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Jean-Baptiste Riccoboni, Tony Monnet, Antoine Eon, Patrick Lacouture, Jean-Pierre Gazeau, et al.. Biomechanical comparison between manual and motorless device assisted patient handling: sitting to and from standing position. *Applied Ergonomics*, 2021, 90, pp.103284 -. 10.1016/j.apergo.2020.103284 . hal-03493442

HAL Id: hal-03493442

<https://hal.science/hal-03493442>

Submitted on 17 Oct 2022

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Biomechanical comparison between manual and motorless device assisted patient handling: sitting to and from standing position

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ABSTRACT

Although lots of assistive devices have been studied to fight against caregivers' work-related musculoskeletal disorders, stand-and-turn devices effects on biomechanical constraints are still unknown. The aim of this study is to provide and compare quantitative data on loads in the low back area resulting from the use of a motorless stand-and-turn device and from manual patient handling. Nine caregivers participated to motion capture and ground reaction forces measurement sessions of three cases of handling: manual handling with one caregiver, manual handling with two caregivers, motorless device assisted handling. Forces and torques at the L5/S1 joint were computed through Inverse Dynamics process. Motorless device assisted handling required the smallest loads whereas manual handling with one caregiver required the biggest loads, the latter being in some cases twice as big as the former. Caregivers should use a stand-and-turn device when handling a patient from sitting/standing to standing/sitting position whenever it is possible.

Keywords: Musculoskeletal disorders, Caregiver, Patient transfer.

Abbreviations:

- MH1C: Manual Handling with One Caregiver,
- MH2C: Manual Handling with Two Caregivers,
- MDAH: Motorless Device Assisted Handling.

1. Introduction

It is now a well-known fact that people working in the healthcare sector, involved in some way in patient handling (called caregivers in the article), are particularly at risk of developing work-related musculoskeletal disorders (WRMSDs), especially at the back, and so to be impacted by all their usual consequences ([Bureau of Labor Statistics, 2016](#); [Health and Safety Executive, 2016/17a](#); [Health and Safety Executive, 2016/17b](#)). Instances can be found in the works of [Applegeet \(2007\)](#), [Hignett et al. \(2016\)](#) and [Ribeiro et al. \(2017\)](#). [Marras et al. \(1999\)](#) referenced several studies which put forward that, among all the activities caregivers perform, patient transfers are the ones that are associated with most of their low-back injuries. More than one-fifth of these transfers aim to get a patient from bed to chair and vice versa ([Knibbe and Friele, 1996](#)), which involve a change from the sitting position to the standing position then to the sitting position again. Patient mobility is nonetheless essential to avoid loss of muscle strength, to prevent deep vein thrombosis or just to attain and maintain independence in activities of living ([Kneafsey et al., 2014](#)).

However and as pointed out by [Roffey et al. \(2010\)](#), it is still difficult to show that workplace manual handling or assisting patients are independently causative of pain at specific areas. WRMSDs are indeed complex problems, with many and various parameters. A few examples of these parameters, while not all directly linked to patient handling, are discussed in the articles of [Carneiro et al. \(2017\)](#), [Holman et al. \(2010\)](#), [Kay et al. \(2015\)](#), [Manyisa and Van Aswegen \(2017\)](#) and [Risør et al. \(2017\)](#). It is therefore essential to detect and identify the elements of patient handling leading to too much stress (compared to the acceptable values recommended by occupational safety and health institutions) then to modify them in order to decrease, nullify or avoid their repercussion (with the expectation of reducing the people exposure to WRMSDs). Commonly manifesting through ergonomics program, this has been the subject of lots of studies these last years like that of [Darragh et al. \(2013\)](#) who mentioned a safe patient handling program recommending that therapists avoid lifting more than fifteen kilograms of patient weight. This recommendation is often known as a “no-lift policy”. A conventional way to reduce the lifted weight during patient transfers is to use mechanical assistive devices. [Waters and Rockefeller \(2010\)](#) and [Garg and Kapellusch \(2012\)](#) indicated that using them as part of an ergonomics program was effective in reducing patient-handling injuries and thereby in reducing the risk of WRMSDs for caregivers.

There are also studies that try to compare the adopted solutions by providing qualitative or quantitative data about their effects or their efficiency and it is in this category that this study belongs, focusing on the potential benefits that mechanical assistive devices can get to the problem of WRMSDs. [Santaguida et al. \(2005\)](#), [Dutta et al. \(2012\)](#), [Garg et al. \(1991\)](#) and [Zhuang et al. \(1999\)](#) worked on a couple of devices going from walking belts to overhead lifts and compared the biomechanical constraints involved in each case. [Dutta et al. \(2012\)](#) calculated and compared floor and overhead lifts forces requirements, finding that the latter resulted in lower loads on caregivers and were predicted to reduce the risk of back injury to caregivers. [Zhuang et al. \(1999\)](#) expected similar outcomes for stand-up lifts as they noticed that the exposure to low-back stress was completely eliminated for sitting down and standing up tasks once the device set up. They also did a psychophysical assessment of some assistive devices ([Zhuang et al.; 2000](#)). Still about sit-to-stand activities, [Daynard et al. \(2001\)](#) analyzed simulated peak and cumulative spinal loads of caregivers when using a sit-stand lift and recommended the use of this device based on the peak values; [Burnfield et al. \(2012\)](#) observed that verbal encouragement from clinicians improved patients’ muscle activation and kinematics to a certain extent when using a sit-to-stand device. Hignett (2003) stated in 2003, though, that no research on turning devices which are different in many ways from the ones previously mentioned have been found. To this day, these devices weren’t the focus of numerous studies. Stand-and-turn devices present two interesting characteristics yet: they are among the less expensive and cumbersome assistive devices. [Ruszala and Musa \(2005\)](#) did evaluate a stand-and-turn aid on general aspects like ease or time of use,

identifying its main utility in the functional setting, but no biomechanical data were provided. Stand-and-turn devices provide firm and steady grips for patients during handling and are expected to reduce the number of cases where caregivers have to generate efforts with uncomfortable postures. Even if several technologies allowing to measure biomechanical constraints exist, like inertial measurement units (Bolink et al., 2016; Faber et al., 2016; Koopman et al., 2018), electrogoniometers (Weiner et al., 2017) and computer vision (Mehrizi et al., 2018), most of the studies in this category have used optoelectronic motion capture system and so will this study. Indeed, optoelectronic motion capture is often considered as the gold standard (Bolink et al., 2016) due to its accuracy and its reproducibility.

The aim of this work is to provide quantitative data about the loads in the low back area, as well as qualitative data about subjects' perceptions, resulting from the use of a motorless stand-and-turn device and to compare them to those resulting from manual patient handling.

2. Methods

2.1 Subjects

As part of its will to reduce the prevalence of WRMSDs affecting their caregivers, the Institut de Cancérologie de l'Ouest (ICO; an institute specialized in both outpatient and inpatient cancer treatments, research and training) issued a call for volunteers among its employees to participate in this study as subjects. Nine caregivers, composed of seven women and two men, accepted and were selected after giving their informed consent in accordance with local ethical procedures. They were from 21 to 59 years old (mean: 38.3; standard deviation: 14.2), were from 155 to 181 centimeters tall (169.7; 9), weighed from 48 to 98 kilograms (66.1; 14.7). There were five nurses and four assistant nurses; all of them knew how to manually handle patient (at least from their initial training courses) and how to use the motorless stand-and-turn device. They had from 0.7 to 41 years of experience (17.2; 15). Seven of them suffered or had suffered from MSDs, mainly at the low back and shoulders areas. They claimed that they manually handle patients 9.5 times a day on average (with a standard deviation of 6.3) and that this require 1.6 persons on average (0.5). They used the motorless stand-and-turn device 0.8 times a day (1.7) and it requires 1.3 persons (0.5).

Each caregiver played the role of the handled patient (called the surrogate patient in this article) several times, meaning they had to imitate the behavior of real patients. Their instructions were to provide the minimum efforts allowing the handling to be carried out. In addition and for the purpose of providing a point of comparison between the subjects, a male surrogate patient (called MSP) measuring 175 centimeters and weighing 63 kilograms participated in all the experiments with the same instructions. More detailed explanations will be given afterwards.

2.2 Setting and equipment

The experiments took place in a motion capture room at the Institut PPRIME. As these measures were not *in situ*, a seat mimicking a hospital bed in terms of functionality (allowing the caregiver to adjust the seat height) and clutter (denying the caregiver to get on seated patient side) was used. This height was not tracked (as determining the best parameters to handle a patient was not an objective of this study) and changed between subjects. The motorless stand-and-turn device used was a Vertic'Easy from HMS-VILGO (Fig. 1) as it is the model owned by the ICO.



Fig. 1. Motorless stand-and-turn device

Its dimensions were 1300mm in height, 510mm in length, 470mm in width and it weighed 16kg unloaded. The position of the handgrips and tibial support were not tracked (for the same reason as the seat one) but did not change during and between experiments, even if the subjects were told that they were allowed to change them depending on what they thought was most comfortable.

2.3. Measurement techniques

By measuring the three-dimensional location of body segments and the mechanical forces applied by the subject on the ground then by using Inverse Dynamics process, it is possible to calculate the joint reaction forces and torques. Several details about the subjects were also requested to be able, notably, to compare the results with those of previous studies.

A Vicon Motion Systems Limited (Oxford, GB) motion capture system composed of 19 MX T40 cameras sampled at 100Hz, connected through Vicon Motion Systems Limited's Nexus 1.8.5, was used for all the recordings. Subjects were equipped with 52 reflective markers following a modified version of the Istituto Ortopedico Rizzoli Full-Body Marker Set (Cappozzo et al., 1995; Leardini et al., 2011), showcased in Fig. 2. Head and upper limbs segments had their movements recorded with a view to describe full-body postures in future studies but were neither used in this one nor included in the biomechanical constraints computation.

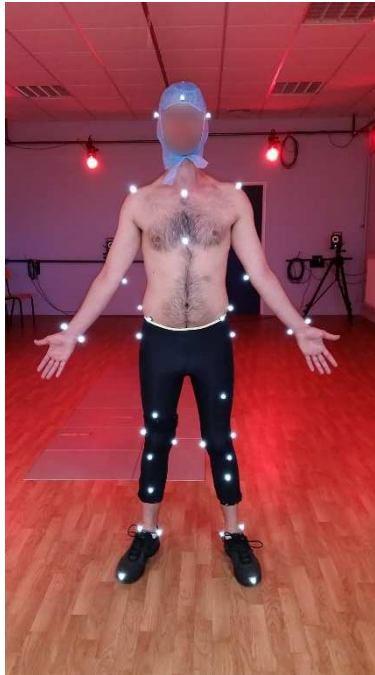


Fig. 2. Subject equipped with markers

Ten M40-600x400 force platforms from SENSIX (Poitiers, FR) sampled at 1000Hz were placed at the center of the recording and calibrated area and were synchronized with the kinematics acquisitions by Vicon Motion Systems Limited's Nexus 1.8.5. Their layout allowed subjects to put their feet "naturally", in their own words, while having one foot per platform during handling.

A questionnaire was submitted to the subjects at the end of each session. Here are the main topics covered: background information (like gender, age, position, seniority...), presence or not of WRMSDs and details about it if so, quantity and perception of manual and motorless device assisted patient handlings. The objective of this questionnaire was to collect caregivers' point of view and opinion.

2.4. Handling methods

Prior to the experiments, observations were made during one month at the ICO premises to get a better understanding of all the tasks performed by caregivers. The following handling methods were chosen from the observations made at the ICO and from the advices of the first participating caregivers. While the techniques employed by the subjects were highly similar, their gestures presented some variations regarding hands positions and orientations in particular. They were given some freedom on this in order to obtain the most natural behavior. The handlings methods were the following:

- Manual handling with one caregiver (MH1C): subjects were asked to lift alone the surrogate patients by facing them and placing their legs on each side of those of the surrogate patients. The [Fig. 4a](#) and [4b](#) illustrate this handling where the subject chose to place his hands on the back of the surrogate patient with his arms under the armpits. In [Fig. 4c](#), the subject chose to place his hands lower on the back, one above the other. This kind of patient handling is common and can be found in other works like that of [Schibye et al. \(2003\)](#).

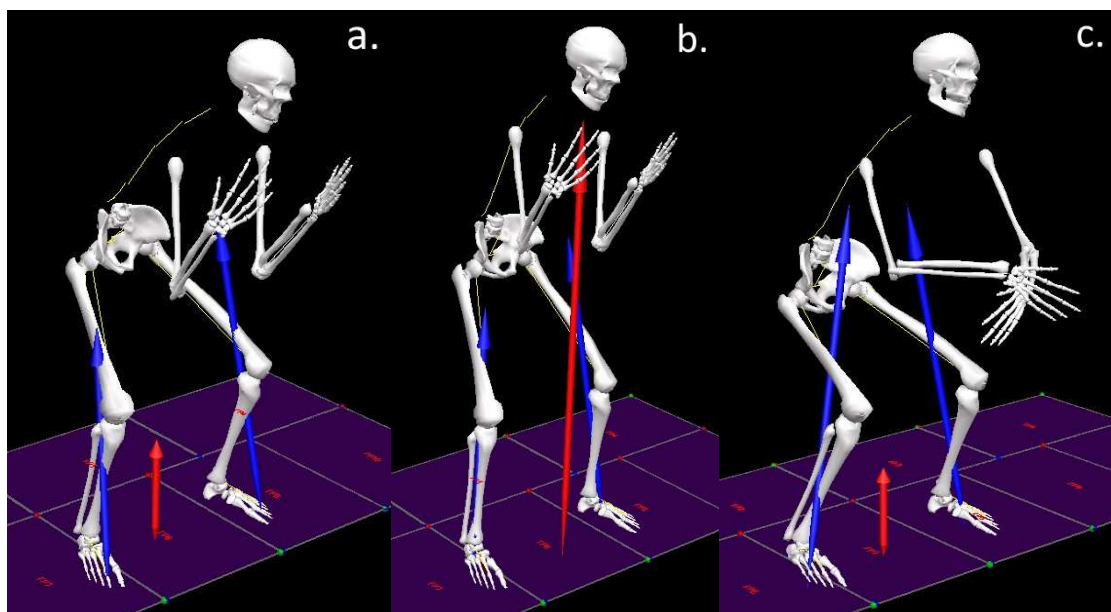
- Manual handling with two caregivers (MH2C): when two caregivers were involved, the one equipped with the markers (called the main caregiver in this article) was on the left of the surrogate patient ([Fig. 4d](#) and [4e](#)) while the other was on the right. Both were free on how to lift the surrogate patient as long as the feet of the main caregiver were entirely on two

different force platforms. The right arm of the main caregiver was placed under the left armpit of the surrogate patient and the right hand was on the left forearm. This kind of patient handling is common and can be found in other works like that of [Schibye et al. \(2003\)](#).

- Motorless device assisted handling (MDAH): the subject faced the surrogate patient when using the motorless stand-and-turn device. The latter was in the middle, the tibial support on the side of the surrogate patient. The subject immobilized the device thanks to the upper handgrips (Fig. 4f) while the surrogate patient used the lower handgrips as a support to stand up. Pictures of a MDAH are shown in Fig. 3. The turning capability of the device was not used.



Fig. 3. Pictures of a MDAH



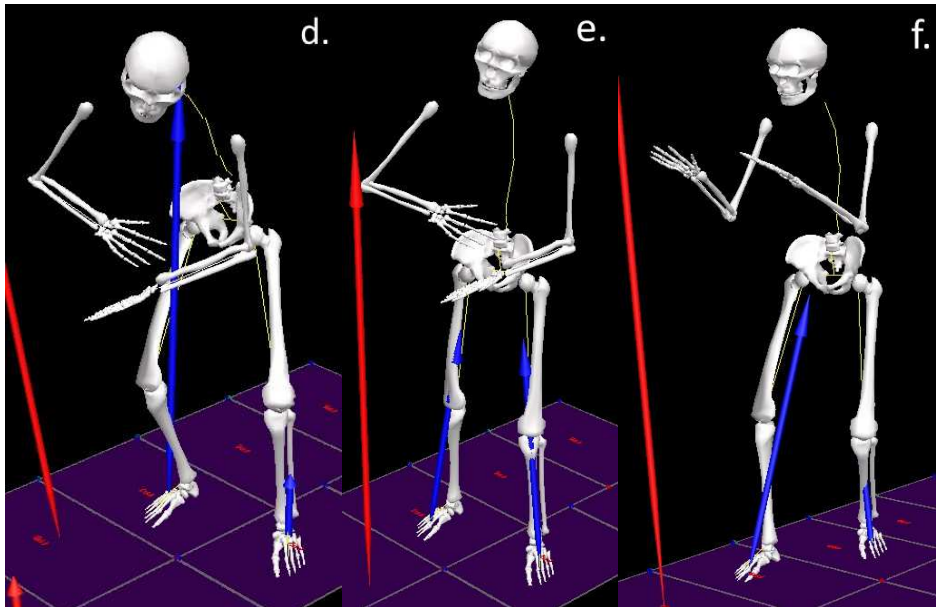


Fig. 4. Examples of handlings obtained with Visual3D, from top left to bottom right: start of MH1C (a.), end of it (b.), start of MH1C showing a different position of the hands (c.), start of MH2C (d.), end of it (e.), MDAH (f.)

2.5. Data collection procedure

Caregivers arrived by group of three at the Institut PPRIME (all recordings took place over three days). They had been previously informed of the general conduct of the recording session, were asked to come with tight clothes and gave their consent through a signed agreement. At their arrival, the different steps of the day were presented to them more thoroughly. Three cases were studied:

- Case number one: the equipped subject (playing the role of the main caregiver) was asked to lift the two other subjects and the male surrogate patient (MSP) up alone (one after another).
- Case number two: the main caregiver was helped by a second caregiver to perform the manual handlings of the last remaining subject and the MSP; then the second caregiver and the remaining subject switched roles.
- Case number three: the main caregiver handled the two other subjects and the MSP with the motorless stand-and-turn device.

Subjects were equipped with the markers one at a time and a few unrecorded trials of manual and motorless device assisted handling were done before each start of recording. Once the subjects felt ready, each case happened in a random order. Surrogate patients were sitting on a seat at a height set by the main caregiver. Each subject performed 3 trials for each configuration, with a resting time of 5 minutes when changing configuration. An example of this description is in the [Table 1](#). Markers were removed from the main caregiver afterwards and positioned on one of the two other subjects (who became the main caregiver) to restart all the procedures described above. When all the recordings for the three subjects were done, their last task was to fill the questionnaire.

Case number	Handling method	Caregiver(s)	Surrogate patient		
			S2	S3	MSP
1	MH1C	S1	3 trials	3 trials	3 trials
2	MH2C	S1 and S2	/	3 trials	3 trials
		S1 and S3	3 trials	/	3 trials
3	MDAH	S1	3 trials	3 trials	3 trials

Table 1. Example of trials recording (S1, S2, S3 are subjects; S1 is the only one equipped with markers; MSP is the male surrogate patient)

2.6. Data analyses

Kinematics and ground reaction forces data were exported as a .c3d file then imported into C-Motion's (Germantown, MD) Visual3D. Beforehand, a custom kinetic model had been built in which segments and joints are considered as rigid bodies and spherical joints respectively. Joints positions were defined as follow: midpoints of the malleoli for the ankles, midpoints of the femoral epicondyles for the knees, results of regression equations for hips adapted from [Bell et al. \(1989; 1990\)](#); the back have been divided into five segments with the six joints being from bottom to top: the fifth, third and first lumbar vertebrae, the seventh and third thoracic vertebrae and the seventh cervical vertebrae. Segments definition of volumes, mass, moments of inertia and center of gravity location were inspired by the work of [Ernest P. Hanavan \(1964\)](#). Associating feet to their corresponding force platforms and performing the Inverse Dynamics process, joint forces and torques were obtained for each segment in its frame of reference. These results were finally compared in the three cases (MH1C, MH2C and MDAH). To improve data readability, each trial was divided in two parts: when subjects helped the surrogate patient to stand up (called the standing up part) and when subjects helped the surrogate patient to sit (called the sitting down part). Answers to the questionnaire were used to know, inter alia, subject's background information and perceptions. To account for the random effect of caregiver, all the trials were kept for the statistical analyses and mixed factor ANOVAs were run for forces and torques to compare standing up and sitting down parts and to compare handling methods. When significant result was found, analyses were followed by a post hoc Bonferroni test for multiple comparisons of means between handling methods. Statistical significance was set at $p < 0.05$.

3. Results

3.1. Loads

[Fig. 5](#) and [Fig. 6](#) (for sitting down and standing up part respectively) present forces and torques at the L5/S1 joint of one of the subjects (weight: 71kg) using each handling method to handle the MSP (weight: 63kg) each time. Graphs for other subjects had similar patterns. Abscissa axis is in percentage of movement completion (0 beginning and 100 end of the movement) and ordinate axis are in N or N.m.

For the sitting down part, maximal values for forces were close between both manual handling methods ($\approx 450\text{N}$ in this case), being slightly smaller in general when the subject used the MH2C method ([Fig. 8](#), more details below), while they were smaller for the motorless handling method ($\approx 300\text{N}$ in this case, corresponding to a 33% reduction). Maximal torques values were less close for both manual handling, being once again smaller when the subject used the MH2C method ($\approx 150\text{N.m}$ for MH1C and $\approx 125\text{N.m}$ for MH2C in this case, corresponding to 17% reduction), and they were even smaller for the motorless handling method ($\approx 80\text{N.m}$ in this case, corresponding to a 47% and 36% reduction respectively). Throughout handling, forces remained constant for the three methods for the first 70% of movement completion while torques increased for the manual handlings and were nearly constant for the MDAH. When looking at the motion files, the rise in forces and torques from 0 to 5% of movement completion happened when the surrogate patient knees started to bend. The drop in forces and torques near 80% of movement completion happened when the surrogate patient started to lie on the seat.

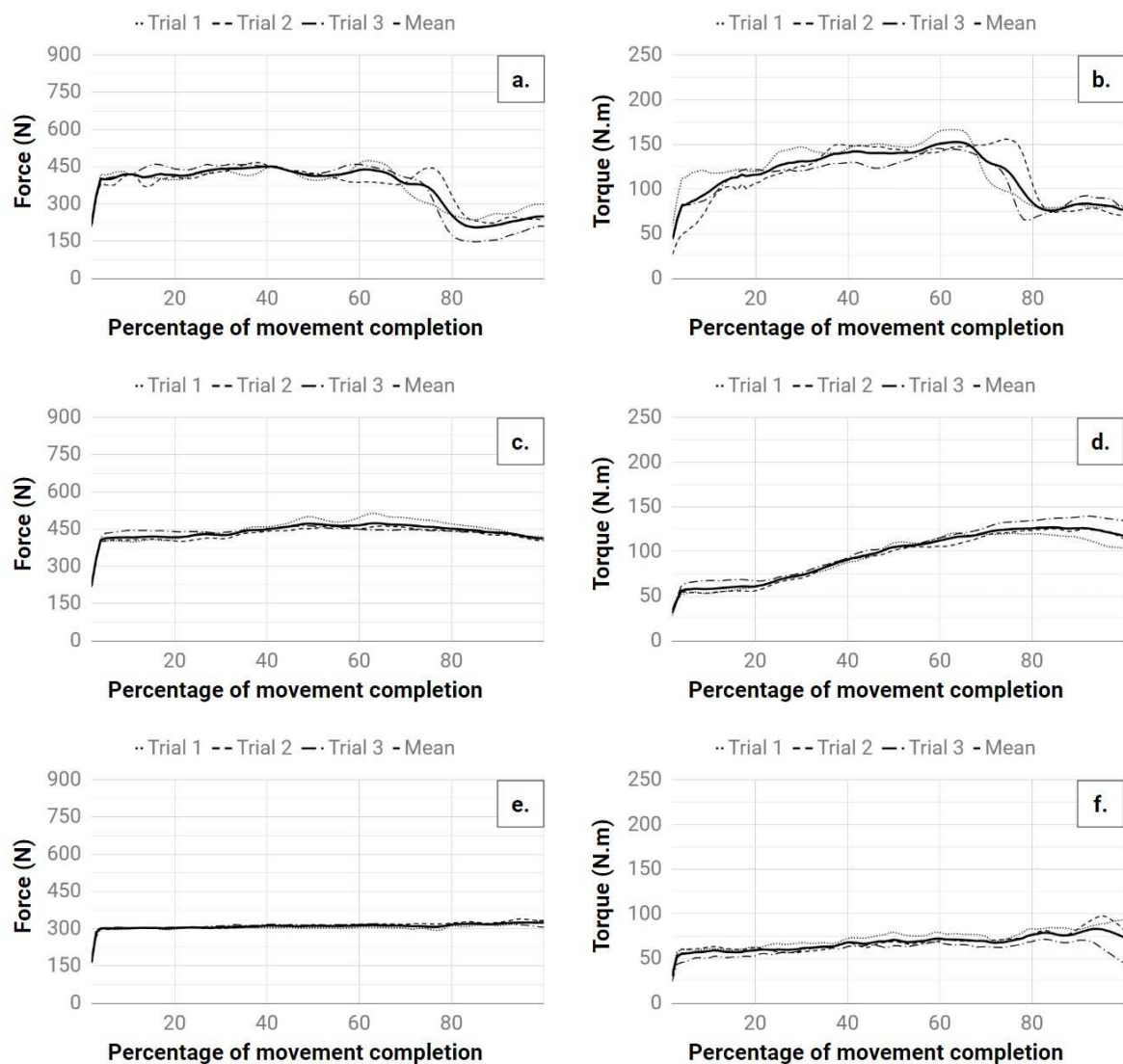


Fig. 5. Forces and torques at the L5/S1 joint during the sitting down part with: MH1C (a. and b.), MH2C (c. and d.), MDAH (e. and f.)

For the standing up part, differences in maximal forces and torques values between handling methods were bigger: MH1C had the highest maximal values (forces: $\approx 750\text{N}$; torques: $\approx 200\text{N.m}$ in this case), MH2C had values in between (forces: $\approx 600\text{N}$, 20% reduction; torques: $\approx 125\text{N.m}$, 38% reduction in this case) while MDAH had the lowest (forces: $\approx 300\text{N}$, 60% and 50% reduction respectively; torques: $\approx 100\text{N.m}$, 50% and 20% reduction respectively in this case). These peak values happened around 50% of movement completion for manual handling methods. Like for the sitting down part, MDAH induced nearly constant forces and torques. When looking at the motion files, the rise in forces and torques from 0 to 5% of movement completion happened when the main caregiver started to pull the surrogate patient up.

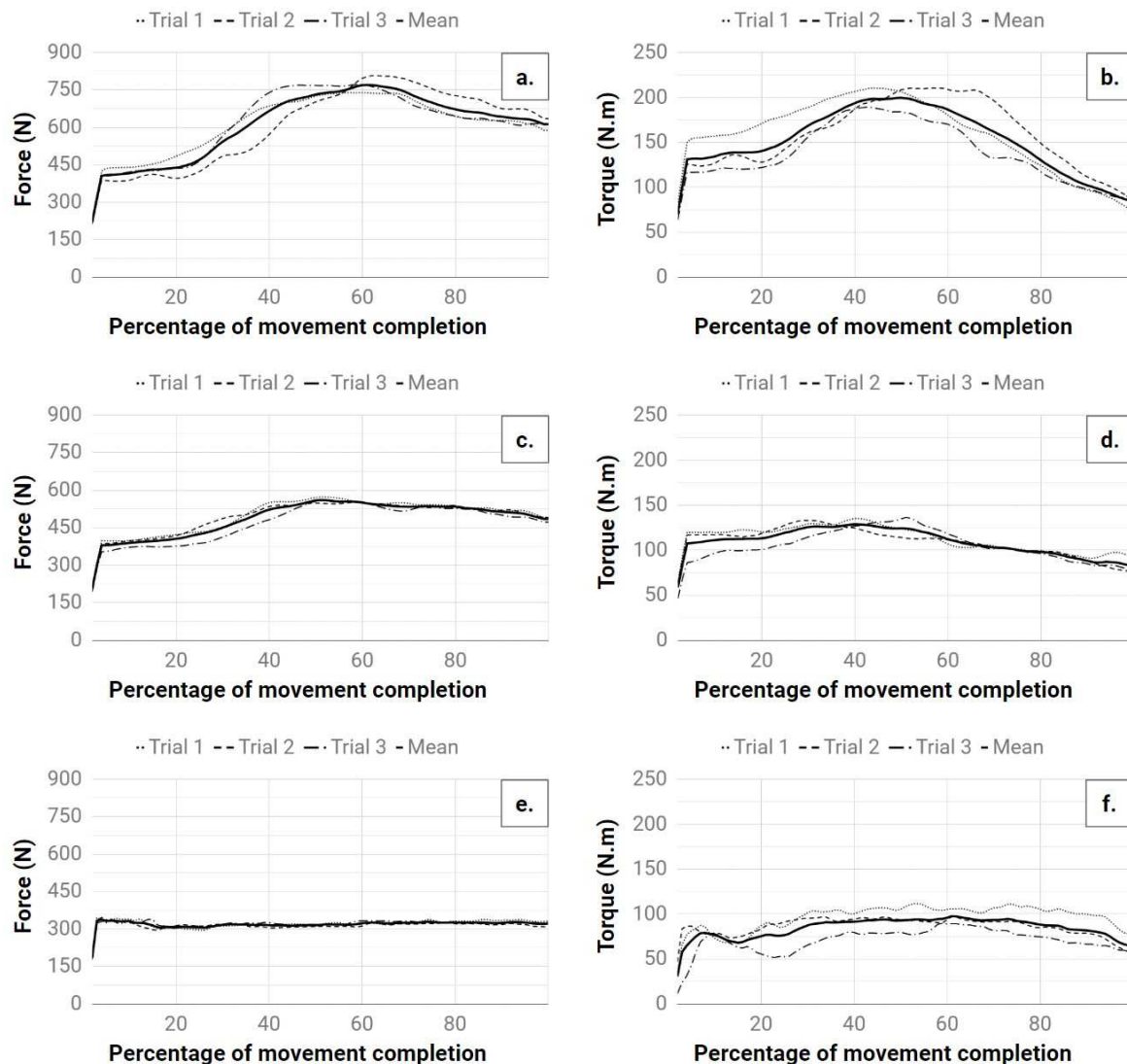


Fig. 6. Forces and torques at the L5/S1 joint during the standing up part with: MH1C (a. and b.), MH2C (c. and d.), MDAH (e. and f.)

Fig. 7 and Fig. 8 illustrate the comparisons between the sitting down and standing up parts and between handling methods respectively. Bars represent the means of the maximal forces and torques values for all corresponding trials and error bars represent the standard deviations.

When comparing sitting down and standing up parts, forces and torques were significantly bigger during the standing up part with the manual handling methods and there were no significant differences with the MDAH method. Mean forces increased from 471.1N to 613.8N ($F=170.9$; $p=1e-6$) with one caregiver, from 454.8N to 537.2N ($F=130.6$; $p=1e-6$) with two caregivers and were the same ($353.3N \approx 350.2N$; $F=1.53$; $p=0.22$) with one caregiver and the motorless stand-and-turn device. Mean torques increased from 114.8N.m to 148.2N.m ($F=74.53$; $p=1e-6$) with one caregiver, from 94.6N.m to 103.0N.m ($F=8.69$; $p=0.0039$) with two caregivers and were the same ($64.4N.m \approx 68.8N.m$; $F=1.26$; $p=0.26$) with one caregiver and the motorless stand-and-turn device.

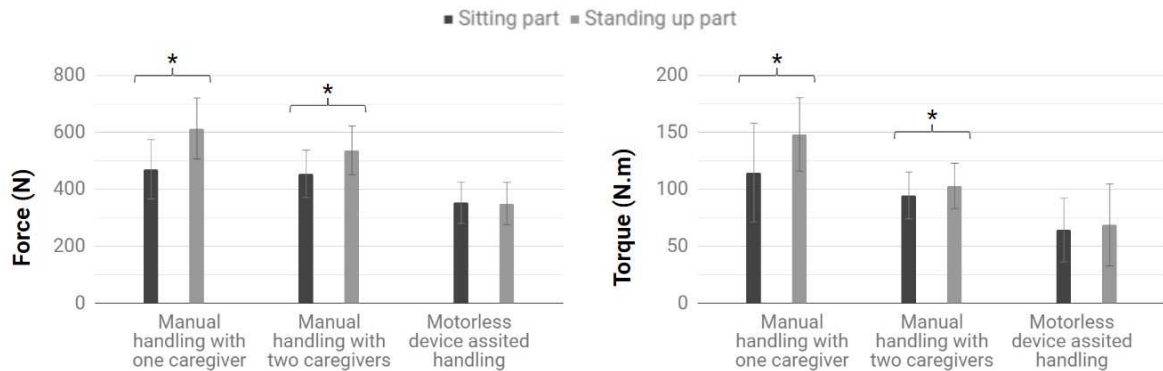


Fig. 7. Comparison between sitting down and standing up part with respect to forces and torques at the L5/S1 joint for each handling method

For the sitting down part: changing handling method induced significant differences for forces ($F=186.7$; $p=0.037$) and torques ($F=118.5$; $p=1e-6$). Multiple comparisons revealed that forces differed with a p-value of 0.037 for the MH1C/MH2C comparison and with a p-value <0.01 for the MH1C/MDAH and MH2C/MDAH comparisons. It revealed that torques differed with a p-value of <0.01 for the three comparisons. For the standing up part: changing handling method induced significant differences for forces ($F=493.4$; $p=1e-6$) and torques ($F=217.1$; $p=1e-6$). Multiple comparisons revealed that forces and torques differed with p-values <0.01 for the three comparisons.

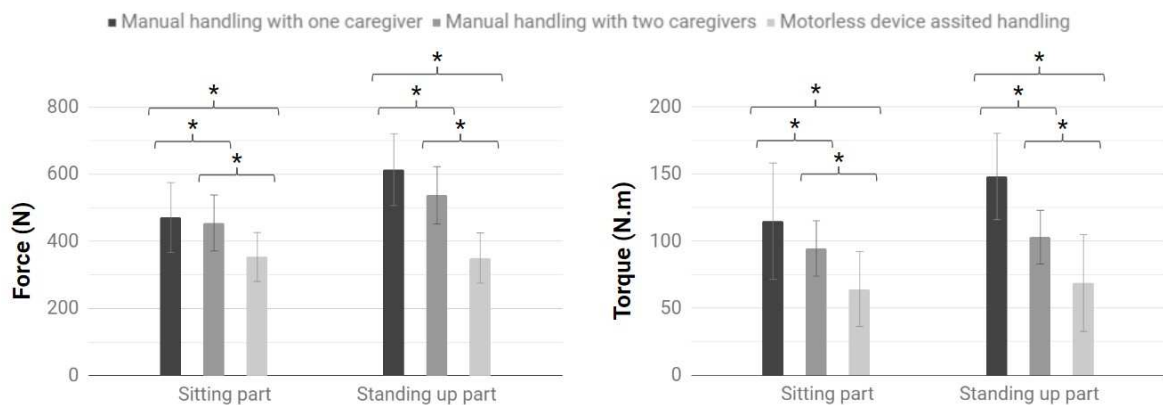


Fig. 8. Comparison between handling methods with respect to forces and torques at the L5/S1 joint for both trial parts

3.2 Questionnaire

Table 2 provides a tally of the caregivers' answers to the questionnaire.

Question	Answer
Do you suffer or have you ever suffered from musculoskeletal disorders?	Yes currently: 4 Yes, but not anymore: 3 No: 2
If yes, which part of the body are/were concerned?	Shoulder: 4 Lower back: 4 Upper back: 3

Rate the pain intensity on a scale from 1 (bearable) to 10 (unbearable).	Mean: 4.7 Standard deviation: 1.8
Rate on a scale from 1 (demanding) to 5 (not demanding) how you consider manual handling from the caregiver point of view?	Mean: 3.3 Standard deviation: 0.9
Rate on a scale from 1 (not comfortable) to 5 (comfortable) how you consider manual handling from the surrogate patient point of view?	Mean: 3.3 Standard deviation: 0.7
Have you ever used the motorless stand-and-turn device alone before today?	Yes: 7 No: 2
Rate on a scale from 1 (demanding) to 5 (not demanding) how you consider motorless device assisted handling from the caregiver point of view?	Mean: 4.3 Standard deviation: 0.7
Rate on a scale from 1 (not comfortable) to 5 (comfortable) how you consider motorless device assisted handling from the surrogate patient point of view?	Mean: 3.7 Standard deviation: 0.9
Which type of handling do you prefer as a caregiver?	Motorless device assisted: 5 Manual: 4
Which type of handling do you prefer as a surrogate patient?	Motorless device assisted: 5 Manual: 4

Table 2. Answers to the questionnaire

Subjects slightly preferred MDAH to manual handling from the point of view of both the caregiver and the surrogate patient. As tight results were expected, they were asked to explain their answers. In favor of the motorless stand-and-turn device, their arguments were: easier to use for the personnel, easier to perform lifts without pain and fatigue, reassuring when the patient body weight is important or when the patient physical abilities are diminished, better protection of caregiver health, better control of patient equilibrium. In favor of manual handling, their arguments were: more pleasant for the personnel and less intimidating for the patient, quicker and more adaptable to the environment, causing less cluttering.

4. Discussion

4.1. MH1C versus MH2C

In light of these results and if the situation allows it, it is recommended that caregivers handle patients with the help of one colleague instead of doing it alone. While the load difference is the smallest of the comparisons between handling methods, caregivers may feel a benefit over the long term because reducing the loads have a positive effect on the exposure to WRMSDs by reducing fatigue phenomenon and risk of injury. Loads were also applied for a shorter percentage of the handling with MH2C, as shown for instance in [Fig. 5b](#) and [5d](#).

4.2. Manual methods versus MDAH

Furthermore, caregivers are strongly incited to use the motorless stand-and-turn device considering the involved loads. This device helped to greatly reduce forces and torques on the low back area for all the subjects. Using it is even more interesting if there is no other caregiver available to help handling patients as this comparison presents the biggest difference.

4.3. Questionnaire

These results were expected because of what have been retained from the month spent at the ICO (unpublished data). The low utilization of the motorless stand-and-turn device by caregivers, compared to the frequency of manual handlings as claimed in section 2.a.i, seemed to be more related to the difficulties in getting it ready for use (e.g. due to its relative unavailability) than to the difficulties of its use. This study could bring more information about its benefits and caregivers' opinion on handling equipment seemed to have evolved through this work as they were more inclined to use them in the future.

4.4 Comparison with previous findings

As written in the introduction, it seems that the biomechanical constraints resulting from the use of a stand-and-turn lift were never studied. That means that it is not possible to compare the results provided in this work on this topic. Two other elements remain to be compared: manual handlings' biomechanical constraints and the loads differences between handling methods for the sit to stand or stand to sit tasks. It is important to remind in this regard that the computations were done using the ascent method of the Inverse Dynamics process. The values presented here are composed of the effect of the subject upper body (bust and upper limbs) mass and the load applied by the surrogate patient which complicate comparisons with studies using other measurement or computation methods. For manual handlings' biomechanical constraints, health care workers in the study of [Schibye et al. \(2003\)](#) were submitted to peak torques lower than those computed in this work (122.9N.m for their MH1C on a sit to stand task compared to 148.2N.m here). Peak forces were given in a different form (compression values mixed with shear and lateral forces). [Jäger et al. \(2013\)](#) also studied sit to stand tasks manually handled but did not describe how they were done. Torques are the ones provided in a separated form (lateral and torsional) this time and only compression values are available. Making in-depth comparisons would unfortunately require making assumptions. For loads differences between handling methods for the sit to stand or stand to sit tasks, the only comparison possible is with other assistive devices which is quite limited in scope as each device is designed to help in a specific situation. Peak spinal compression values obtained by [Daynard et al. \(2001\)](#) were significantly smaller in groups having assistive equipment at their disposal compared to the group relying on manual transfers (2010N/2555.6N versus 3108N). [Garg et al. \(1991\)](#) found two-person transfers required significantly smaller forces than one-person transfers, with reduction percentages close to those given in this article (around 40%). These comparisons regrettably bring very little to the discussion, as the tasks, techniques, equipment and models used differ greatly from one study to another. That being said, the findings in this work are going in most studies' direction: dividing the loads between caregivers and/or using assistive device help reducing loads and thus fighting against WRMSDs.

4.5 Limitations

To begin with, the number of subjects was quite low. This was mainly due to the fact that it was not possible for the ICO to send more people as it would have been difficult to ensure quality care without enough employees. Means presented in this study may vary with more subjects. Having both genders further diminish the reliability of the comparisons. The subject data (like age, size, weight, experience...) present sometimes important standard

deviation and, in combination with the small pool of subject, this could affect the results in unknown ways. Experience with an assistive device, for instance, can help the caregivers to lower the loads on their low backs (Dutta et al.; 2011). As more than 60% of the caregivers working at the ICO present MSDs (unpublished results), it has been decided to not exclude them from the selection of subjects because it would have been even more difficult to find participants and also it would have been even less representative of this population. Subjects suffering or having suffered from MSDs may have behaved differently from others, which may have altered the values of the biomechanical measurements. It should be noted that all the subjects were able to pull themselves up with the motorless stand-and-turn device. There are cases where real patients cannot do so because they are too weakened, using a motorless stand-and-turn device is then not possible. Caregivers are often well aware of this fact but it is worth to mention it. Tang et al. (2017) studied the strength requirements for patients using a sit-to-stand lift but the device is too different from the one considered in this article to use their results. Surrogate patients in this study were not affected by mobility impairments which is often not the case in healthcare facilities. Firstly, they relied on the main caregivers handling to sit or to stand and according to the latter, the needed efforts to handle the surrogate patients were close to the one they provide in their job. Secondly, doing the experiment with impaired subjects would not have been an overall better choice as it is simpler for healthy subjects to do less efforts than the other way around and that finding willing persons with similar handicaps is difficult and would have introduced even more variability in the outcomes.

The experiments were done in a motion capture room. Despite the efforts made to mimic a hospital room and the numerous trials performed before recording, environment and technical requirements may have impacted subject behavior. Only one model of motorless stand-and-turn device were tested. Results may be different with other models and/or brands.

About caregivers' tiredness, data collection procedure had to be efficient in order to allow the caregivers to get back to their job as soon as possible. Therefore, fatigue may have induced an increasing bias in the values of the biomechanical measurements through the day as the resting time of 5 minutes between handling cases might have been insufficient.

There are two important points about handling methods. First, only one method to handle the surrogate patient for each case of handling was tested, each method described as the best one for its case according to the caregivers. It could be interesting to test several methods for each case and to compare them. Second, while most of the aspects of each methods were imposed, some (like hands position) were decided by the subject. Results should not have been significantly affected but further research should be done.

Subjects worn shoes during the experiments because they do at the hospital. As described by Debbi et al. (2012), force platforms give an approximate location of the center of pressure and therefore induce an approximation in calculations. Despite having ten force platforms and that the caregivers told they felt no constraints about the placement of their feet, instrumented force shoes could have been interesting to use notably as they could facilitate *in situ* measurements. Some applications and information about this technology can be found in the work of Faber et al. (2010; 2018). As pointed out by Ghezlbash et al. (2018) and since the biomechanical model used here includes posteriorly shifted joints and frictionless spherical joints, the computed spinal loads are likely overestimated. This phenomenon is even more complex when considering that there is a displacement of the center of rotation during motion (Senteler et al.; 2018). Research done by Nerot et al. (2018) could help but is yet limited to the standing position. This should not however change the findings described here because this work was done on comparisons. Finally, it should be noted that there are side effects when using handling equipment: some risks are discussed in the study of Elnitsky et al. (2014) and Menzel et al. (2004) mentioned the problem of loads displacement to wrists and hands. Unfortunately, neither the means nor the time were available to consider this last point for the motorless device assisted handlings. Oakman et

al. (2018) tried to widen the WRMSDs issue by highlighting the gaps of modern workplace risk management practices.

5. Conclusion

To be helped by another caregiver or by the use of a motorless stand-and-turn device when handling a patient from sitting to standing position or from standing to sitting position reduce loads in the low back area. Although sometimes difficult to obtain or to set up because of several adverse conditions, these aids are well received by the caregivers. It is suggested, if the situation allows it, to use them considering the reduced loads they require.

Acknowledgments

This project was conducted as part of a partnership between the Institut PPRIME and the Institut de Cancérologie de l'Ouest (ICO). It was funded by the ICO. Thanks go to all the persons involved in the project, with a particular attention for the caregivers, who were approachable and cooperative right from the start until the very end. Findings, conclusions, views and recommendations expressed in this article do not necessarily reflect those of the ICO. Mention of product names does not constitute endorsement by the Institut PPRIME and the ICO.

Funding: This work was partially funded by the French government research program "Investissements d'Avenir" through the Robotex Equipment of Excellence [grant number ANR-10-EQPX-44].

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