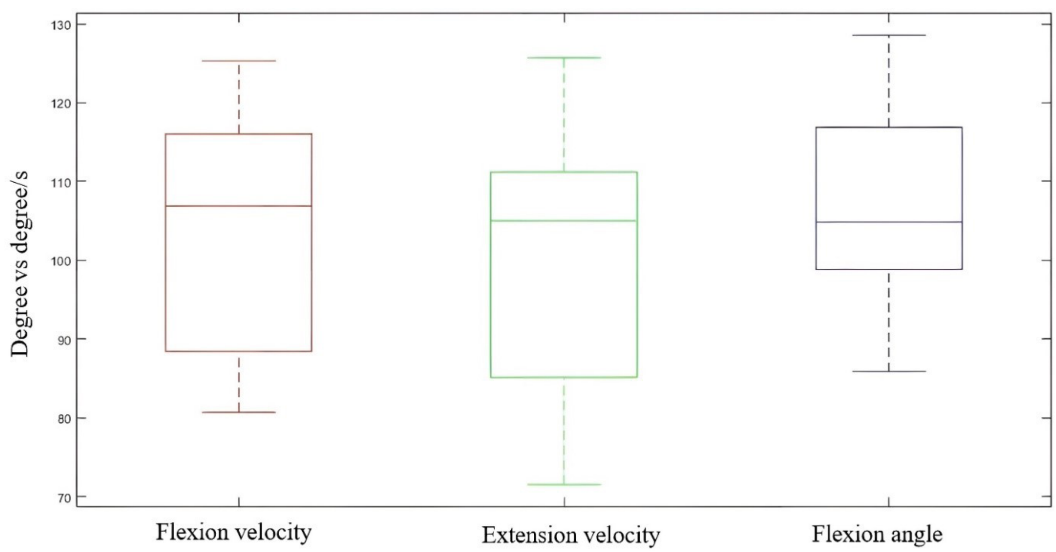

Figure 6. Average flexion velocity, extension velocity, and flexion angle.

Discussion

This study established that a group of general service workers presented no electrical silence in their paraspinal longissimus and multifidus muscles. Consequently, these workers may experience LBP or discomfort currently or in the near future. These findings are based on the analysis of their FRRs, which shows values of 2.98 and 7.21 for the longissimus and multifidus muscles, respectively (16).

The FRR is an indicator of the presence or absence of the FRP. The FRP is directly related to electrical silences in the paraspinal muscles during maximum relaxation in anterior trunk flexion, when the electrical activity drops to facilitate the concentric contraction necessary for trunk extension. However, the absence of the FRP indicates prolonged contraction of lumbar muscles, even when unnecessary, causing discomfort and potentially resulting in chronic LBP (27). Several authors have investigated the FRP by assessing muscle activity during different postures and movements to detect, evaluate, or predict pain, which is associated with the presence of electrical silences during maximum voluntary flexion (12-14, 17, 19).

It is difficult to normalize the signal when it is measured during maximum contraction of the paraspinal muscles in patients with chronic LBP. Nevertheless, this difficulty was overcome by calculating the FRR as suggested by Watson *et al.* (1997). They found that the normalization process could be unreliable due to pain-related anxiety, fear of re-injury, compensation, and other psychological factors, leading to intrasubject variation between tests (12, 16, 28). Thus, in the occupational setting, FRR analysis with direct measurement using sEMG can help to anticipate injuries in the lumbar region (29, 30)critically appraise, compare, and summarize the literature on the reliability, discriminative validity and responsiveness of the flexion relaxation ratio (FRR, particularly in jobs that require hip flexion and extension postures. This type of analysis should improve the planning of preventive actions for the musculoskeletal health of workers.

The participants presented a higher angular velocity than that reported in similar studies on lumbar flexion (31, 32). This could indicate a favorable condition of the population under study, considering that the angular velocity of flexion and extension show an individual's capacity to control the eccentric flexion and concentric muscular activity necessary to raise the trunk in extension against gravity (33).

Incorporating a biomechanical analysis of the low back (using sEMG) into occupational medical examinations could help to prevent work-related musculoskeletal injuries by timely detecting electromyographic silences in the longissimus and multifidus muscles, especially for jobs involving hip flexion and extension. Despite the high cost associated with direct measurement methods such as sEMG (9), around $400.000 COP (~100 USD) per person in this study at Laboratorio de Biomecánica y Rehabilitación from Instituto Tecnológico Metropolitano (May 2024), these diagnostic aids are crucial for improving occupational epidemiological surveillance of low back injuries in all relevant occupational fields.

Therefore, the potential value of this technique could be a long-term cost saver compared to major injury expenses associated with lack of early-stage intervention or work absence and possible subsequent rehabilitation process. It should be noted that sEMG should be carried out by adequately trained professionals, such as biomedical personnel, as well as possessing signal processing skills to obtain a correct diagnosis that will contribute to prevention activities. Training on the potential, application, and interpretation of sEMG is also necessary for occupational physicians, occupational health and safety professionals, ergonomists, occupational risk insurers, and other occupational health and safety professionals.

Additionally, the authors recommend approaching possible ethical issues by implementing this methodology within worker populations, such as those with potential for worker anxiety or discrimination based on test results. Given the benefits of its implementation, the information provided by this methodology must be handled ethically with absolute confidentiality and care supported by occupational risk insurers to avoid issues of workplace harassment.

This study focused on employees who work in maintenance and general services. Their tasks, despite having a pre-defined schedule, are varied and subject to frequent modifications based on the needs and requirements of the workplace. As a result, it was not possible to classify said tasks. Future studies with similar populations should accurately classify workers' roles and perceptions of pain or discomfort to establish a clear correlation with FRRs.

The methodology used in this study could be replicated with workers in other economic sectors (e.g., health care, agriculture, and transportation) to improve the early detection of back injuries or ailments. Given that the Third National Survey on Occupational Safety and Health Conditions in Colombia reported that 23.1% of employees suffer from back injuries at work (34), replicating this protocol could enhance the analysis of the FRR and encourage the adoption of preventive measures.

The results of this study demonstrate that, in the long term, maintenance and general service workers may suffer from chronic low back discomfort or pain as a consequence of their daily duties. In this context, sEMG is a quick, painless, and non-invasive tool for objectively evaluating their predisposition to LBP using ratios or calculations as the one used in this study, FRRs.

In addition, quantitative data of sEMG calculations can be combined with clinical expertise to provide an objective diagnosis more accurate than those obtained from observational methods and self-reports, which are commonly employed in occupational health and safety. The electromyographic silence evaluation proposed in this study should be considered by the different occupational health actors for the prevention, monitoring, and rehabilitation of the working population at risk of LBP.

Future studies can include more participants from other economic sectors and classify the duties they perform and are exposed to.

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Author's contribution statement

Sara Cecilia Herrera Espitia: Contribución sustancial a la concepción o diseño del artículo o a la adquisición, análisis o interpretación de los datos. Capacidad de responder por las cuestiones relacionadas con la exactitud o integridad de cualquier parte del trabajo.

Natali Olaya Mira: Contribución sustancial a la concepción o diseño del artículo o a la adquisición, análisis o interpretación de los datos. Participación en el diseño del trabajo de investigación o en la revisión crítica de su contenido intelectual. Aprobación de la versión final del manuscrito enviado. Capacidad de responder por las cuestiones relacionadas con la exactitud o integridad de cualquier parte del trabajo.

Isabel Cristina Soto-Cardona: Contribución sustancial a la concepción o diseño del artículo o a la adquisición, análisis o interpretación de los datos. Participación en el diseño del trabajo de investigación o en la revisión crítica de su contenido intelectual. Aprobación de la versión final del manuscrito enviado. Capacidad de responder por las cuestiones relacionadas con la exactitud o integridad de cualquier parte del trabajo.
Jonathan Osorio Vasco: Contribución sustancial a la concepción o diseño del artículo o a la adquisición, análisis o interpretación de los datos. Participación en el diseño del trabajo de investigación o en la revisión crítica de su contenido intelectual. Aprobación de la versión final del manuscrito enviado. Capacidad de responder por las cuestiones relacionadas con la exactitud o integridad de cualquier parte del trabajo.

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