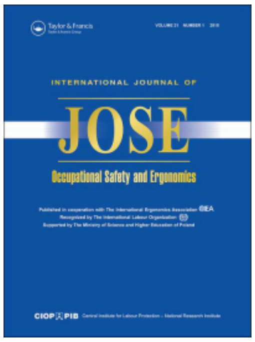

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Obesity effects on muscular activity during lifting and lowering tasks

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Obesity is an emerging health problem and its incidence has been increasing throughout the workforce. In industrial workstations, vertical handling tasks (VHT), including lifting and lowering, are very common and can cause a significant muscular overload for the involved workers. During these tasks, muscular activity may be considerably affected by workers' body conditions. This study aims to analyze and compare the muscular activity in subjects with different obesity levels, using surface electromyography (EMG), during predefined VHT. Six different VHT (combining 5, 10 and 15-kg loads with two task styles) were performed. EMG data normalization was based on the percentage of maximum contraction during each task (MCT%). The results show that obesity influences the MCT%, which in turn increases the muscular effort during VHT. The current investigation demonstrates that obesity is a relevant musculoskeletal risk factor regarding VHT. The engineering analysis and design implications of this work can thus be perceived.

Keywords: obesity; vertical handling tasks; muscular activity; electromyography; percentage of maximum contraction during each task

1. Introduction

Over the last decades, obesity has been recognized as a central health problem in industrialized countries. From worldwide statistics, it is possible to observe that obesity has more than doubled since 1980, estimations being that 600 million people are obese with a body mass index (BMI) > 29.9 [1]. Obese workers represent a growing fraction of the workforce [2] and this is often associated with several disorders, including musculoskeletal disorders (MSDs), which can negatively affect productivity [3–5]. Different studies have shown a correlation between obesity and the increase in absenteeism, mainly due to MSDs [6,7] Among a sample of 1120 US workers, Gu et al. [8] concluded that overweight and obese workers were 25–68% more likely to suffer MSDs than normal weight workers.

It is well known that the incidence of MSDs is frequently related to stressful working postures [9]. These postures can be affected by workers' excessive body fat mass (BFM) [10], which is expressed as a percentage of the total body weight. However, the effects of obesity on posture maintenance during occupational tasks have been seldom studied. Founded on this statement, Park et al. [11] carried out psychophysical research, verifying that obese subjects reported greater perceived overload during static box-holding tasks for different working postures. Another study by Gilleard and Smith [12] also showed that a more flexed trunk posture, increased hip joint moment and an increased hip-to-bench distance are presented by obese subjects during a simulated standing work task. Additionally, it has been demonstrated that obese subjects, when compared with normal weight subjects, exhibit more problems with work-restricting pain, including lower back pain (LBP) [13].

LBP is one of the most common musculoskeletal problems in industrial workstations, representing high costs to industry and influencing negatively the workers' quality of life [14]. Workers who perform manual materials handling (MMH) are exposed to a greater risk of developing LBP and/or MSDs, when compared with those whose jobs do not require this type of task [15]. However, tasks including manual lifting are very common in a wide variety of workstations and are associated with several occupational and individual MSD risk factors [16,17].

One of these individual risk factors is workers' body composition, including their level of obesity [18]. In this field of investigation, Singh et al. [19] demonstrated using a psychophysical approach that obesity does not reduce the maximum acceptable weight during manual lifting. In addition, these authors pointed out that this particular issue requires further investigation, which should include other types of data, such as biomechanical parameters. Xu et al. [20] analyzed the lifting kinematics and kinetics in subjects with different body compositions and verified that obese subjects registered greater values for the kinematics

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trunk variables than normal weight subjects. The effect of excessive BFM on the function of the locomotor system is not yet well understood. Thus, ergonomic studies are required to provide a more complete understanding of obesity effects on work performance [21], including during manual lifting and lowering tasks. In this field, recent research developed by Corbeil et al. [22] studied the trunk kinematics in normal weight and obese workers, during vertical handling tasks (VHT) of moving boxes between a conveyor and a hand trolley. The results obtained by these authors indicate that the anthropometric characteristics of obese workers are related to a significant increase in peak lumbar loading.

From a biomechanical point of view, the handicapping effect of excessive BFM and/or impaired motor coordination can justify the poor physical performance of obese people [23], which may affect the performance of handling tasks in occupational contexts [22]. Although the functional limitations of obese workers are known, the effect of obesity on muscle performance still needs to be investigated [23]. In this field, previous studies have correlated obesity to impairments in muscle activity, such as decreased relative values of muscle strength expressed per unit body mass [24] and a faster rate of muscular strength loss [25]. The modifications in muscle activity can increase the individual predisposition to develop MSDs [26]. Regarding occupational contexts, one of the crucial elements in MSD prevention deals with understanding the muscular demands related to commonly performed tasks [27], including manual lifting and lowering. For this purpose, surface electromyography (EMG) has been widely utilized in ergonomic studies focusing on various risk factors for MSDs, aiming at the optimization of lifting tasks to reduce the risk of these disorders [27–30].

Thus, the main objective of this study was to investigate the differences in muscular activity during VHT, among a sample with normal and obese participants. Therefore, the study tested whether obesity is related to the increase in muscular overload during these tasks.

The study also intended to investigate some task conditions (different weights and physical postural restraints) which may produce different muscular responses for obese subjects. The current study extends previous authors' work [31] by including a more detailed analysis of the effect of different occupational conditions, differentiating between the tasks of lifting and lowering whereas the previous study only considered lifting tasks.

2. Materials and methods

2.1. *Participants*

The study group consisted of 14 participants with different body compositions. Volunteers were recruited through emails sent to all contacts of the research group database (including university students, researchers and professors). The criteria for selection were as follows: no occurrence of injuries, within the working age and in a profession with similar physical requirements. All participants reported that they did not present any type of MSD and received a briefing on the study objectives, nature and potential risks. Then, the participants were asked to sign an informed consent before the experimental trials.

For sample characterization, different personal data were collected: the BMI, the abdominal circumference (AC) and the BFM percentage. To determine the BFM by bioelectrical impedance, a BF306-body fat monitor (OMRON®, Japan) was utilized. This equipment defines the level of obesity integrating the participants' BFM percentage, age, gender, height and weight [32]. Therefore, according to this bioelectrical impedance equipment, the current study sample was subdivided into the following three levels: normal, high obesity and very high obesity [33]. Primarily, the obesity levels were defined by bioelectrical impedance, but, as evidenced in Table 1, each level is also in line with the World Health Organization [1] standards for BMI interpretation: BMI < 25, normal; BMI ≥ 25, overweight; BMI ≥ 30, obese.

2.2. *Experimental procedure*

In a laboratorial context, each trial was performed and subdivided into four phases: standing up (rest position); reaching (represented in Figure 1); lifting to shoulder height; and lowering, replacing the box to the initial position. In order to analyze properly the EMG data, the duration of each phase was controlled and measured using a chronometer. The duration of the lifting and lowering motion phase was on average between 4 and 8 s (a higher duration was utilized during the tasks with a higher load). At the end of each trial 1 min of rest was allowed and each trial was performed only once [34], with the intent to avoid muscular fatigue. It should be noted that the VHT frequency did not exceed the acceptable minimum of time intervals (32.1 s) between repeated liftings defended by Lee [35] for loads of 15 kg.

As can be observed in Figure 1, the participants stood in front of the test box, which was placed on a platform with the box handles to the participants' knee height. The simulated VHT were performed with both hands and in the sagittal plane. With the aim of simulating a realistic working performance, the participants were allowed to adopt their preferred handling technique relative to the posture adopted (as defended by Kingma and van Dieën [36] and Corbeil et al. [22]). The feet position was also defined by each participant in order to maintain the load close to the body and maintain the same position across the lifting and lowering of the same trial (as applied by Sangachin and Cavuoto [37]). With this purpose, before the EMG data acquisition, participants were allowed to simulate the task of box lifting and lowering without a load.

Table 1. Mean (*SD*) of anthropometric data across the participants' obesity levels ($N = 14$).

Anthropometric variable	Normal ($n = 5$)	Overweight ($n = 4$)	Obese ($n = 5$)
BMI	20.4 (1.9)	26.2 (1.2)	33.6 (2.9)
BFM (%)	18.3 (6.1)	21.7 (1.1)	34.2 (6.8)
AC (cm)	75.0 (12.0)	84.1 (3.4)	104.4 (13.5)

Note: AC = abdominal circumference; BFM = body fat mass; BMI = body mass index.

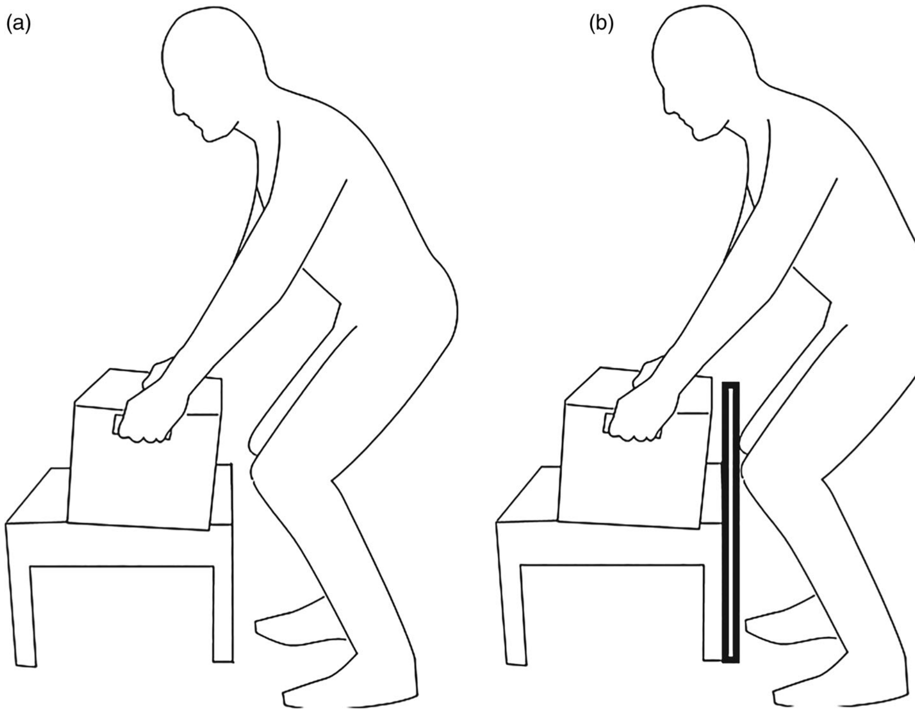

Figure 1. Representation of the reaching position during (a) freestyle and (b) constrained style with a barrier.

Each participant performed six symmetrical trials (3 loads × 2 styles) of lifting and replacing a test box with good handles, with loads of 5, 10 and 15 kg, in constrained and free conditions. Between different tests, the order of the trials with different conditions was randomly defined. The loads respected the recommended weight limit by the NIOSH equation [38]. During the constrained scenario, the box was placed behind a barrier 60 cm high, which replicates an industrial bin (as used by McKean and Potvin [28]). The barrier was constructed considering the anthropometric data of the Portuguese population [39], since the participants were all Portuguese, their stature (171.4 ± 8.7 cm) being included into 90% of the stature values of this population, so the height of barrier exceeded the knee height of all participants and represented a similar constraint for all of them.

2.3. EMG equipment and parameters measured

During the VHT performance, the muscle activity was recorded by a portable EMG system (PLUX wireless biosignals®, Portugal). The sampling frequency was 1000 Hz [40]. The skin preparation and the fixation of EMG electrodes to the participant's body were made according to the surface electromyography for the non-invasive assessment of muscles (SENIAM) guidelines [41].

Bilateral muscle activity was assessed for selected sets of muscles: right and left erector spinae (iliocostalis) at L2 (RI, LI); right and left erector spinae (longissimus) at L1 (RL, LL); right and left deltoideus anterior (RD, LD) (Figure 2). These muscles are placed in body areas that do not present high fat mass accumulation, which could compromise the EMG data acquisition. Additionally, the selection of these muscles was based on their functionality during the VHT performance, namely, the deltoideus anterior acts in glenohumeral joint mobilization and the erector spinae muscles are responsible for trunk extension and stabilization during the VHT performance [30,42]. Evaluation of the percentage of maximum contraction during each task (MCT%) was considered for each trial, segregating lifting and lowering tasks, and for each muscle.

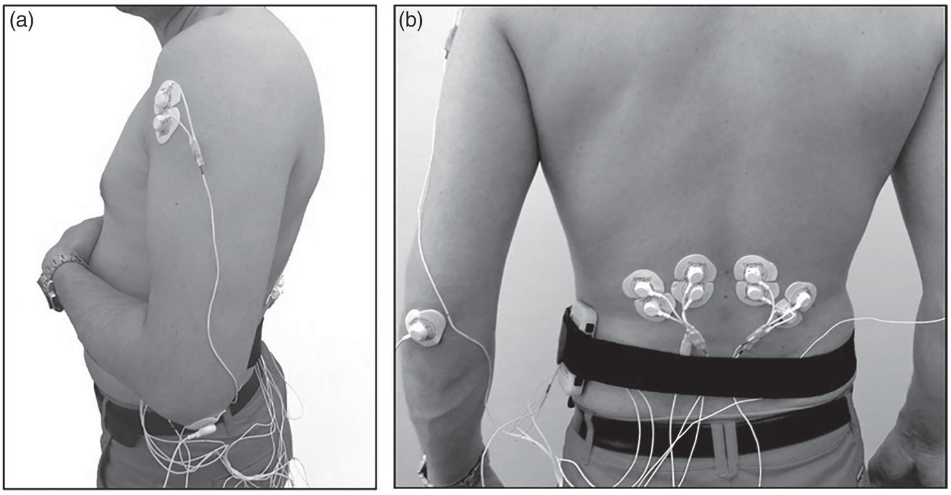

Figure 2. Sensor placement at the (a) arm (left deltoideus) and (b) lower back muscles studied.

2.4. Data processing and statistical analysis

AcqKnowledge version 3.9.0 was used to process and analyze the EMG data. The raw EMG signals were amplified, high-pass filtered at 10 Hz and low-pass filtered at 500 Hz, rectified and smoothed through the digital algorithm root mean square (rms). EMG data were normalized to the peak value during each handling task, according to the following equation:

$$\text{MCT\%} = \frac{\text{mean amplitude}}{\text{peak value}} \times 100\%,$$

where MCT% = percentage of maximum contraction during each task.

This normalization technique consists of transforming the absolute values of EMG amplitude into relative values to a reference value (considered as 100%). In this case, the reference value was estimated through the peak value throughout each of the VHT (lifting or lowering). It should be noted that this technique of normalization, based on the dynamic peak as a reference value, has been pointed out as the best way to normalize dynamic contractions, especially in studies that involve participants with restrictions in the performance of maximum voluntary contractions in isometric postures (as, e.g., individuals with musculoskeletal and/or obesity pathologies) [43–45].

Statistical analysis was conducted using IBM® SPSS version 22.0. The MCT% mean values were analyzed across all participants (and not between groups) by testing whether the increase in BFM is correlated with the increase in the MCT%. Pearson correlation tests were applied in order to test and verify this hypothesis, since normal behavior on variables was found with the Shapiro–Wilk test.

Finally, multivariate analysis of variance (MANOVA) was applied because the assumption of normality was verified by the Shapiro–Wilk test, and the sphericity of the data was rejected by the Mauchly test. As the estimated ϵ value is greater than 0.75, the Huynh–Feldt correction is considered to interpret the results for intra-subject effects [46]. Significance was determined at $p < 0.05$.

MANOVA allowed us to test the following effects on the MCT% values: (a) the load effect (5, 10 and 15 kg); (b) the effect of the presence of a physical barrier between the load and the participants' body (freestyle versus constrained condition); (c) the task effect (lifting versus lowering); (d) the interaction between these conditions. Only for this analysis was a differentiation between normal and obese participants (including individuals with high and very high levels of obesity) considered.

3. Results

3.1. Muscular activity and obesity

Considering all EMG data obtained, Pearson's correlation test demonstrated a significant linear statistical association, in the sense that the BFM increase (considering all subjects' sample) is related to the MCT% increase (Table 2). This relation was positive and significant in different muscles across different task conditions. Additionally, the results presented in Table 2 show that there are more statistically significant correlations for the lifting tasks compared with the lowering tasks.

3.2. Muscular activity of obese individuals across different VHT

During VHT, the different occupational conditions, and subsequent risk factors, do not work independently but rather in coordination [47]. Considering this statement, the summary of statistical significance of the effects tested by MANOVA is presented in Table 3.

The results indicated that the muscle activity during the VHT is significantly influenced by the load. This significant variation in the mean MCT% occurs in the LI, RI, RL

Table 2. Summary of statistical significance for the positive relation between increasing BFM and MCT% for the muscles analyzed.

Trial condition		Muscle considered					
		LI	RI	LL	RL	LD	RD
Lifting	5 kg freestyle	0.035	0.048	0.009	–0.199	–0.057	0.265
	5 kg constrained	–0.175	0.256	0.506	–0.052	0.641*	0.130
	10 kg freestyle	0.792**	0.611*	0.257	0.211	0.572*	0.442
	10 kg constrained	0.414	0.584*	0.260	0.429	0.742**	0.761**
	15 kg freestyle	0.671**	0.830**	0.687**	0.273	0.421	0.524
	15 kg constrained	0.448	0.407	0.539*	0.431	0.530	0.486
Lowering	5 kg freestyle	0.545*	0.413	0.484	–0.333	0.096	0.289
	5 kg constrained	0.522	0.292	0.591*	0.276	–0.175	–0.205
	10 kg freestyle	0.152	0.321	0.476	0.150	–0.043	0.388
	10 kg constrained	0.575*	–0.165	0.217	0.304	0.298	0.259
	15 kg freestyle	–0.015	0.030	0.116	0.103	0.232	0.280
	15 kg constrained	–0.029	–0.270	–0.397	–0.228	0.203	0.026

*$p < 0.05$; **$p < 0.01$.
Note: BFM = body fat mass; LD = left deltoideus; LI = left iliocostalis; LL = left longissimus; MCT% = percentage of maximum contraction during each task; RD = right deltoideus; RI = right iliocostalis; RL = right longissimus.

Table 3. MANOVA results for each muscle studied (tests of within-subject effects).

Condition tested	Muscle considered					
	LI	RI	LL	RL	LD	RD
Load	0.009*	0.018*	0.765	0.049*	0.652	0.031*
Load and obesity	0.010*	0.325	0.086	0.011*	0.022*	0.106
Load and task	0.099	0.410	0.095	0.076	0.064	0.769
Load and barrier	0.845	0.343	0.418	0.561	0.089	0.359
Load, obesity and task	0.001*	0.188	0.024*	0.101	0.527	0.744
Load, obesity and barrier	0.461	0.696	0.531	0.771	0.083	0.105
Load, task and barrier	0.727	0.374	0.572	0.357	0.594	0.488
Load, obesity, task and barrier	0.628	0.804	0.793	0.739	0.139	0.351

*$p < 0.05$.
Note: LD = left deltoideus; LI = left iliocostalis; LL = left longissimus; MANOVA = multivariate analysis of variance; RD = right deltoideus; RI = right iliocostalis; RL = right longissimus.

and RD muscles, along the different loads considered. This variation is similar for these four muscles, in the sense that the MCT% increases significantly when the load increases from 5 to 10 kg and when it decreases from 10 to 15 kg (with higher mean values for 15 kg compared to the 5-kg load), as represented in Figure 3.

Additionally, MANOVA also showed that a significant effect of the load variation on the MCT% occurs for obese participants, similar to the variation described previously (Figure 3). These results indicate that the load is a factor with significant effects on muscle activity. However, the existence of the barrier during VHT did not produce any significant variation in MCT% (as demonstrated by MANOVA).

4. Discussion

The results demonstrate that the relation between subjects' BFM and MCT% is positive and significant in different muscles across different task conditions, indicating that obesity seems to be an individual factor that increases the muscular activity, and consequently the respective overload.

Data presented in Table 2 also show that there are more statistically significant correlations for the lifting tasks compared with the lowering tasks. This is an expected result, because most of the studied muscles are extensors of the spine (iliocostalis and longuissimus). As demonstrated by previous studies, during MMH the activity of the trunk muscles increases, especially during lifting [28,30,42]. During lowering, the activity of these muscles may decrease due to the involvement of other muscles, as well as the likely individual strategy of taking advantage of the gravity action to lower the load.

These variations in muscular activity during the tasks could be influenced by the participants' posture adopted. As mentioned previously, in order to simulate real work situations, participants held the load as close to their bodies as possible, and assumed the more comfortable posture and feet position for each one (as in Corbeil et al. [22]

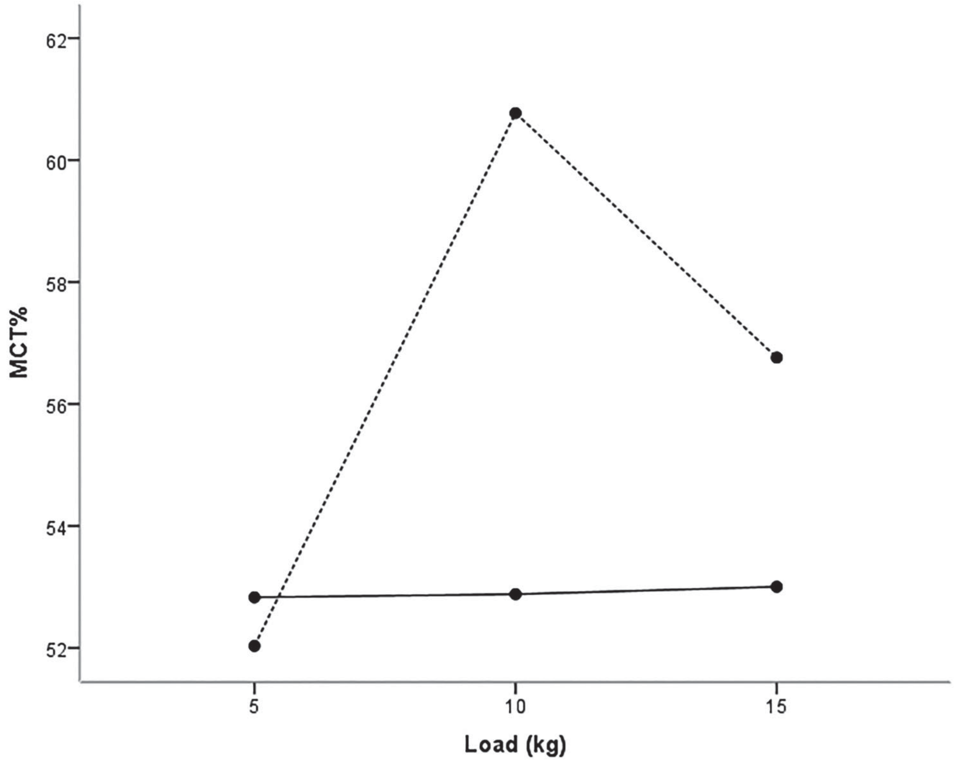

Figure 3. MCT% mean variation across the different loads studied, differentiating the values of obese and normal participants. Note: MCT% = percentage of maximum contraction during each task; dashed line = obese; solid line = normal.

and Kingma and van Dieën [36]). In this field, Sorensen et al. [48] showed that the feet position during VHT, e.g., shoulder aligned or more distant/close, does not influence muscle activity.

It also should be noted that the mean amplitudes of the VHT were 96.0 ± 7.8 cm and each vertical amplitude was according to the participant's anthropometric data (as in Singh et al. [19] and McKean and Potvin [28]), in this case between the participant's knee and shoulder heights. This fact conditioned the participants' posture, causing trunk flexion to reach and lower the load, as well as trunk extension during the lifting. However, it is considered that this work should be continued in future with analysis of the kinematic data in order to better understand this variation in muscle activity throughout these tasks.

Regarding the significant correlations found for the deltoids, they are also more representative in lifting tasks, explained by the fact that the anterior deltoid is a muscle involved in shoulder flexion which occurs during the VHT [49].

These findings are corroborated by Park et al. [11], who also demonstrated that obese subjects reported a greater perceived overload during box-holding tasks. Tetteh et al. [30] also showed increased amplitude of deltoid muscle contractions in overweight workers (with BMI $\geq$ 25) during handling loads. Briefly, from a biomechanical point of view, obesity seems to affect the muscular activity while performing VHT, increasing the overload in the involved muscles.

Although the current study did not quantify the musculoskeletal overload during lifting and lowering, it is considered that factors which could produce higher muscular activity/effort, such as obesity, present a higher potential to increase the MSD risk [50]. However, obesity is an individual risk factor which is not commonly included in MSD risk assessment [11,30]. Therefore, it is clear that the obesity must be investigated as a MSD risk factor during manual lifting and lowering.

Relative to the MANOVA, the load effect is significant and varies in the sense that the MCT% increases significantly when the load increases from 5 to 10 kg, and when it decreases from 10 to 15 kg. This effect of the load through the MCT% variation is due to the increase in muscle activity of the trunk extensors and upper extremities, potentiated by the load increase [47]. However, when handling the heaviest loads, some postural correction may occur (since the participants were allowed to adopt their preferred handling technique) and a weight transfer to the lower body can take place [29], which may explain the variation observed for the 15-kg loads.

These results indicate that the load is a factor with significant effects on muscle activity, as has been observed in previous studies [51–53]. Additionally, MANOVA also showed that a significant effect of the load variation on the MCT% occurs for obese participants, similar to the variation described previously (as shown in Figure 3). However, in general and as expected, higher mean values were observed in obese participants compared to normal weight subjects, especially when handling higher loads, in this case 10 and 15 kg.

In contrast to the authors' initial expectations, the existence of the barrier during VHT did not produce any significant variation in MCT% (as demonstrated by MANOVA). It was expected that the existence of this barrier would constrain knee flexion and therefore increase trunk flexion, especially in obese individuals, due to BFM accumulation in the abdominal region. During the VHT, the trunk muscles are activated in order to create an extension moment, and the risk of MSDs is directly dependent on the lumbar flexion described [54]. Therefore, it was expected that the results would show that the existence of the barrier was an occupational risk factor that could increase the muscular effort, as indicated by McKean and Potvin [28], and, therefore, should influence the MCT% variation of the studied muscles. However, through the results obtained, there was no significant influence of the barrier on this variable, either for obese or for normal weight participants, across all of the tested tasks. This result may be related to the fact that in the current study the load height at the beginning and at the end of each task is equal to the participants' knee height, instead of being placed on the floor as occurred in McKean and Potvin's study [28]. Possibly, when this occupational condition occurs, it may become less relevant, from a biomechanical point of view, to have a physical barrier.

Finally, it should be highlighted that the results pointed out that EMG data are influenced by the workers' body composition [55], and globally they show that obesity seems to be a significant overload factor for muscle activity during VHT, increasing the risk of MSD development. For this reason, the workers' body composition should be considered during ergonomic assessments at workstations. In this field, companies should invest in obesity prevention programs and in workstation interventions considering the different workers' anthropometric characteristics, in order to prevent or reduce MSDs.

4.1. Limitations and future work

The current study has several limitations that need to be noted. First, the size sample (14 participants) constitutes an important limitation. Increasing the sample size might be an important objective for future investigation. However, it was very challenging to collect data from obese volunteers. Despite this, the obtained data demonstrated statistical validity. The data normality was verified for all variables and the results showed several statistically significant (and relevant) correlations. Taking into account the specificity of the EMG technique, and comparing with previous studies in this field, the reported results are relevant. In fact, several studies on the same issue have been performed with similar sample sizes, e.g., the studies developed by Kingma and van Dieën [36] with 10 volunteers, by Paskiewicz and Fathallah [45] with 12 volunteers, by Xu et al. [20] with 11 volunteers and by Sangachin and Cavuoto [37] with 14 volunteers.

The study was limited to the extent that only six muscles were monitored with EMG. However, the selection of these muscles was influenced by their functionality during VHT and body position, trying to avoid corporal regions with more accumulated adipose mass, exactly because this would compromise the EMG data acquisition. However, as mentioned earlier, the EMG data were normalized, which increased accuracy of data analysis.

In short, the outcomes are in line with the existing literature, and the current study can also be seen as a good starting point for future investigation in this research field. This area requires further research, which should be oriented to considering other types of data, such as information on kinematics.

5. Conclusions

The current study points out that obese workers present changes in their muscular activity during lifting and lowering loads, when compared with their normal weight counterparts. The obtained results confirm that the increase in BFM is positively related to the increase in muscular effort, which can increase the risk of MSDs during lifting and lowering tasks. Therefore, obesity must be included in the MSD risk assessment and the need for investment to implement effective measures for obesity prevention in work contexts should be highlighted.

Moreover, the results indicate that the load is a factor with significant effects on muscle activity, producing a different effect between obese and normal weight subjects (registering higher values of muscle contractions in obese subjects). Concerning the existence of the barrier during the VHT, this workstation configuration did not produce any significant variation in MCT%.

In general, the current study outcomes are in line with the available literature and emphasize the need to deeply explore this research topic, e.g., by enlarging the considered participant sample.

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