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Biomechanics of the dorsolumbar region during manual patient lifting

Biomecánica de la región dorsolumbar durante el levantamiento manual de pacientes

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ABSTRACT

Background: Many work-related accidents and diseases that affect nursing assistants' health and the economy of companies are attributed to manual load handling. Among the available methods to analyses these tasks, NIOSH is one of the most commonly adopted. Furthermore, the implementation of biomechanical techniques enables to create and assess records that quantify the complexity of injuries. The objective is to evaluate the biomechanics of manual patient handling by the NIOSH method complemented with electromyography of the lumbar region and videogrammetry of the gesture. **Methods:** In a simulated work environment a patient was lifted to a gurney while the stability of the dorsolumbar region was calculated using electromyography. At the same time, the kinematics of the main joints involved in the gesture were recorded using videogrammetry. These data were compared with those of the NIOSH method to establish the main factors that may have an influence on the performance of manual load lifting. **Results:** The maximum recommended weight was found to be above the lifted weight. Besides, the lifting index suggested that the task could cause musculoskeletal issues. The coactivation of the pairs of medial muscles presented values under 50%. The kinematics of all the joints exhibited points of inflection during lifting and a wide variation of the amplitude of movement throughout the gesture. **Conclusions**: The variables that affect lifting depend on the design of the work environment. Moreover, they are closely related to articular kinematics and the height of the participants, who demonstrated good stability in the dorsolumbar region.

Keywords: Patient lifting; NIOSH; EMG; Kinematics; Occupational Health.

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I. INTRODUCTION

In the health care sector, practitioners often need to move patients who lack functional autonomy whether for rehabilitation, treatment, or hygiene (1). This task is known as "manual load lifting" because it requires a physical effort (2).

These activities have to be carried out manually due to the absence of technical equipment adapted to the conditions of a typical space where non-autonomous individuals are transported (1). However, they entail work-related accidents and diseases that have consequences on practitioners' health and the economy of companies (3) As a result, the profitability of the latter is reduced along with the employability and work capacity of the affected individuals, while the social cost of public health rise (2).

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There is an important relationship between manual load lifting and the onset of dorsolumbar conditions and pains. Morbidity and disability rates related to these pathologies are still high, which reveals a lack of understanding of a condition that is therefore underrated and undertreated (4). As a result, their effects are one of the most important action points for prevention in occupational health (more specifically, ergonomics).

Several epidemiological and biomechanical studies have identified the main risk factors associated with pain caused by manual load lifting, such as frequent leaning, spine rotations, and movement repetitions (5) However, indirect or direct methods can be employed to analyse this task. The former is based on observing the activity, e.g. the NIOSH (National Institute for Occupational Safety and Health) equation. The latter require different types of electronic devices and equipment to capture data (3) e.g. biomechanical analyses such as videogrammetry and electromyography. Said methods support in-depth studies of the dorsolumbar region and suggest the correct way individuals should perform manual load liftings.

Nevertheless, indirect and direct techniques have not been part of the same study. As a result, connecting the information and identifying the main factors behind pains in the dorsolumbar region of practitioners that complete said task every day constitutes a novel approach (6). This project analyses biomechanical and functional aspects that provide a more comprehensive description of this professional gesture in health care.

II. METHODS

2.1. Population. The sample was composed of 26 men with the following characteristics on average: age 38.04 (Standard Deviation: 11.379); height, 1.73 m (SD: 0.060); weight, 78.00 kg (SD: 9.526); and no background of musculoskeletal conditions that may affect the study.

2.2. Study Design. A gurney and a chair were installed to recreate the load lifting environment in health care and the conditions of the interaction between assistants and patients. The participants were instructed to freely repeat three times the gesture: lifting and moving an active patient with a weight of 73.2 kg from a 0.43m-tall chair to a 0.8m-tall gurney located 0.8 m away from said chair in the horizontal plane. Additionally, to analyze the kinematics of the movements, the gesture was divided into 5 phases: *Preparation* (phase 0) starts with the assistant in anatomical position and continues until after the knee is bent. *Lifting* (phase 1) occurs when the load (active patient) is held by the assistant. *Initial carrying* (phase 2) is the vertical movement of the patient. *Final carrying* (phase 3) refers to the horizontal displacement of the load. Finally, during *unloading* (phase 4) the assistant places the patient onto the gurney.

2.3. Data Processing. This gesture was characterized by incorporating anthropometric variables and those related to the work environment found in the NIOSH equation, as usually applied in this type of studies to define the Recommended Weight Limit (RWL) (7, 8) given by equation 1.

$$WL = LC \ x \ HM \ x \ VM \ x \ \ DM \ x \ AM \ x \ FM \ x \ CM \qquad (1)$$

where LC, is the load constant; HM, horizontal location; VM, vertical location; DM, vertical distance of the movement; AM, asymmetry; FM, frequency; and CM, grip.

The Lifting Index (LI) was calculated as the quotient between the weight of the lifted load and the RWL established for the task, as given in equation 2.

$$LI = \frac{Weight\ of\ the\ lifted\ load}{RWL} \quad \mathbf{(2)}$$

This index defines the risk the task represents in three intervals: LI ≤ 1, no problem is caused; $\mathbf{1 < LI < 3}$, problems may be caused; $\mathbf{LI \geq 3}$, some workers will suffer problems (7, 8)

The signals of the surface electromyography (EMGs) were captured with 3M® surface electrodes placed 2 cm apart on muscles in the abdominal and dorsolumbar regions(9,10): straight abdominal (SA), external (EO) and internal (IO) abdominal oblique muscles, longissimus (LO), iliocostalis (IL), and lumbar multifidus (LM) (**Figure 1**).

Figure 1. Placement of the surface electrodes

The signal was acquired with an ML138 differential bioamplifier integrated to a PowerLab 16/35 polygraph manufactured by AD Instruments Inc. A sampling frequency of 2 kHz was selected, and the signal was preprocessed with LabChart Pro software that implemented a 60-Hz notch filter and a bandpass filter with a cut-off frequency between 10 and 500Hz.

Matlab software was employed to calculate the coactivation percentage, which is a measure of the stability of the dorsolumbar region. The signals obtained from the muscles were filtered once again using a fifth-order digital Butterworth bandpass filter with cutoff frequencies between 10 Hz and 300Hz. The Root Mean Square (RMS) value of each resulting signal was calculated with a window of 250 samples and an overlapping of 50 samples. As a result, four muscle groups were created: SA/LO, SA/IL, SA/LM and EO/IO. Subsequently, each one of them was normalized using equation 3.

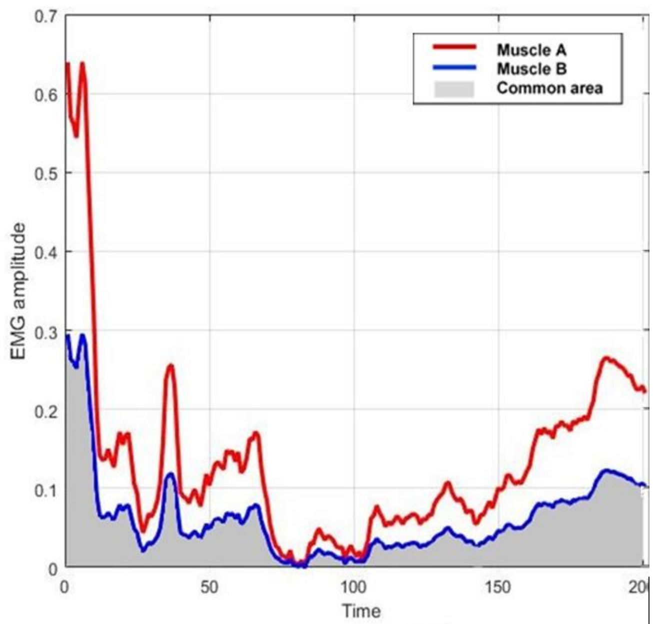
$$X_n = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (3)$$

where X_n represents the normalized signal; X, the original signal; and X_{min} and X_{max}, the minimum and maximum values of the original signal, respectively. Next, the coactivation percentage between muscle pairs was calculated with equation 4.

$$\%COACT = 2 \times \frac{common\ region\ A\ \&\ B}{region\ B + region\ A} \times 100 \quad (4)$$

where $\%COACT$ is the coactivation percentage between agonist and antagonist muscles; $\mathbf{R}egion\ A$, the area of muscle A under the curve of the processed EMG signal; $\mathbf{R}egion\ B$, the area of muscle B under the curve of the processed EMG signal; and $A\ \&\ B\ common\ area$, the common area of activity between muscles A and B (9) (**Figure 2**).

Figure 2. Area of the percentage of muscle coactivation



Two high-speed video cameras (Basler acA 640-120gc) connected to Contemplas software were used to capture the kinematics. In addition, reflective markers were placed on the most prominent bony landmarks, according to a modified Davis protocol (11). Subsequently, the articular movements of the ankle, knee, hip, and the lumbar spine were recorded in the sagittal plane. The lumbar spine was also studied in the posterior frontal plane.

Figure 3. Placement of the reflective markers

2.4. Statistical analysis. The statistical package SPSS 24.0 was used to treat the data, and the Shapiro-Wilk determined the normality of the data. The level of statistical significance considered in this study was 0.05.

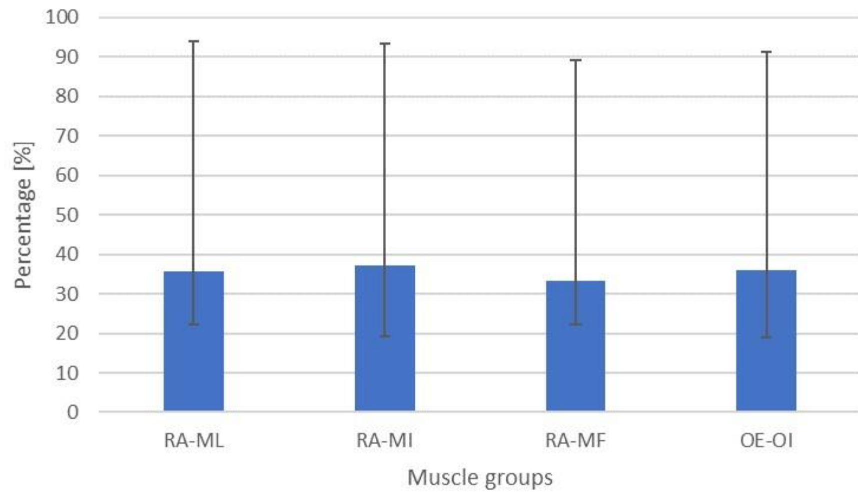
2.5. Ethical aspects. Nursing assistants at a public mental health-care institution —namely ESE Hospital Mental de Antioquia—voluntarily participated in this study. They signed an informed consent approved by the ethics committee of Instituto Tecnológico Metropolitano that observes the regulations introduced by the Declaration of Helsinki, as recommended by the World Medical Association (12)

III. RESULTS

All the variables related to the NIOSH equation exhibited normality. The mean weight limit recommended for the population under study is 38.7 kg (SD: 2.0), and the lifting index is 1.9 (SD: 0.1).

3.1. Muscle Coactivation. The coactivation of the muscles involved in flexion and extension presented normality; conversely, the coactivation of oblique muscles exhibited non-normality during torso rotation. Furthermore, the coactivation percentage of the straight abdominal muscle compared to the longissimus was 35% (SD: 22.1); to the iliocostalis, 37% (SD: 19.27); and to the lumbar multifidus, 33% (SD: 22.33). Likewise, the coactivation potential of the oblique muscles reached 36.13% (SD: 18.89) during rotation (**Figure 4**).

Figure 4. Muscle coactivation percentage



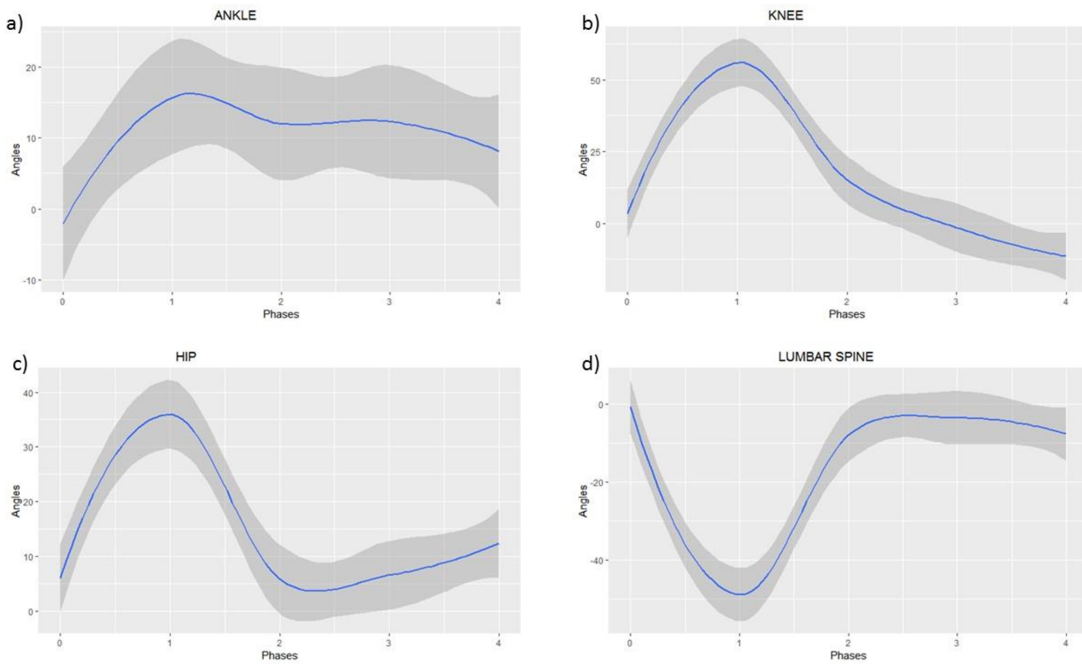
3.2. Articular Kinematics. The data of all the angles of the joints involved in the gesture showed normality in all the phases, except for the ankle during *preparation*, the spine in the frontal plane in *lifting*, the knee during the two phases of *carrying*, and the spine in the sagittal plane in *final carrying*. Additionally, all the joints revealed points of inflection during lifting and variations in the amplitude of movement throughout the execution of the gesture (**Figure 5**).

From the sagittal plane, the gesture starts with a plantar flexion of the ankle during *phase 0* that changes to dorsiflexion in *phase 1*. Between those two movements, the average angle of this joint was calculated at 15.67° (SD: 14.68), which varies in approximately 10.81° (SD: 18.72) (**Figure 5a**).

The knee joint exhibits a full flexion from the start, and it reaches a maximum angle in *phase 1*, approximately 55.86° (SD:17.9). This movement continues during *carrying* and *unloading*, and the extension varies 0.81° on average (SD: 21.52) (**Figure 5b**).

In this gesture, the hip starts in a flexion position that reaches its highest point, 35.93° (SD: 20.35), during *phase 1*, followed by an extension that continues to *phase 2*. This position is maintained until the movement is stabilised and completed in a joint range between 5.85° (SD: 10.72) and 12.34° (SD: 12.11) (**Figure 5c**).

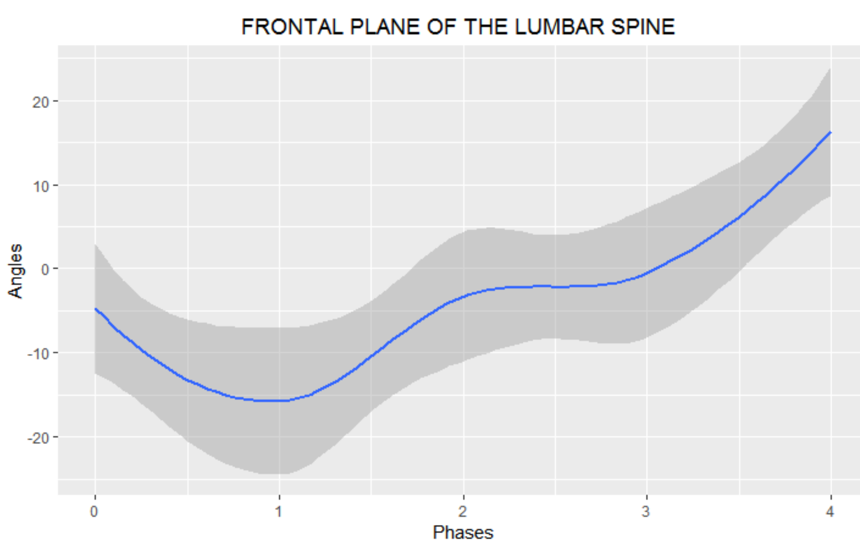
Figure 5. Kinematics of joint angles - Sagittal Plane a) Ankle; b) Knee; c) Hip; d) Lumbar Spine



The movement of the lumbar spine observed from the sagittal plane is composed of a maximum flexion (48.98° on average, SD:26.21) followed by a slight extension (6.44° on average, SD: 10.28) to be able to lift, move, and unload the patient until reaching the anatomical position while trying to achieve balance (**Figure 5d**).

Finally, the joint kinematics of the vertebral column in the frontal plane in *phase 0* revealed a rightward inclination and, at the exact moment of the lifting in *phase 1*, it smoothly changed leftward, balancing between both sides to try to achieve balance so that mobility can be compensated during the execution of the gesture (**Figure 6**).

Figure 6. Lumbar Spine - Frontal Plane



IV. DISCUSSION

The spatial distribution of furniture and equipment in the workplace, as well as the execution of the task, should be changed. In this case, the lifted weights exceeded the recommendations and low muscle coactivation was detected, which means adequate stability of the dorsolumbar region. Points of inflection were observed in all the joints during *lifting*, along with a wide variation of the amplitude of movement throughout the gesture.

The RWL calculated for the population under study depends on the lifting and carrying distances (8); in this study, it is greater than the lifted weight, which is reflected in an LI between 1 and 3 (8);. In accordance with the work by Pérez Domínguez and Caicedo (3, 13) these results suggest that nursing assistants are exposed to risks that may result in problems in the dorsolumbar region when they manually lift and carry patients.

In general, the coactivation percentages of all the muscle pairs were under 50%. When this percentage approaches 100%, stability decreases; when it tends to 0%, it increases (13).

Additionally, during flexion and extension movements, the straight abdominal and multifidus muscles presented the lowest coactivation. This may be due to the role of the multifidus in the stabilization of the vertebral column, since this muscle is activated before the load is supported or an extreme movement is executed and it contributes to the control of the neutral position of the spine (14). Likewise, the abdominal straight coordinates the main flexing actions of the trunk because it controls the external forces the vertebral column experiences (15). Furthermore, the straight abdominal and iliocostalis muscle pair presented the highest coactivation percentage, which suggests low lumbar stability for flexion and extension movements. This is because the iliocostalis is a deep muscle of the trunk located close to the centre of rotation of the vertebral segment, which makes it better prepared to control the mobility at the segmental and not at the global level (16)l

The coactivation data suggest adequate lumbar stability during rotation, because lumbar muscles are involved in physical activities and provide rigidity that helps to balance external loads, thus controlling the mobility of the lumbar spine (17) Moreover, the non-normality of the coactivation data of trunk rotation may have been due to the fact that, during the task, some participants moved the patients while rotating the trunk and others configured the posture with some steps to prepare to unload.

These results reveal that the stability of the spine is activated when there is a combination of muscles of the abdominal region and the lower back (18) working synergistically to balance the external load so that the resulting force is transferred and handled by the local stabilization system (16). As a result, if stability is good, part of the energy of the movements of the limbs may displace the pelvis and the trunk, thus affecting the limbs involved in the gesture and causing additional harmful stress on muscles. These circumstances produce several pains and subsequent dorsolumbar pathologies (14).

These kinematic results show a high variability of the ankle, possibly due to the spatial distribution of the workplace in relation to the height of the participants. More specifically, this environment forced them to execute the bipedal standing supported on the metatarsal region (standing on tiptoes) and a wide extension of the hip during *initial* and *final carrying* to reach the necessary height to unload the patient onto the gurney.

The maximum flexion experienced by the knee and the hip during *lifting* is necessary to gain momentum in order to vertically move the load and thus avoid the incorrect flexion of the lumbar spine in the sagittal plane. Similarly, lateral inclinations in the frontal plane should be avoided when the gesture is executed.

Considering the fact that non-autonomous patients are lifted and carried every day and throughout work shifts, this task should be performed by two assistants. Furthermore, nursing assistants should be retrained in postural hygiene for the execution of this task in order to reduce the risk of suffering from musculoskeletal injuries. Besides rearranging the furniture and equipment at the workplace, implementing patient lifts should be considered as an alternative to eliminate this occupational risk.

The techniques employed in this study, although more specific than traditional ones, may present errors. For example, the signal of the surface electromyography may be affected by the presence of adipose tissue in the abdominal region, and the videogrammetry may be disturbed by the markers (19). Nevertheless, they provide a deeper understanding that enables the biomechanical analysis of the dorsolumbar region during manual load lifting. Future works should employ the method called Movement and Assistance of Hospital Patients (MAPO) (20) or other relevant risk assessment strategies in this field.

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Conflicts of interest. The authors declare no conflict of interest.

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