Differences in muscular activity between obese and non-obese workers during manual lifting

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Abstract
The prevalence of obesity is increasing throughout the workforce. Manual lifting tasks are common and can produce significant muscle loading. This study compared muscular activity between obese and non-obese subjects, using surface Electromyography (EMG), during manual lifting. Six different lifting tasks (with 5, 10 and 15 kg loads in free and constrained styles) were performed by 14 participants with different obesity levels. EMG data normalization was based on the percentage of Maximum Contraction during each Task (MCT). Muscle Activation Times (AT) before each task were also evaluated. The study suggests that obesity can increase MCT and delay muscle AT. These findings reinforce the need to develop further studies focused on obesity as a risk factor for the development of musculoskeletal disorders.

Keywords: obesity; manual lifting; surface electromyography; maximum contraction during task; muscle activation time.

Diferencias en la actividad muscular entre trabajadores obesos y no obesos durante la elevación manual de cargas

Resumen
La prevalencia de la obesidad está aumentando también entre los trabajadores. Las tareas de elevación manual son comunes y pueden producir una significativa carga muscular. El actual estudio comparó la actividad muscular entre sujetos obesos y no obesos, mediante la aplicación de electromiografía de superficie (EMG) durante la elevación manual de cargas. Seis tareas de elevación muy diversas (con cargas de 5, 10 y 15 kg y con estilos de elevación libre y restringido) fueran solicitadas a los 14 sujetos con diferentes niveles de obesidad. La normalización de los datos de EMG fue basada en el porcentaje de la contracción máxima (MCT) durante cada tarea. También se ha evaluado el tiempo de la activación (AT) del músculo antes de cada tarea. El estudio sugiere que la obesidad puede aumentar el MCT y retrasar el AT del músculo. Estos resultados refuerzan la necesidad de desarrollar nuevos estudios, los cuales se deben centrar en la obesidad como un factor de riesgo para la aparición de síntomas y trastornos musculoesqueléticos.

Palabras-clave: obesidad; elevación manual; electromiografía de superficie; contracción máxima durante la tarea; tiempo de activación muscular.

1. Introduction

1.1. Effects of obesity on work performance

Improved social conditions among the population have led to an increase in the incidence of obesity in several countries, principally in the industrialized world. Global statistics confirm that obesity has more than doubled since 1980 and that, currently, more than 1.4 billion adults are overweight [1]. Obese subjects therefore represent a growing fraction of the workforce [2].

Obesity can be associated with psychological, social and physical problems, including Work-related Musculoskeletal Disorders (WRMSDs), which can negatively affect productivity [3,4]. Additionally, overweight subjects are absent from work due to illness more frequently and for longer periods than the non-obese [5]. This absenteeism is frequently related to WRMSDs [6].

Specific studies have analyzed different activities of daily life, comparing obese with non-obese subjects. Biomechanical studies of human walking have demonstrated that body fat mass (BFM) affects this activity [7]. For example, obese subjects reveal higher ground reaction forces [8], altered knee joint kinematics [9] and higher metabolic rates, even though the explanation for this last aspect has not been clearly established [10].

Additionally, stressful working postures are known to be related to the risk of WRMSDs. These postures can be affected by excessive BFM. However, the effects of obesity on posture maintenance during occupational tasks are rarely investigated [11]. Postural analysis tools, frequently used in workplace ergonomic interventions, seem to consider only people with normal weight. Based on this assumption, Park et al. [12] carried out psychophysical research with obese and non-obese subjects who were asked to perform static box-holding tasks in different working postures. In this study, the obese group reported higher perceived overload in all the postures considered, demonstrating that obesity increases postural stress. The findings of another study [13], also showed that the trunk posture of obese subjects was more flexed and that they experienced increased hip joint moment and greater hip-to-bench distance during a simulated standing work task.

Furthermore, it has also been demonstrated that obese subjects have more problems with work-restricting musculoskeletal pain than subjects of normal weight [14]. From the biomechanical point of view, excessive body mass can negatively affect the behavior of muscles and spine during the performance of physical activities. Different studies have correlated obesity with impairments to muscle activity, such as decreased muscle strength [7,15,16], as well as with lower back pain [17,18], although the epidemiological research literature has still not demonstrated a clear link between obesity and the latter phenomenon [19].

It is important to emphasize that lower back pain and its associated disorders continue to be the most common musculoskeletal problem in the workplace. It is associated with high costs to industry and can negatively influence the quality of life of workers. Several findings have shown that workers who perform manual materials handling, including lifting tasks, are exposed to a greater risk of back pain and/or WRMSDs than others whose jobs do not require this type of task [20,21]. However, such activities are very common in a wide variety of industrial workplaces [22]; they can have a range of additional occupational and individual WRMSD risk factors associated with them too. One of these individual risk factors is individual body composition, including excessive BFM [20].

In this context, Singh et al. [23] used a psychophysical approach and showed that obesity does not seem to reduce the maximum acceptable weight during manual lifting. However, these authors pointed out that this area requires further study, using other kinds of data, such as biomechanical information. Consequently, Xu et al. [24] analyzed lifting kinematics and kinetics in subjects with different body compositions, testing the hypothesis that heavier people lift more slowly, in order to minimize musculoskeletal load. However, obese subjects in fact registered higher values for kinematic trunk variables than their normal weight counterparts.

As mentioned above, although obesity has been intensively studied in recent years, research findings remain somewhat controversial. For example, the effect of excessive BFM on the function of the locomotor system is not yet well understood [7]. In addition, ergonomic studies are required to provide a more complete understanding of the effects of obesity on work performance [25], including during manual lifting tasks.

1.2. Assessment of obesity

Currently, obesity is assessed using different techniques, but each has several potential limitations and they should therefore be applied with caution. Among other available techniques, which include the body mass index (BMI), percentage of BFM, waist circumference (WC), WC/height ratio and WC/hip ratio, have been widely used in the assessment of obesity and to quantify the risk of obesity-related disorders [26].

It should be noted that in previous research into the effects of obesity on work performance, BMI has been the principal indicator used for obesity assessment. BMI is only based on a subject's weight and height; it does not distinguish fat-free body mass and fat mass, as it does not characterize body fat mass distribution [27]. BMI is an anthropometric measure commonly applied in epidemiological studies. However its specificity and predictive ability in identification of health problems associated with obesity have been questioned. BMI is considered to be a fallible measure for a detailed assessment of body composition and, therefore, should not be used to classify the individual level of obesity [28], implying the need to use more appropriate and comprehensive obesity assessment techniques.

For these reasons, in this study obesity levels were categorized according to subjects' BFM, determined by bioelectrical impedance analysis (BIA). This body composition assessment technique is easy to apply, non-invasive, relatively inexpensive and portable [29]. BIA allows for the quantification of body impedance by connecting electrodes to different areas of the body in order to create a circuit through which a current can pass. As the different human tissues exhibit different resistances to the passage of electric current, BIA devices determine the amount of lean body mass and body water as well as fat. Thus, the BFM can be obtained by calculating the difference between weight and lean body mass in individuals [28]. These results are obtained by way of predictive analytical expressions adjusted to individual factors such as gender, age, height and level of physical activity. These equations (which vary according to the equipment used) must be validated for the population in question, including obese individuals [30].

1.3. Muscular activity analysis during manual lifting

Obesity has been associated with impaired muscle function and reduced muscle strength [7,15,16]. These alterations to muscle activity can increase an individual's predisposition to WRMSDs [31]. Concerning occupational contexts, one of the key elements in WRMSD prevention is understanding the muscular demands of commonly performed tasks [32], such as manual lifting. In this field, surface EMG has been widely used

in ergonomic studies focused on various risk factors for MSDs, in an effort to optimize lifting tasks and so reduce the risk of such disorders developing [32-34]. In order to analyze muscular activity for each obesity level, surface EMG data was collected, as the principal role of the technique is the objective evaluation of muscle activity associated with particular manual work tasks [35].

The main purpose of the current study was to examine possible differences between the muscular contraction and activation times of obese and non-obese subjects during manual lifting. The intention was also to study some task conditions (different load weights and postural restraints) that might produce variations in muscular responses for the obese subjects.

2. Materials and Method

2.1. Subjects and experimental trials

Ten healthy males and four women, with no history of musculoskeletal disorders, volunteered to participate in the study. After signing an informed consent form, different anthropometric measures (weight, stature, shoulder height, WC) were collected. An OMRON BF306 Body Fat Monitor was used to determine the individuals' obesity levels (5 were "Normal", 4 were "High" and 5 were "Too high"). This equipment measures the BFM percentage based on electric resistance (determined by BIA) and also integrates personal data, such as the height, weight, age and gender of participants, in order to accurately define individual obesity levels [36]. The personal data used in the obesity level definition are presented in Table 1.

In the sagittal plane, 6 symmetrical trials (3 loads x 2 styles) of lifting and replacing a test box with goods handles, and with loads of 5 kg, 10 kg and 15 kg respectively, were performed in constrained and in free conditions (Table 2). During constrained lifting, the box was placed behind a 60 cm high barrier simulating one side of an industrial bin. The high barrier was constructed to measure 120% of average male and female knee heights [34]. The box loads complied with the recommended limits defined by Portuguese national legislation [37] and in some of the guidelines published by the National Institute Occupational Safety and Health (NIOSH) [38].

Table 1.
Anthropometric data, BFM percentages and obesity levels.

Participants (n = 14)	Age (years)	Gender	Body fat mass (%)	Obesity Level
1	28	Male	15.7	Normal
2	24	Male	20.5	High
3	36	Male	22.9	High
4	28	Female	18.3	Normal
5	24	Male	12.4	Normal
6	20	Male	22.3	High
7	21	Female	16.5	Normal
8	53	Male	36.0	Too high
9	46	Female	41.2	Too high
10	22	Male	39.8	Too high
11	24	Male	21.3	High
12	23	Female	28.5	Normal
13	40	Male	27.0	Too high
14	20	Male	26.1	Too high

Source: The authors.

Table 2.
Study design overview, taking into account the 6 trial conditions.

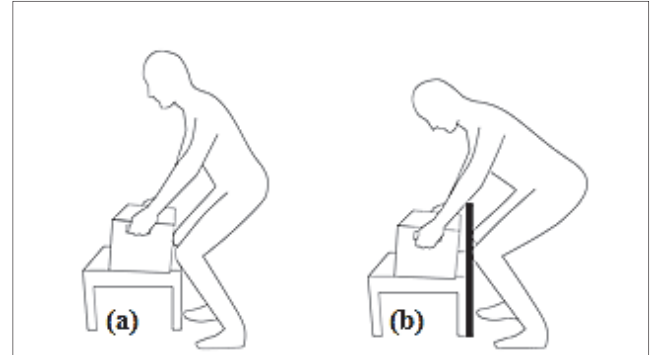| Trials	Loads			Styles	
	5 kg	10 kg	15 kg	Free	Constrained
1	●			●	
2	●				●
3		●		●	
4		●			●
5			●	●	
6			●		●

Source: The authors.

Figure 1. Schematic representation of the reaching position during (a) freestyle and (b) constrained style with barrier.
Source: The authors.

During the trials, participants stood in front of a height platform adjusted to each subject's standing knee height. They used both hands to lift the box vertically up to shoulder height and to return it to its original position in a single slow movement. In order to simulate a realistic working situation, no specific foot-placing instructions were given. The movement was subdivided into 4 phases: standing up (rest position), reaching (represented in Fig. 1), lifting, and replacing the box. However, the data analyzed in this paper relates only to the lifting phase.

2.2. EMG data collection

A portable EMG system (PLUX wireless biosignals®) was used to collect EMG data while the subjects performed the manual lifting tasks. EMG activity was collected using bipolar surface electrodes with 1 cm diameter and an inter-electrode distance of 2 cm. The EMG electrodes were affixed to the subject's body using standard placement procedures for Surface Electromyography for the Non-Invasive Assessment of Muscles [39] The zones of electrode placement were shaved, abraded and cleansed with rubbing alcohol absorbed into cotton rounds to lower the skin's electrical impedance [35].

The electrodes were located at 3 muscles recruited during this type of task: the right and left *Erector spinae* (*iliocostalis*) at L2 (RI, LI), the right and left *Erector spinae* (*longissimus*) at L1 (RL, LL) and the right and left *Deltoideus Anterior* (RD, LD) (Fig. 2).
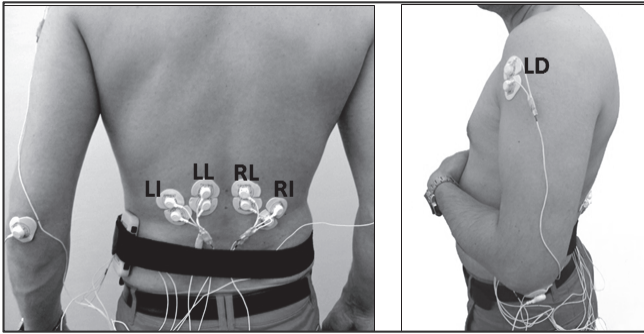
Figure 2: Sensor placement at the different muscles analyzed.
Source: The authors.

Muscle selection was based on their functionality during this type of task. The *Erector spinae* muscles are spine extensors, significantly recruited during vertical handling tasks [34]. The *Deltoideus Anterior* muscle acts during arm abduction, assists arm flexion, extension and rotation, and is also responsible for shoulder joint stability [40]. In addition, it was observed that fat mass accumulation was not high in these zones of the selected muscles, which, had it been, might have compromised EMG signal acquisition. At least one neutral reference (ground) electrode was fixed on the elbow per subject.

2.3. EMG signal processing

AcqKnowledge 3.9.0 software was used to process the EMG data. The raw EMG signals were amplified, high-pass filtered at 20 Hz and low-pass filtered at 500 Hz, rectified, and smoothed. The digital smoothing algorithm used was the root mean square (RMS), which reflects the mean power of the EMG signal [35] for each muscle and for each phase of the experimental trials. EMG data were normalized to peak value during each lifting trial, according to the following expression (1).

$$\text{MCT percentage} = \frac{Mean\ amplitude}{Peak\ value} \times 100 \qquad (1)$$

This normalization procedure has been utilized in other EMG studies with subjects presenting restrictions in their ability to perform maximum voluntary contractions, such as sufferers of musculoskeletal pathologies or obesity [41]. In addition, before each lifting trial, muscle AT was evaluated. This muscle onset quantification was based on a threshold defined by multiple SD of EMG-baseline noise [35]. In this experimental design, the independent variables were the different box loads, lifting style and obesity level. The dependent variables consisted of the MCT percentage and muscle AT.

2.4. Statistical analysis

A statistical analysis was conducted using the *IBM® SPSS® Statistics 22.0* software. For each task condition, the mean MCT percentages were compared across the subjects belonging to different obesity levels, in order to test the following hypothesis: greater mean MCT percentages are observed in individuals with higher BFM percentages. Accordingly, outcomes were compared using Pearson correlation tests, because the variables were found to behave normally ($p>0.05$ in the Shapiro-Wilk test).

Each muscle was then tested to see whether the task conditions (loads and barrier) produced significant effects on the mean MCT percentages in obese subjects. For this purpose a repeated measures ANOVA was applied. The assumption of normality was verified using the Shapiro-Wilk test, and the sphericity of the data was rejected by the Mauchly test ($p <0.05$). As the *epsilon* estimated value is greater than 0.75, the Huynh-Feldt correction was used to interpret the results for intra-subject effects.

Additionally, for each muscle considered, the following null hypothesis was also tested: i.e., that the distribution of AT is the same across different levels of obesity. To assess the normality of the AT values, the Kolmogorov test with Lilliefors correction was performed but, for most of the variables studied, this condition was not verified. Thus, the non-parametric Wilcoxon Mann-Whitney test was also applied. To reject the hypothesis, the decision rule was used to detect statistically significant evidence if $p<0.05$.

3. Results and Discussion

3.1. MCT percentages across obesity levels

Relative to the mean MCT percentage, a comparison of the values associated with different obesity levels showed that this variable presents higher values in the groups of "High" and "Too high" obesity. This difference was more evident in the lifting tasks involving the handling of the heavier loads, in this case, 10 and 15 kg (Fig. 3).

The Pearson correlation test demonstrated a significant linear statistical association, in that increased BFM was related to increases in MCT. This positive relation was established for the different muscles analyzed in different task conditions, as shown in Table 3.

It should be noted that the extensor muscle forces associated with these EMG values are the dominant contributor to compressive loading on the lumbar intervertebral joints [42], increasing the risk of back disorders. However, obesity is an individual risk factor commonly not included in WRMSD risk assessment. Therefore, obesity should be studied as a WRMSD risk factor during lifting.

3.2. MCT percentages of obese subjects across task conditions

During lifting tasks, the different conditions and associated risk factors do not work separately but in conjunction [43]. Accordingly, the effects of load weight and lifting style on MCT percentages of obese subjects were investigated. The summary of statistical significance for these interactions is presented in Table 4.
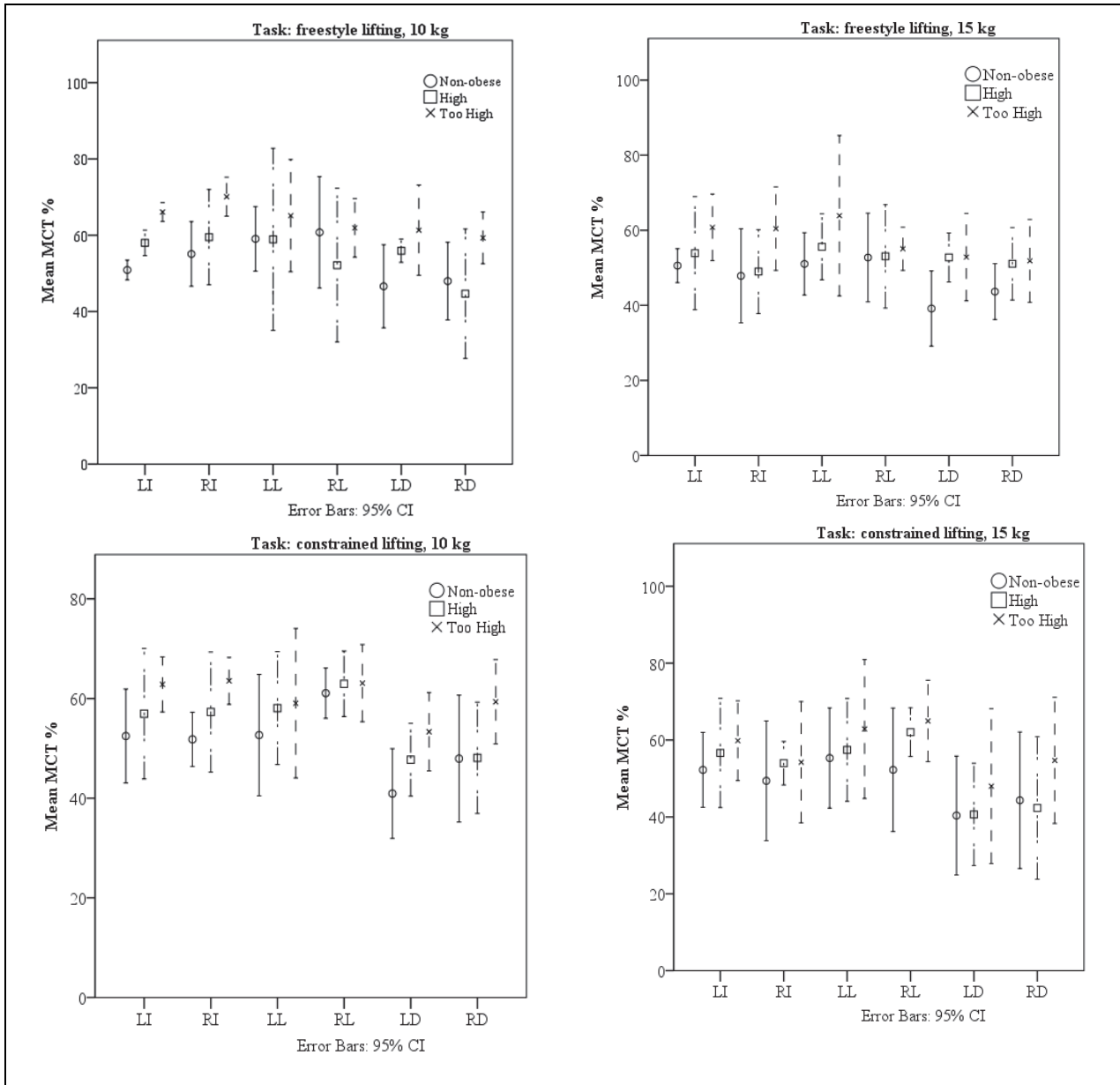
Figure 3: Representation of mean values for MCT percentage of the muscles involved across the different obesity levels and task conditions (exclusively for the handling of 10 kg and 15 kg loads). Error bars denote SD.
Source: The authors

Table 3.
Summary of statistical significance for the positive relation between individuals' BFM percentages and MCT percentages for the muscles analyzed.

Trials conditions	Muscles analyzed					
	LI	RI	LL	RL	LD	RD
5 kg Freestyle lifting	--	--	--	-	--	--
5 kg Constrained lifting	--	--	--	-	$r = 0.641*$	--
10 kg Freestyle lifting	$r = 0.792**$	$r = 0.611*$	--	-	$r = 0.572*$	--
10 kg Constrained lifting	--	$r = 0.584*$	--	-	$r = 0.742**$	$r = 0.761**$
15 kg Freestyle lifting	$r = 0.671**$	$r = 0.830**$	$r = 0.687**$	-	--	--
15 kg Constrained lifting	--	--	$r = 0.539*$	-	--	--

Legend: r coefficient of Pearson correlation; -- non-significant; * statistical significance at $p<0.05$; ** $p<0.01$.
Source: The authors.

Table 4.
Statistical significance of the influence of load and lifting style (with and without barrier) for the obese group.

	LI	RI	LL	RL	LD	RD
Obesity*Load	0.010 *	0.325	0.086	0.011 *	0.022 *	0.106
Obesity*Load*Barrier	0.461	0.696	0.531	0.771	0.083	0.105

Legend: * statistical significance at $p<0.05$.
Source: The authors.

Table 5.
Means (SD) of muscle AT across the tasks conditions for non-obese and obese subjects (including subjects with "high" and "too high" obesity levels).

			LI	RI	LL	RL	LD	RD
5 kg	Non-obese	Freestyle	-0.210 (0.358)	-0.251 (0.317)	-0.231(0.303)	-0.218 (0.286)	-0.235 (0.241)	-0.199 (0.174)
		Constrained	-0.201 (0.359)	-0.047 (0.392)	-0.253 (0.075)	-0.340 (0.079)	-0.287 (0.067)	-0.237 (0.362)
	Obese	Freestyle	0.079 (0.342)	-0.048 (0.393)	0.040 (0.389)	-0.088 (0.397)	0.031 (0.347)	0.044 (0.316)
		Constrained	-0.189 (0.276)	-0.199 (0.358)	-0.011 (0.392)	-0.115 (0.421)	-0.194 (0.257)	-0.200 (0.221)
10 kg	Non-obese	Freestyle	-0.151 (0.373)	-0.043 (0.414)	-0.330 (0.054)	-0.259 (0.083)	-0.255 (0.228)	-0.187 (0.368)
		Constrained	-0.245 (0.301)	-0.140 (0.342)	-0.427 (0.043)	-0.127 (0.452)	-0.312 (0.125)	-0.076 (0.227)
	Obese	Freestyle	-0.229 (0.115)	-0.208 (0.201)	-0.124 (0.341)	-0.152 (0.353)	-0.166 (0.255)	-0.129 (0.235)
		Constrained	-0.043 (0.342)	-0.152 (0.301)	-0.181 (0.367)	-0.061 (0.415)	-0.152 (0.232)	-0.151 (0.228)
15 kg	Non-obese	Freestyle	-0.295 (0.125)	-0.289 (0.199)	-0.313 (0.124)	-0.255 (0.201)	-0.319 (0.156)	-0.314 (0.068)
		Constrained	-0.254 (0.397)	-0.296 (0.204)	-0.314 (0.210)	-0.177 (0.262)	-0.178 (0.530)	0.006 (0.485)
	Obese	Freestyle	-0.044 (0.360)	-0.004 (0.526)	-0.169 (0.231)	-0.096 (0.388)	-0.160 (0.346)	-0.079 (0.306)
		Constrained	-0.116 (0.336)	0.048 (0.351)	-0.086 (0.344)	-0.042 (0.310)	-0.068 (0.269)	0.064 (0.203)

Source: The authors.

Significant differences mean MCT percentages of the following muscles exist for the different loads, as follows: LI [F(2; 96)= 4.863]; RL [F(2; 96)= 4.726] and LD [F(2; 96)= 3.949]. That is, significant variation exists across the different loads, in the sense that MCT values increase between 5 and 10 kg and decrease between 10 and 15 kg (being higher with 15 kg than with 5 kg loads). In these situations, the mean MCT percentages are higher in obese subjects, compared to their normal counterparts.

With increased load weight, muscle activity of the trunk extensors and the upper-extremity increases too [43]. These results from existing research are consistent with the observations of the present study, which found that MCT values increased during the lifting of 10 kg loads. However, handling of the heaviest loads can result in a load transfer to the lower body [44], which might explain the variation observed for loads of 15 kg.

In this context, many lifting tasks require workers to lift from industrial bins. The barriers formed by their sides can constrain knee flexion and increase trunk flexion during such tasks [34]. During symmetrical lifting, the trunk muscles are activated to create an extension moment, the risk of WRMSDs being broadly dependent on the resulting lumbar curvature [45]. Therefore, at the beginning of the current study, the authors predicted that excess BFM could negatively affect the posture adopted during these tasks, with the result that the constrained situation should contribute to increasing the muscular effort required at that point of the lifts. However, in obese subjects mean MCT percentages did not differ significantly under conditions of constraint caused by the high barrier, for any lifting cases.

A previous study [34] reported that in freestyle lifts the muscle activation levels were significantly lower than those for constrained situations. In the current study, this difference is not evident, perhaps because the location of muscles studied was different.

3.2. Muscle AT in obese and non-obese subjects

Concerning muscle AT, a descriptive statistical summary of these values across tasks conditions for non-obese and obese subjects is provided in Table 5.

Concerning the effect of obesity on the distribution of AT, the null hypothesis tested was rejected in the following task conditions: 10 kg constrained lifting in LL muscle ($p=0.029$) and 15 kg constrained lifting in RI muscle ($p=0.042$). Therefore, these statistically significant differences in the distribution of AT suggest that obese individuals have higher values when compared with the non-obese. These greater delays in AT registered for obese subjects suggest that increased BFM can reduce the

ability of skeletal muscle to activate rapidly before starting a movement, as also occurs in other groups with locomotor difficulties, such as the elderly or individuals with musculoskeletal disorders [31].

This poor correlation between muscle AT and increased BFM may be attributable to deficiencies in the AT quantifier currently being used.

3.3. Limitations and future work

There are several limitations that should be discussed with respect to this study. First of all, most lifting tasks in workplaces are not scaled. It is also likely that differences may exist for all obesity levels between tasks with different constraints and loads. The study was limited to the extent that only a few muscles were monitored with EMG. However, the selection of which muscles to monitor was influenced by body position, and trying to avoid regions with more accumulated adipose mass.

It is important to clarify that, since this is a pilot study in the field, the sample examined was made up of only fourteen participants. This constitutes a significant limitation. Increasing the sample size might be an important objective for future investigation.

The results of this research appear to demonstrate that increased BFM can produce some changes in muscle activity during lifting. In general, the outcomes are in line with the existing literature and emphasize the need to explore this research topic further. Excessive BFM can lead to an overreaction of the recruited muscles, causing increases in spine compressive loading and a subsequent risk of back injury. However, in order to examine this relation, further tests must be performed. Consequently, this area requires further research, which should be oriented to considering other type of data, such as information on kinematics.

4. Conclusions

The prevalence of obesity is increasing among the workforce. This research suggests that obese individuals can present changes in their muscle activity during lifting, compared to non-obese individuals. Obesity is an individual risk factor, which is very often neglected when assessing the risk of WRMSDs. Further studies are required to examine obesity as a WRMSD risk factor during lifting. Future work will involve a kinematics study, which will be carried out soon, and which it is hoped will improve our understanding of the effects of obesity on individual lifting capability.

Acknowledgments

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