# Electromyographic and Kinematic Patient Handling Risk Assessment: Overhead Lift Versus Floor Lift

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**Abstract** The use of mechanical patient lifting devices has already been proved to reduce the risk of caregiver injury during patient transfers. Despite this evidence, nowadays this equipment is still underused in the working environment. This study aims to compare sEMG activities and trunk kinematic, obtained by means of an optoelectronic system, between overhead lift devices versus floor lift devices and to verify if the patient movement with a mechanical lift may be safely performed. Seven experienced operators were studied by means of surface electromyography during an 85 kg surrogated patient handling from the bed to the wheelchair and vice versa by a single caregiver at a time using both a floor lift and an overhead lift. Results show that the use of these devices allows the operator to work safely and could be helpful in case of reduced fitness for work.

**Keywords** Patient lifting · Surface electromyography · Trunk kinematic · Low back disorders · Mechanical lifts

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# 1 Introduction

Among all workers, healthcare workers have the highest incidence rate for nonfatal occupational injury and illness involving days away from work [1] and low back disorders (LBD) are referred as the most common type of damages, [1]. A broad consensus is spreading on the fact that these injuries are mostly caused by the patient handling [2]. It has been shown that older workers perform tasks differently than younger workers due to declines in muscle properties [3]. These age based differences are particularly important to account for, since the risk of back injury increases with age [4]. Similarly, it is important to recruit trained operators as subjects since experience has been shown to change the way operators perform tasks [5].

It has been demonstrated that the use of mechanical devices (lifts) to handle patients reduces the risk of incurring accidents during patient moving by healthcare operators, hence it would be a good practice to use these devices to prevent injuries [6]. Moreover, this solution has direct economic benefits as a result of reduced compensation claims [6]. Patient handling with the help of overhead and/or floor lift has been extensively analyzed, [5, 7–9]. There are no studies, that actually evaluate the patient handling during the entire task, from the corset insertion to its removal, when it is performed wholly by one operator. This study evaluates the activity of trunk antagonist muscles and trunk kinematic of experienced workers with a overhead and a floor lift, during the movement of an 85 kg-completely dependent patient. The aim of this work is to investigate the compression at L5/S1, by computing a co-activation index, and to compare the measured trunk kinematic with the values prescribed by the European standard in order to give a practical instrument to compare different kind of devices and to test if a patient handling device could be used by the operator to work safely.

# 2 Materials and Methods

## *2.1 Participants*

Seven experienced health workers were enrolled in this study (5 men and two women, age: 39.86 ± 13.02 years, height: 1.73 ± 0.09 m, weight: 72.29 ± 13.15 kg, body mass index, BMI: 23.86 ± 2.65 kg/m$^2$). None of them had a history of either musculoskeletal disorders or neurological diseases or had recently taken any drugs. The participants voluntarily performed the study trials in the laboratory. They signed an informed consent form prior to participation in the study after receiving a detailed explanation of the study procedure. The study was approved by the local ethics committee and conformed to the Helsinki declarations. An 85 kg man simulated an entirely dependent patient in all trials.

## 2.2 Instrumentation

The surface myoelectric signals were acquired with a sampling rate of 1000 Hz, using a 16-channel Wi-Fi transmission surface electromyograph (FreeEMG 1000 System, BTS, Milano, Italy). After skin preparation, bipolar surface electrodes Ag/AgCl (H124SG, Kendall ARBO, Donau, Germany), prepared with electroconductive gel (diameter 1 cm, distance between the electrodes 2 cm), were placed bilaterally over the muscle belly of the erector spinae (longissimus) and rectus abdominis (medium). Electrodes were placed in the direction of the muscle fibres, according to the European Recommendations for Surface Electromyography (SENIAM) [10]. The activity of each muscle was expressed as percentage of the maximal voluntary isometric contraction (MVCi). The MVCi contraction exercises were executed according to the European Recommendations for Surface Electromyography (SENIAM) [10]. Each subject performed the MVCi exercise for each muscle two times.

The kinematic acquisition was performed using a six infrared cameras optoelectronic system (SMART-DX 6000, BTS, Milano, Italy), [11]. Spherical markers, covered with aluminum powder reflective material, were placed over prominent bony landmarks, according to the International Society of Biomechanics (ISB) recommendations [12, 13]. In particular, markers were positioned over the left and right acromion, the spinous process of the 7th cervical and 5th lumbar vertebrae, and over the right and left posterior superior iliac spinae. Kinematic data were acquired with a sample rate of 340 Hz. Spatial accuracy was 0.2 mm in the three spatial dimensions. To be able to carry out the practical tests with the overhead lift, a frame that simulates the operation obtainable with the mounting of the overhead track has been assembled in the laboratory. The lifting frame for withdrawals with corset is equipped with an electrical device that allows the postural change of the patient, from sitting to the supine position and all intermediate positions.

The overhead lift is equipped with remote control, which controls all functions of the equipment: rising/descending, forward/ back, height adjustment of the lifting frame and setting of the device for the patient's postural change. The equipment is also equipped with a quick coupling which allows to replace the various lifting frames according to the requirements. The overhead lift used, is characterized by: (i) power supply 24 V; (ii) workload security kg 272 kg.

In order to perform the experimental procedure described below, even with floor lift, a completely electric multipurpose floor with a vertical telescopic lifting column lift was used. The lifting frame for withdrawals with corset is equipped with an electrical device that allows the patient postural change from sitting to supine and all intermediate positions. The lifter is equipped with remote control and a push button panel placed on the additional lifting column. The two handsets regulate all aspects of the lift: rising/descending, legs' opening/closing and patient's postural adjustment. The equipment is provided with a quick coupling which allows to change the various lifting frames according to the requirements. The floor lift also allows the operator to change electrically, through the use of a remote control, the posture of the patient to be moved. The floor lift has the following technical features: (i) power supply 24 V with removable battery; (ii) overall dimensions 1118 × 718 mm; (iii) wheels' diameter 100 mm; (iv) overall lift weight 70 kg; (v) workload security kg 227 kg.

## 2.3 Experimental Procedure

The biomechanical assessment of the operator during the handling of the patient with overhead and floor lift was carried out by splitting the task into a series of sub-tasks.

Furthermore, two scenarios were considered: when the patient is moved from the bed to a wheelchair and vice versa.

As far as the floor lift is concerned, the following sub-tasks were analyzed in each scenario:

1. Enter the corset on the bed/on the wheelchair;
2. Transportation of the floor lift at the bed (on which the patient is lying)/to the wheelchair (on which the patient is seated);
3. Attaching the corset to floor lift;
4. Transporting the patient with floor lift from the bed to the wheelchair/from the wheelchair to the bed;
5. Release of the corset on the wheelchair/on the bed;
6. Removal of the corset from the wheelchair/from the bed.

As regards the overhead lift, the analyzed sub-tasks are the same tested with the floor lift except for the moving of the lift to the bed and to the wheelchair without the patient, that were not considered in this scenario because the operator did not do anything relevant from the biomechanical point of view. Each operator has carried out the patient handling in each scenario for each type of lifter twice. All the tests were performed using a 70 cm-fix-height bed, which model the worst condition that can be found in hospitals.

## 2.4 Data Analysis

After a tracking procedure (Smart Tracker, BTS, Milano, Italy), which was required to assign a label to each marker, data were processed using Analyzer software (Smart Analyzer, BTS, Milano, Italy) and MATLAB software (MATLAB 7.4.0, MathWorks, Natick, MA, USA).

Electromyographic signals recorded during all tasks performed by each operator were bandpass filtered (cutoff frequencies of 30 and 450 Hz), rectified with respect to the mean value, low pass filtered with a Hamming filter having a cutoff frequency at 5 Hz, normalized to the maximum value of MVCi (processed according to the same procedure), normalized to the cycle duration and reduced to 100 samples using a polynomial procedure during each sub-task. Then, for each subject, the following indices were computed for each muscle and each sub-task: maximum value of the signal, average rectified value (ARV) and muscle co-contraction function (TMCf), [14].

The kinematic evaluation was based on trunk movements on the sagittal, frontal and transverse anatomical planes. In each anatomical plane, trunk Range of Motion (RoM) for each sub-task was defined as the difference between the maximum and minimum value of trunk angles within the corresponding sub-task.

### 2.5 *Statistical Analysis*

The statistical analysis was performed using PASW software (PASW Statistic 17, formerly SPSS, Chicago, USA). For each scenario, the average of all the kinematic and electromyographic parameters was calculated.

Shapiro–Wilk test was applied to verify the null hypothesis that the acquired sample (in relation to the parameters calculated) came from a normally distributed population. Parametric paired t-tests were performed to detect any significant differences between the use of overhead and floor lift during the following three subtasks: corset attaching to the lift, patient moving, from the bed to the wheelchair and vice versa, and corset release. $p$-values less than 0.05 were considered statistically significant. All the results are expressed as mean ± standard deviation.

## 3 Results

The Shapiro–Wilk test showed that all the considered variables were normally distributed.

As regards the electromyographic data, the maximum value of the right erector spinae normalized signal was statistically greater during the corset removal, in the first scenario, with the floor lift than with the overhead lift (0.23 ± 0.11 and 0.18 ± 0.08, $p = 0.04$, respectively), Table 1. During the patient movement from the wheelchair to the bed, the maximum value of both the right and left side was statistically greater with the wheeled lift than for the overhead lift (right erector spinae: wheeled lift 0.18 ± 0.08, overhead lift 0.12 ± 0.06, $p = 0.047$; left erector spinae: wheeled lift 0.17 ± 0.07, overhead lift 0.12 ± 0.05, $p = 0.002$, respectively), Table 2.

In the second scenario, during the sub-task of corset attachment to the wheeled lift a statistically higher value of the maximum of the TMCf was found than during the sub-task of corset attachment to the overhead lift (4.78 ± 1.45 and 4.19 ± 1.40, $p = 0.009$, respectively), Fig. 1.

**Table 1** sEMG maximum and ARV values of the four muscle activity (mean ± standard deviation) for each sub-task in the first scenario (patient moved from the bed to the wheelchair)

| sEMG maximum value | | | | | |
|---|---|---|---|---|---|
| Activity | Lift type | R rectus abdominis | L rectus abdominis | R erector spinae | L erector spinae |
| Corset insertion | – | 0.100±0.068 | 0.119±0.067 | 0.318±0.139 | 0.319±0.134 |
| Lift transport | Floor | 0.037±0.027 | 0.034±0.019 | 0.152±0.071 | 0.149±0.054 |
| Corset attachment | Floor | 0.089±0.122 | 0.076±0.122 | 0.303±0.159 | 0.282±0.110 |
| | Overhead | 0.042±0.028 | 0.055±0.073 | 0.274±0.158 | 0.269±0.089 |
| Patient transport | Floor | 0.042±0.028 | 0.038±0.017 | 0.178±0.084 | 0.180±0.066 |
| | Overhead | 0.035±0.026 | 0.051±0.076 | 0.163±0.108 | 0.158±0.076 |
| Corset release | Floor | 0.155±0.245 | 0.065±0.095 | 0.225±0.109 | 0.225±0.081 |
| | Overhead | 0.048±0.052 | 0.059±0.091 | 0.184±0.084 | 0.193±0.076 |
| Corset removal | – | 0.245±0.345 | 0.289±0.557 | 0.308±0.101 | 0.309±0.130 |
| sEMG ARV | | | | | |
| Corset insertion | – | 0.023±0.013 | 0.022±0.008 | 0.115±0.056 | 0.119±0.042 |
| Lift transport | Floor | 0.018±0.014 | 0.016±0.010 | 0.052±0.029 | 0.049±0.012 |
| Corset attachment | Floor | 0.020±0.015 | 0.018±0.013 | 0.103±0.054 | 0.107±0.038 |
| | Overhead | 0.019±0.015 | 0.018±0.016 | 0.089±0.038 | 0.109±0.039 |
| Patient tran sport | Floor | 0.019±0.015 | 0.016±0.011 | 0.056±0.031 | 0.056±0.021 |
| | Overhead | 0.017±0.014 | 0.016±0.015 | 0.047±0.031 | 0.057±0.034 |
| Corset release | Floor | 0.023±0.021 | 0.019±0.018 | 0.081±0.045 | 0.077±0.022 |
| | Overhead | 0.018±0.015 | 0.018±0.019 | 0.072±0.037 | 0.072±0.022 |
| Corset removal | – | 0.022±0.018 | 0.025±0.024 | 0.114±0.048 | 0.111±0.035 |

As regards the kinematic data, trunk flexion-extension RoM showed in the first scenario, a statistically higher value with the floored lift than with the overhead lift during the sub-tasks of corset attaching and removal (corset attaching: 52.03 ± 9.57 and 36.52 ± 6.06, $p = 0.003$, respectively, corset removal: 43.93 ± 8.74 and 32.69 ± 6.49, $p = 0.038$, respectively) while in the second scenario trunk flexion-extension RoM showed a statistically higher value with the floored lift than with the overhead lift during the sub-tasks of patient moving and corset removal (patient moving: 29.99 ± 9.59° and 15.85 ± 9.11°, $p = 0.03$; corset removal: 40.68 ± 11.23° and 22.84 ± 8.21°, $p = 0.002$, respectively), Fig. 2. As far as trunk lateral bending RoM is concerned, both in the first and second scenario, a statistically higher value was found during the corset removal with the floored lift that with the overhead lift (first scenario: 61.98 ± 15.13° and 33.72 ± 8.73°, $p = 0.001$, respectively; second scenario: 46.53 ± 6.59° and 35.59 ± 5.67°, $p = 0.001$, respectively). Trunk rotation RoM showed a statistically higher value during the corset removal with the floored lift that with the overhead lift in the first scenario (31.36 ± 19.67° and 21.97 ± 15.87°, $p = 0.023$, respectively) and during patient moving in the second scenario (28.73 ± 13.37° and 20.57 ± 10.33°, $p = 0.034$, respectively), Fig. 2.

**Table 2** sEMG maximum and ARV values of the four muscle activity (mean ± standard deviation) for each sub-task in the second scenario (patient moved from the wheelchair to the bed)

| sEMG maximum value | | | | | |
|---|---|---|---|---|---|
| Activity | Lift type | R rectus abdominis | L rectus abdominis | R erector spinae | L erector spinae |
| Corset insertion | – | 0.058±0.036 | 0.150±0.199 | 0.304±0.135 | 0.292±0.075 |
| Lift transport | Floor | 0.050±0.045 | 0.050±0.043 | 0.116±0.051 | 0.140±0.046 |
| Corset attachment | Floor | 0.063±0.077 | 0.083±0.199 | 0.207±0.096 | 0.215±0.084 |
| | Overhead | 0.047±0.054 | 0.057±0.085 | 0.202±0.092 | 0.211±0.091 |
| Patient transport | Floor | 0.042±0.033 | 0.093±0.152 | 0.183±0.087 | 0.175±0.073 |
| | Overhead | 0.034±0.025 | 0.035±0.029 | 0.122±0.066 | 0.122±0.055 |
| Corset release | Floor | 0.056±0.044 | 0.069±0.074 | 0.202±0.094 | 0.241±0.081 |
| | Overhead | 0.059±0.070 | 0.060±0.086 | 0.218±0.134 | 0.257±0.102 |
| Corset removal | – | 0.145±0.122 | 0.160±0.096 | 0.272±0.199 | 0.274±0.108 |
| sEMG ARV | | | | | |
| Corset insertion | – | 0.019±0.035 | 0.023±0.127 | 0.106±0.209 | 0.109±0.172 |
| Lift transport | Floor | 0.023±0.019 | 0.022±0.018 | 0.042±0.018 | 0.051±0.014 |
| Corset attachment | Floor | 0.018±0.016 | 0.019±0.015 | 0.075±0.039 | 0.079±0.036 |
| | Overhead | 0.018±0.014 | 0.018±0.018 | 0.083±0.044 | 0.082±0.031 |
| Patient transport | Floor | 0.018±0.058 | 0.017±0.013 | 0.051±0.025 | 0.057±0.024 |
| | Overhead | 0.018±0.016 | 0.015±0.014 | 0.051±0.032 | 0.048±0.022 |
| Corset release | Floor | 0.019±0.015 | 0.021±0.013 | 0.076±0.025 | 0.091±0.024 |
| | Overhead | 0.020±0.016 | 0.018±0.017 | 0.082±0.052 | 0.093±0.038 |
| Corset removal | – | 0.032±0.027 | 0.034±0.025 | 0.094±0.040 | 0.102±0.034 |

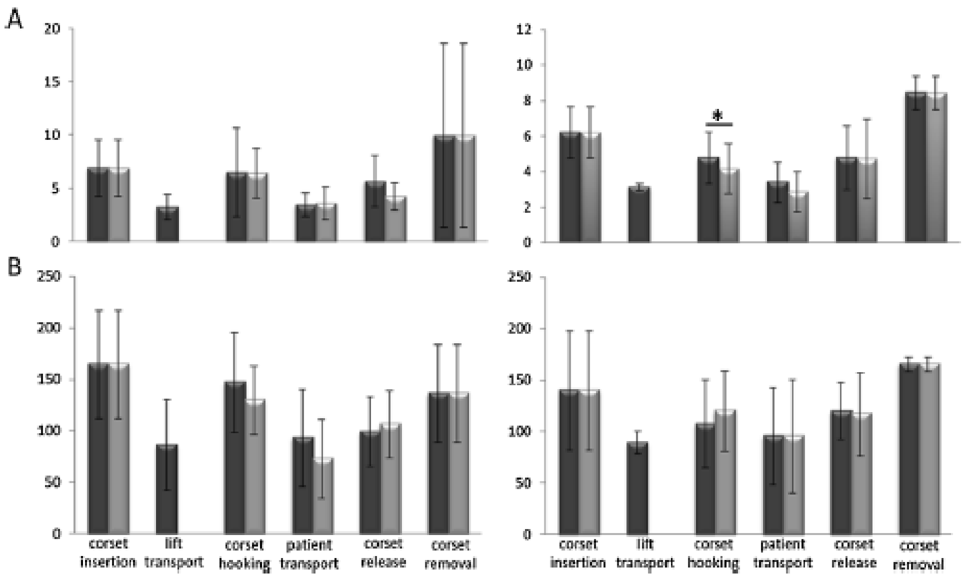


**Fig. 1** Panels A (both *left* and *right*): maximum value of the TMCf (mean ± standard deviation) during all the sub-tasks. Panels B (both *left* and *right*): area of the TMCf (mean ± standard deviation) during all the sub-tasks. In all the panels, *dark grey bar* are relative to the use of the floor lift and *light grey* ones to the overhead one

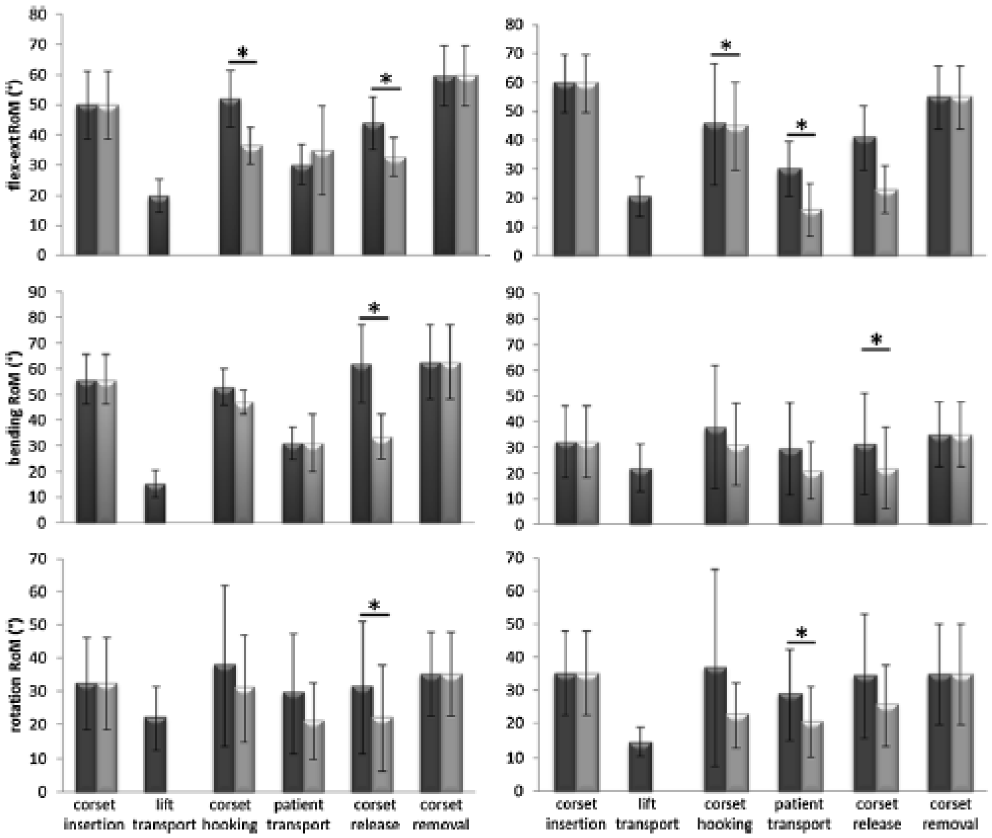


**Fig. 2** Mean and standard deviation of the trunk RoMs in the three spatial planes in the first (*right panels*) and second (*left panels*) scenario with floor (*dark grey bars*) and overhead (*light grey bars*) lift

## 4 Discussion

In the present study, we evaluated the biomechanical differences resulting from the use of an overhead and floor lift using a quantitative approach based on advanced motion analysis methods.

Concerning the recorded electromyographic activity, the Middle Rectus Abdominis (both right and left) were, on average, slightly activated during all the analyzed sub-tasks with both floor and overhead lifts, while the Erector Spinae (both left and right) were more engaged than the abdominal muscles in all the sub-tasks with both wheeled and overhead lifts, although they also showed values of assets on average modest, Table 1.

The higher maximum value of the right erector spinae normalized signal during the corset unhooking, when patient is moved from the bed to the wheelchair, with the floor lift than with the overhead lift, may be due to the different operator posture caused by the trolley size. The statistically significant higher maximum value of both the right and left side with the floor lift than for the overhead lift during the patient movement from the wheelchair to the bed, as for the higher maximum value of the TMCf, could be due to the fact that the operator, with the floor lift, is involved in push and pull tasks in order to move the trolley and the patient, while with the overhead lift the operator should only operate a remote control and limit patient's oscillations. Anyway, the muscle effort is on average very low even with the floor lift, in fact there is no difference between the two lifts when the patient is transported from the bed to the wheelchair, because both the lifts allow to electrically modify patient's posture and this implies a reduction of the muscle effort while using the lift.

As far as trunk kinematic is concerned, trunk flexion/extension ROM data were consistent with the UNI EN ISO 1005-4 [15] indications, in both scenarios and with both types of lift, thus ensuring a safe healthcare operator posture, during all the procedure from the corset insertion to its removal. Instead, trunk lateral bending and rotation RoM fall in the range considered only conditionally acceptable according to the UNI EN ISO 1005-4 [15], which means that the values are acceptable only if the position is not kept for long durations by the same person. Hence, the lift allows globally the healthcare operator to work safely. Moreover, the lower values obtained with the overhead lift with respect to the floor lift may be due to the different operator postural conditions because of the trolley size. However, as can be seen in Fig. 2, the trunk lateral bending and rotation RoM, are very far from the recommended value of 10°, therefore it could be better to invest on a proper training in order to avoid, even for few seconds, wrong postures, characterized by high trunk lateral bending and twisting as suggested by the UNI EN ISO 1005-4 [15]. In this way it could be possible to better use the mechanical aids in order to actual reduce the risks from manual handling of patients. Finally, it can be observed that for both electromyographic and kinematic parameters the highest values were found during the corset insertion and removal, which are the two sub-tasks without the help of the mechanical aid. A solution to face this problem could be a proper training or the employment of two operators.

## 5 Conclusions

The results obtained confirm the data in the literature on the effectiveness of the use of mechanical aids to maintain the biomechanical effort during the patients handling at low values.

There are some differences in the biomechanical load when using the overhead lift, with which the muscle effort, although it is low with both lifts, is further reduced with respect to the floor one. The differences between the two lifts are due to the lack of the push and pull sub-tasks with the overhead lift and to the different operator posture caused by the trolley size with the floor lift. Globally, the muscle effort is low, hence the co-activation index is the most adequate and representative of different load conditions. In conclusion, the results obtained could be a practical tool for the physicians, when they have to express an opinion in case of reduced fitness for work.

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