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# Biomechanics and ergonomics in women material handlers

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Sustainable Prevention and Work Environment

# Studies and Research Projects

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**PEER REVIEW**

In compliance with IRSST policy, the research results published in this document have been peer-reviewed.

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# SUMMARY

Many women work as material handlers, yet there has been little interest in this population because most material handlers are men. Some studies have noted significant differences in how men and women perform handling tasks, but such studies are few and far between. Nonetheless, though there are far fewer women handlers in certain sectors (transport and equipment operation, for example), in others, such as food and services, women often constitute close to half the labour force and must occasionally perform material handling tasks. It is thus important to study this population. The purpose of this research project was to gain a better understanding of the differences in how women and men handlers work. It was assumed that the work strategies of experienced women material handlers would differ from those of male handlers.

The data from this study were compared with those gathered for a study comparing expert and novice male workers (Plamondon et al., 2010). The study was designed to highlight the differences between men and women in a work context where the load was the same in absolute terms (15 kg for both sexes) or in relative terms (men: 15 kg; women: 10 kg)—given that a woman's strength is, on average, approximately two-thirds that of a man (10/15 kg = 2/3). Three experimental sessions were held. The first consisted mainly in evaluating the physical capacities of the subjects and giving them a chance to become familiar with the experimental conditions. In the two other sessions, the handlers performed tasks in two different contexts. Load characteristics (weight, fragility and centre-of-gravity offset), lifting and deposit height and handler fatigue were modified to solicit the widest possible variety of work techniques from the handlers.

Biomechanical data were gathered and ergonomic observations were made during the three experimental sessions using motion tracking systems, a large force platform and a system for measuring muscle activation. The results demonstrate that the women handlers in our study (15 subjects) are not as strong as the expert male handlers (15 subjects) or the novice male handlers (15 subjects), with muscle strength (lifting strength and trunk muscle strength) measuring between 49% and 63% of that of the men. Given the size differences of the sexes, it was also expected that peak loading of the back (resultant moment at L5/S1) during the handling tasks would be higher in the men. However, when the resultant moments were normalized with trunk weight, these differences disappeared in most cases. On the other hand, the results show that the women worked differently from the expert male handlers, using techniques more like those employed by the novice male handlers. For the same absolute load of 15 kg, for example, the women, compared to the expert male handlers, took longer to transfer the boxes; inclined the upper body more; bent the lower back more; bent the knees less when lifting boxes from the floor; had lower trunk angular velocity; and kept the boxes closer to their bodies. Most of the women used a very different lifting technique from the expert male handlers, which basically involved extending the knees first and the upper body after. This technique can cause greater lumbar flexion than is observed in expert male handlers and can place the internal passive structures of the lumbar spine at risk. On the other hand, it is a very efficient technique energywise.

When the same relative load was handled (men: 15 kg; women: 10 kg), both back loading and task duration diminished for the women. However, the women held the boxes farther from their bodies with the smaller load, and so lumbar flexion did not decrease under most conditions. This

means that the most direct method of intervention is to reduce the load carried by the women, but this will not reduce lumbar flexion under most conditions. Training is another type of intervention, but it has little impact on lumbar loading. A third possibility is to increase the height from which the boxes are lifted. In fact, most of the risks reported herein apply only under handling conditions where the load is lifted from the floor—a fraction of most handling tasks. The risk to the back drops substantially when the load is lifted from hip height. All these types of intervention not only increase the safety margin for the back but also reduce the physical exposure of handlers, men as well as women.

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# 1. INTRODUCTION

The risks of occupational back injury are still very high today. Based on a systematic literature review of prevalence studies of low back pain, Walker (2000) states that 12% to 33% of respondents reported back pain on the day of the interview, 22% to 65% reported back pain in the last year and 11% to 84% reported back pain at some time in their lives. According to the National Research Council (2001), about 70% of the population will at one point suffer back pain, and the costs to society are in the billions. In Québec, 2,244,000 workers, that is, close to 63% of the Québec work force targeted by the EQCOTESST[1] (Stock et al., 2011), experienced musculoskeletal pain that interfered with their activities and about three-quarters (72.3%) attributed the pain to their work. The back is the part of the body most frequently mentioned by workers as a source of pain (38.4%). Prevalence of musculoskeletal disorders (MSD) attributed to one's main job correlates very strongly with exposure to measured physical work demands. Thus prevalence of MSDs among material handlers (causing pain in a least one body region) is about 55%. According to the EQCOTESST (Stock et al., 2011), MSDs are significantly more prevalent in women than in men. A number of reasons are suggested: for example, risk factors are different for women, even when they have the same job (see Quin, 2011, as well). The differences may also be explained by the fact that with equal physical work demands, women are working closer to their physiological limit than men.

According to statistics issued by the Commission de la santé et de la sécurité du travail (CSST), a total of 21,811 spinal disorder were reported in 2010 and these accounted for 30% of all compensated occupational injuries (Provencher and Barbeau, 2011). Interestingly, the number of spinal disorders dropped by 17.1% over the period from 2007 to 2010. Average compensation in 2010 was $3,960 and a total of $86.3 million were paid in income replacement benefits. As for frequency, spinal injuries were more prevalent among graduate nursing assistants (2,290 cases, 2,009 women) and material handlers (1,827 cases, 310 women) than in any other occupation. The lumbar region was the location of the most injuries (60% of injuries) and excessive effort was the cause most often citied (40% of cases between 2007 and 2010). In Québec, 36,650 people hold a job with the title “material handler” (major group: trades, transport and equipment operators and related occupations): 89% are men (32,695) and 11% are women (3,955) (Statistics Canada, 2008). Note that according to the EQCOTESST (Stock et al., 2011), only a small proportion of non-management salaried employees who were absent from work for musculoskeletal pain perceived as been related to work filed a workers' compensation claim (less than one in five reported their injury to the CSST). In other words, the CSST statistics on MSDs show only the tip of the iceberg.

## 1.1 Material handling and the risk of back injury

All our research assumes an association between material handling and risk of back injury. Numerous literature reviews (Ayoub et al., 1997; Bernard, 1997; Burdorf and Sorock, 1997; da Costa and Vieira, 2010; National Research Council, 2001; Nelson and Hugues, 2009; Vingard and Nachemson, 2000) as well as specific studies of the association (Gardner et al., 1999; Hoogendoorn et al., 2000; Liira et al., 1996; Yeung et al., 2002) indicate a moderate to strong

1. Québec Survey on Working, Employment and OHS Conditions.

association between manual material handling and back injury. Frequent bending and twisting of the upper body and lifting of heavy objects also appear to increase the risk of back injury. Causes have not been clearly identified, but the National Research Council (2001) concluded there is a clear relationship between back disorders and the physical load imposed by manual material handling. This relationship has been called into question, however, by recent systematic literature reviews (Roffey et al., 2010a; Roffey et al., 2010b; Wai et al., 2010a; Wai et al., 2010b; Wai et al., 2010c). Without describing in detail all the reasons why the relationship between back pain and manual material handling has not been definitively demonstrated, reviews of this type have the advantage and the drawback of very strict inclusion criteria, which means that conclusions are based on a very small number of studies. Such reviews are undoubtedly worthwhile, but they often end by recommending that additional, methodologically superior studies are required.

On the other hand, preventive measures have not been very effective to date in reducing the incidence of back pain (Burdorf and Sorock, 1997), probably because the problem is multifactorial and solutions are rarely simple. Preventive measures generally consist in reducing the physical work demands or increasing the capacity of the individual worker—or a combination of the two approaches, so that the demands of the work do not exceed the capabilities of the worker (Frank et al., 1996). Thus, when there is a risk of injury, the ideal solution is to eliminate manual lifting. Ayoub et al. (1997) suggest two approaches: 1) mechanical aids; and 2) work station redesign for optimal working height. If the risks cannot be eliminated, they should be diminished by reducing work demands and awkward movements or by altering the task, the workstation or the material handled. As a last resort, when these interventions are not applicable, the possibility of improving the worker's capacity, specifically his/her handling techniques, could be considered, the idea being to provide training programs to educate workers so they will use safe handling techniques. Two recent systematic literature reviews (Verbeek et al., 2011; Clemes et al., 2010) call this approach into question, but a third suggests it can be worthwhile (Robson et al., 2012). Verbeek et al. (2011) [follow-up to Martimo et al., 2007] performed a Cochrane systematic review of 18 articles (selected from a list of 1874) that met their inclusion criteria (randomized controlled trials and cohort studies). Twelve of the articles looked programs to train hospital employees in safe patient transfer techniques; two looked at programs for airline baggage handlers; two at programs for construction workers; one at training for workers in a distribution centre; and one at programs for postal workers handling mail. The authors conclude that there is no evidence to support the claim that a training program can prevent back pain. The other review, conducted by Clemes et al. (2010) [see Haslam et al., 2007, as well], for the Health and Safety Executive (HSE, England) came to pretty much the same conclusion, except that these authors suggest that training programs might be more effective with a multidimensional approach that included training managers/supervisors as well as workers, interventions tailored to the industrial sector, use of appropriate equipment or job redesign. Haslam et al. (2007) suggest that training should focus on changing attitudes and behaviour and promoting risk awareness among workers and managers. Last, the study by Robson et al. (2012) takes a more positive position on the effects of training, but emphasizes nonetheless that positive impacts on worker health have yet to be demonstrated.

It is not surprising that three recent reviews (Verbeek et al., 2011; Clemes et al., 2010; Robson et al. 2012) come to the conclusion that existing training programs are not effective in preventing back pain. In fact, a number of authors have indicated that the techniques taught in training programs are not used in the workplace (Baril-Gingras et Lortie, 1995; Kuorinka et al., 1994; Lortie and Baril-Gingras, 1998; St-Vincent and Tellier, 1989; Chaffin et al., 1986; Garg and Saxena, 1985) and that this type of intervention (training) is ineffective in preventing injuries (Kroemer, 1992). However, before concluding once and for all that training as a method of intervention is doomed to failure, we must ask why training has failed to prevent injury. For example, we need to ask questions about the **quality of the intervention:** the objectives of the program, the content, specificity and duration of the training, the competence of the trainers, the evaluation techniques and the follow-up to the program. In fact, none of the systematic reviews looked at the quality of the interventions, which varies tremendously from one study to the next, and they were unable to evaluate if physical exposure declined after the intervention. In addition, we must without doubt reconsider the whole approach of teaching the "safe" lifting technique. In fact, there is probably no single "correct" or "safe" technique but rather a whole set of techniques that can be used depending on the work context and the individual characteristics of the worker (Authier and Lortie, 1993; Kuorinka et al., 1994; Parnianpour et al., 1987; Sullivan, 1995). We clearly need to reconsider our existing methods of intervention and find a more sound theoretical model—one that considers the physical exposure of material handlers. The old (existing?) model, in which a single two-hour theoretical (information?) session suffices, is no longer tenable.

## 1.2 Studies of expert handlers

Spinal loading inevitably depends on the work performed. Preventive measures generally consist in reducing the physical work demands, improving the individual's capabilities or a combination of these two so that work demands do not exceed the worker's capabilities (Frank et al., 1996). One way of understanding work demands and identifying effective preventive measures is to study work strategies used by expert and novice handlers. Studies (Authier et al., 1995; Authier et al., 1996) show that experienced handlers recognized as experts by their fellow-workers develop techniques that differ from those of novice handlers and that are not only safe but also efficient. These techniques are of interest, because they could help in developing more suitable workplace training programs. A few rare biomechanical studies compare the work methods of experienced and novice material handlers (Gagnon et al., 1996; Granata et al., 1999). Other studies have validated expert handling techniques (footstep, knee flexion, base of support and lifting, handgrip and load tilting strategies, for example) when simulated by novices, demonstrating their potential for reducing the risks of injury during manual material handling (Delisle et al., 1996b; Delisle et al., 1996a; Delisle et al., 1998; Delisle et al., 1999; Gagnon, 2003). Gagnon (2005) catalogued biomechanically safer strategies used by experts: for example, expert footwork (positioning/displacement) strategies result in less energy expenditure by reducing load transfer duration and trajectory. Similarly the experts' box manoeuvre strategies (handgrips and tilts) reduce mechanical work markedly and back loadings slightly.

Continuing the work of Gagnon and Lortie, Plamondon et al. (2010) conducted a study designed to find out more about the differences in handling techniques used by expert and novice handlers in a variety of different handling situations. Fifteen expert and fifteen novice male material handlers were selected to perform three series of tests during which they had to transfer boxes. The results of the study demonstrated that the expert handlers generally bent the lumbar spine less when lifting and depositing the boxes. In addition, they did not bend their upper bodies forward as much and they bent their knees more. In fact, the expert handlers seemed better positioned to support back loadings during the box transfer and they allowed themselves more room to manoeuvre. Also, the expert handlers were closer to the box, horizontally as well as vertically, when lifting as well as depositing the load.

## 1.3 Studies of women handlers

Some studies have noted significant differences between men and women in the techniques used during handling tasks, but such studies are few and far between. That material handling is largely performed by men has certainly contributed to the limited presence of women in material handling studies. However, many women have demonstrated that women can perform the same tasks as men, and access to traditionally male jobs is becoming easier for women, thanks to better employment equity policies in industry and greater understanding of real work demands—both of which promote their integration. Often there is a higher back injury rate among men than women. On the other hand, women generally occupy positions that are less physically demanding, and when injury rates are adjusted to account for this bias, the incidence of injury among women is higher than among men (Gardner et al., 1999). There seems to be a direct correlation between increased job lifting requirements and higher rates of back injury in all workers, but especially in women (Kraus et al., 1997). The risk of back injury is also higher among less experienced workers (Gardner et al., 1999).

Sex is one of the most important variables to consider in material handling work. Height and weight are two key variables that distinguish men from women. For example, in the U.S. between 1988 and 1994, average height and weight[2] were 1.756 m and 82.1 kg for men, compared to 1.618 m and 69.2 kg for women (Chaffin et al., 2006). In other words, women have shorter segments, and this can affect how they handle material. Muscle strength, on average, is not as great in women. As indicated by Chaffin et al. (2006), it is frequently stated that on average a woman's muscle strength is two-thirds that of a man. However, this is the average value of different muscle groups, and the value spread can easily range from 33% to 86% of the muscle strength of a man (Ayoub and Mital, 1989). Kumar and Garand (1992), for example, tested peak strength in men and women when stoop lifting (back bent, knees straight) and squat lifting (back straight, knees bent), and peak strength in the women ranged from 41% to 94% of that in the men and depended on posture and technique. This means that for the same absolute load, a woman will always have a relatively greater load to support than a man, which generally means that she has to exert greater physical effort. It is important to note that though the physical capacity of many women approaches or exceeds that of some men, and that such women are capable of performing the same physical tasks as a man, we must not conclude that the risks are the same for a woman as for a man (Mital et al., 1997). Thus, it has been observed that when lifting intensity increases (continuous load of more than 22.7 kg), the number of back injuries increases, but male sex and older age are protective factors (Kraus et al., 1997). It is thus not surprising that all the tables based on psychophysical studies have standards for women that are different from those for men.

There are also differences in movement coordination between men and women, as demonstrated in hip-knee coordination in the study by Lindbeck and Kjellberg (2001). When women perform

2. Data from the National Health and Nutrition Examination Survey (NHANES), cited in Chaffin et al. (2006) p.46-47.

material handling tasks, the position of the trunk is straighter than in men (less lumbar flexion) and they tend to use their hips more (Marras et al., 2003; Davis et al., 2003). Women also seem to generate a higher level of muscle contraction when they perform tasks similar to men, in particular recruiting secondary agonist muscles (Marras et al., 2002; Marras et al., 2003). In complex lifting tasks, relative spine loading seems to be greater in women than in men, increasing the risk of back injury when exposed to the same handling conditions. On the other hand, men have heavier upper bodies and thus must support greater compression forces (and, in certain situations, shear forces) than women performing the same tasks (Marras et al., 2002). The men's intervertebral disks, however, have greater compressive strength.

In a recent study of lifting (Kotowski et al., 2007), subjects were evaluated under three different load conditions: 1) the weight of the load was known; 2) the weight of the load was not known; and 3) the weight of the load was constant but unknown. Not knowing the weight of the load affected lifting kinematics, but, interestingly, women did not react the same way as men. Women tended to slide the box toward their chest first, which was not the case with the men, who lifted the box immediately. Women adopted a technique that was safer than that used by the men, though the latter in some cases perceived the risk of injury to be greater. According to the authors, this is because the absolute loads (4.5, 9.1 and 13.6 kg) were relatively light for the men, which was not the case for the women. Had the boxes been heavier, the men might have adopted a lifting technique similar to that of the women (Kotowski et al., 2007). Is it possible, then, that lifting technique is a function of muscle strength? In a study of lifting strategies in the elderly, Puniello et al. (2001) demonstrated lower extremity muscle strength (power in the hips and knees) played a significant role in the choice of lifting strategy. Subjects with stronger legs generally used a leg-dominant (squat) strategy. We also know that lifting technique changes depending on load magnitude (Schipplein et al., 1990), fatigue (Trafimow et al., 1993) and experience (Authier et al., 1996). And last, Sadler et al. (2013) recently concluded that when loads are standardized to an individual's strength characteristics (10% of maximum isometric back strength: 7 kg for men and 5 kg for women), there is no significant effect of gender on box lifting technique.

Many women work as material handlers. Unfortunately, there has been little interest in this population, mainly because most material handlers are men. However, though there are far fewer women handlers in certain sectors (transport and equipment operation, for example), in other sectors, such as food and services, as well as in box stores, women often constitute close to half of the labour force and must occasionally perform material handling tasks. It is thus important to study this population. A number of research questions require answers. For example, how do the handling strategies women use differ from those used by men, given the differences in muscle strength and anthropometric characteristics? Have women developed know-how that differentiates them from their male fellow-workers and reduces their risk of injury? In general, women do not have the same physical capacity as men, which means they are at greater risk of injury when performing physically demanding tasks. However, the relationship between physical strength and back disorders is difficult to demonstrate, probably because physical strength is just one factor among many that must be considered in any manual task. Though physical strength is undeniably important, there are certainly lifting strategies that can enable some people to adapt to manual labour even though they do not have exceptional physical strength.

## 1.4 Objectives

The objective of this research project was to understand how the techniques of men and women handlers differ. Our hypothesis was that experienced women handlers use strategies that differ from those used by experienced male handlers. The data gathered for this study were compared with those collected for the research project on expert and novice handlers (099-367), for which the research subjects were male. This made it possible to investigate differences between handlers on the basis of two key variables: sex (this project) and experience (project 099-367).

There are different types of lifting strategies. Safe strategies are those whose primary goal is to protect the back, whereas efficient strategies aim to achieve production objectives and minimize effort exerted. Safe strategies were identified mainly on the basis of back loading variables that reduce effort and muscle fatigue. Efficient strategies were identified based on task duration and path length.

Load characteristics (weight, content fragility and centre-of-gravity offset), lifting and deposit height as well as handler fatigue were variables that were altered to solicit a wider variety of strategies from the subjects. In addition, to get a better understanding of the effects of gender, the women handled an absolute loads identical to that handled by the men (15-kg box) as well as an identical relative load (10-kg box). This design made it possible to highlight the differences between the sexes, to better characterize the women's handling strategies and to show the differences between the sexes in lifting technique as well as physical characteristics.

To make it easier to understand the results and facilitate discussion, the report describes each of the three experimental sessions of the project:

1. In the first session, physical capacity measurements were taken and the subjects were introduced to the different experimental procedures (Chapter 3).
2. In the second session, the subjects transferred boxes from a conveyer to a hand trolley and the impact of modifying load characteristics (weight, weight distribution and stability) on handling technique was studied (Chapter 4).
3. In the third session, the subjects transferred boxes continuously from one pallet to another, and the impact of changing the pace on the handlers' technique was studied as well as the cumulative impact of physical fatigue (Chapter 5).

As some of the methodology was used in all three sessions, the next section of this report (Chapter 2) outlines this common methodology. Each session is then described in a separate chapter (chapters 3, 4 and 5), which includes a methodology section specific to that session and a results section, and Chapter 6 is devoted to ergonomic observations. To avoid repetition, the discussion is presented in a separate chapter, Chapter 7. The report ends with the conclusions of the project.

# 2. METHODOLOGY: COMMON ELEMENTS

This section describes the elements of the methodology common to all three experimental sessions. Each session (methodology, results and discussion) is then looked at separately.

## 2.1 Subjects

Three groups of subjects were recruited. The first two were recruited for an earlier study (Plamondon et al., 2010) and the third, a group of women material handlers, was recruited for this study. The first group consisted of 15 expert handlers who met the four following criteria: a minimum of five years of experience; a low incidence of injury (particularly to the back); no injuries in the year preceding the study; and recommendation by the company's recruitment manager. Three companies participated in the recruitment, with one recruiting seven experts, another recruiting three and the third recruiting five. The second group comprised 15 novice handlers who met the following criteria: minimum handling experience, ranging from three to six months; and no injuries in the year preceding the study. The novice handlers were mainly recruited with the help of a poster, or by word of mouth. All the women participants were recruited from different warehouse stores of a large beverage distribution company and were initially expected to meet the same criteria as the expert male handlers. The recruitment of women proved difficult, however, and the criterion of a low lifetime incidence of injury had to be dropped. Consequently, the women were not classified as experts but as workers with experience. None of the participants presented musculoskeletal problems that could affect their normal way of working and all problems reported were minor. Table 2-1 shows the main anthropometric characteristics of the handlers. The two groups of male subjects (expert and novice handlers) were similar in weight and height. The women, as expected, were shorter and weighed less (the difference very close to significant). Note that the three groups were significantly different in terms of experience, and that the women and the experts were, on average, in their forties, which was not the case with the novice handlers.

**Table 2-1: Anthropometric characteristics of subjects (n=45)**

| Variable | Experts (E) n = 15 | | Novices (N) n = 15 | | Women (W) n = 15 | | *p* value[3] |
|---|---|---|---|---|---|---|---|
| | M[1] | SD[2] | M | SD | M | SD | |
| Age (years) | 38.1 | 9.8 | 25 | 5.9 | 41.1 | 8.6 | **<0.01** N< E and W |
| Weight (kg) | 75.9 | 12.2 | 74.2 | 11.4 | 66.8 | 10.3 | 0.08 |
| Height (m) | 1.71 | 0.07 | 1.75 | 0.05 | 1.62 | 0.07 | **<0.01** W < E and N |
| Years of experience | 15.4 | 9.3 | 0.5 | 0.4 | 7.3 | 2.3 | **<0.01** N < W < E |
| Trunk moment at L5/S1 (Nm)[4] | 96 | 17 | 95 | 15 | 70 | 10 | **<0.01** W < E and N |

1. M = mean
2. SD = Standard deviation
3. Probability, one-way ANOVA for measuring group effect (experts, novices and women)
4. Trunk moment at L5/S1 is the gravitational effect of the weight of the trunk in horizontal position.

## 2.2 Measurement systems

Several measurement systems were used in the three experimental sessions: two dynamometers, a surface electromyography system and two photogrammetric measuring systems (video and optoelectronic cameras). Each of these systems is described in greater detail in Appendix B.

## 2.3 Biomechanical segment model

The participants were instrumented to make it possible to use a biomechanical segment model designed to estimate loading at L5/S1 on the basis of kinematic and kinetic data. The model was developed over a number of years of research and has been exhaustively validated (Gagnon and Gagnon, 1992; Desjardins et al., 1998; Plamondon et al., 1996). It requires attachment of 12 rigid clusters of markers to each of the following segments: head (1); back at C7 (1), T12 (1) and S1); both upper arms (2); both forearms (2); both thighs (2) and both feet (2). Each cluster of markers is composed of four LED diodes (seven for the feet) fixed to an aluminum plate or a styrofoam block which is glued to the subject's skin. Signals collected from these clusters of markers by four Optotrak columns were used to locate 48 anatomical landmarks in relation to their respective marker cluster so segment joint centre positions could be determined. The data were then filtered using a quintic spline, and linear and angular velocities and accelerations were derived. Segment parameters were estimated using Jensen's elliptical method (1978). External forces on the feet were collected using the force platform. All these input data were then integrated into the segment model to calculate net moments at L5/S1 (flexion-extension, lateral bending and torsion moments) using the equations of Hof (1992). The margin of error on these calculated moments was estimated at less than 10 Nm (Plamondon et al., 1996). To ensure the validity of the moments at L5/S1, those calculated using a bottom-up approach (approach used in this study) were compared to moments determined by a top-down approach for the 30 subjects in the standing anatomical position. RMS errors between the two models were generally less than 7 Nm, similar to those reported by Plamondon et al. (1996).

## 2.4 Borg scale

Perceived back and leg muscle fatigue and perceived overall fatigue were measured using a Borg scale. The Borg CR10 scale was used to measure perceived muscle fatigue and overall fatigue following physical effort, and no instrumentation was required. Subjects were asked to rate their fatigue (following maximum effort or a series of box transfers) on a scale of 0 to 10, where zero meant no fatigue at all and 10 meant maximum fatigue. In experimental session 1, the subjects had an opportunity to become familiar with the scale, which was used to evaluate perceived fatigue in the other two sessions.

# 3. SESSION I: PHYSICAL CAPACITY

The first session had two objectives: 1) to measure the handlers' anthropometric characteristics and physical capacity (strength and endurance); 2) to provide an opportunity for the handlers to become familiar with the experimental procedures. First, the experimental protocol was explained to each subject, and then each was asked to voluntarily sign a consent form approved by the ethics committee for health research involving human subjects of the Faculty of Medicine and Health Sciences at the University of Sherbrooke. Once the consent form was signed, each subject completed two questionnaires: a modified Nordic Musculoskeletal Questionnaire (Forcier et al., 2001), which provides information on musculoskeletal health; the Physical Activity Readiness Questionnaire (PAR-Q), used to ensure that no health problems prevent physical activity. None of the research subjects gave positive answers to any of the questions on the PAR-Q, which might have meant they could not participate in the study. Tests of physical capacity followed, and the session concluded with an activity to help participants become familiar with the study procedures and let them see that they could perform the handling tasks as usual, despite the wires and the markers stuck to their skin.

## 3.1 Physical capacity tests

The physical tests performed were as follows:

1. Aerobic capacity test: submaximal step test modified from the Siconolfi Step Test (Siconolfi et al., 1985) by Gall and Parkhouse (2004). This test is designed to measure cardiorespiratory capacity under stress. The participant steps up and down a single step (height = 28 cm) for three minutes at a pace of 18 steps per minute for the first stage and 24 steps per minute for the second stage. Tables are used to estimate maximum aerobic capacity based on average heart rate.

2. General test of maximum isometric lifting strength. The participant is standing, upper body and knees bent, positioned to grasp a handle at knee height (half stoop, half squat, Figure 3-1a). This test consists in exerting maximum extension force against a load cell fixed to the floor (Chaffin et al., 1978; Chaffin et al., 2006). Three tests were performed.

3. Back extensors (Erector spinae)
    a. Isometric strength test: The subject is placed upright in a dynamometer (Figure 3-1b), the pelvis stabilized as described in Larivière et al. (2001). The subject exerts maximum effort for six seconds in extension (three tests), in flexion (two tests), in lateral flexion left and right (two tests) and in right and left axial rotation (two tests).
    b. Isometric endurance test: The subject is placed as for the strength test. The test consists in exerting to exhaustion an isometric extension force of 150 Nm for men and 100 Nm for women (two-thirds of the average maximum value for men). The two-thirds ratio is used in a number of studies (Larivière et al., 2008; Reeves et al., 2006).

**a) General lifting test** **b) Testing of back muscles**

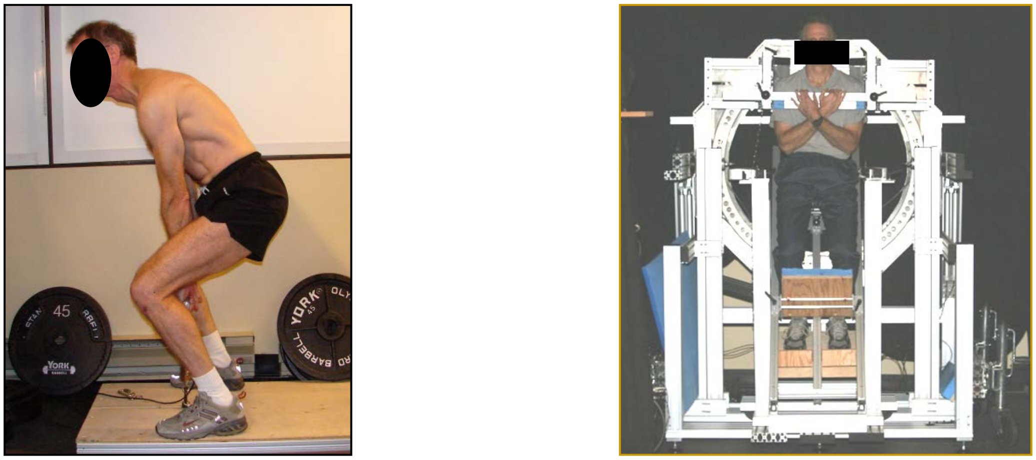

**Figure 3-1: Physical capacity tests**

## 3.2 Statistical analyses

Descriptive statistical analyses of all variables were performed first. Then a one-way ANOVA was applied to determine if there were significant differences between the expert men, the novice men and the women.

## 3.3 Results

Table 3-1 shows the results of the physical testing of the three groups of handlers. The only significant difference between the two groups of male handlers was in maximal oxygen consumption. In the novices, $VO_2$ max was higher than in the experts ($p$=0.01) but comparable to $VO_2$ max of the women. In all maximum strength tests of the muscles of the upper body, the women's results were 49% to 63% those of the men. There was no significant difference between the three groups only in the one test where relative physical capacity of the women compared to the men was considered (two-thirds the capacity of the men), that is, the test of endurance of the muscles of the upper body in extension.

**Table 3-1: Physical capacity averages and standard deviations (SD) in experts (E), novices (N) and women (W)**

| | Expert (SD) | Novice (SD) | Women (SD) | %♀[1] | *p* | |
|---|---|---|---|---|---|---|
| $VO_2$ max (mL/kg/min) | 39.4 (6.8) | 46.1 (6.8) | 44.1 (5.3) | 112 | **0.02** | **E < N** |
| Lifting strength (kg) | 138 (28) | 139 (25) | 68 (16) | 49 | **<0.01** | W < E, N |
| Extension moment (Nm) | 347 (68) | 322 (59) | 186 (37) | 54 | **<0.01** | W < E, N |
| Flexion moment (Nm) | 162 (32) | 171 (31) | 103 (19) | 63 | **<0.01** | W < E, N |
| R. lat. bending moment (Nm) | 204 (24) | 197 (28) | 125 (32) | 61 | **<0.01** | W < E, N |
| L. lat. bending moment (Nm) | 211 (32) | 207 (24) | 133 (35) | 63 | **<0.01** | W < E, N |
| R. rotation moment (Nm) | 124 (22) | 135 (36) | 61 (14) | 49 | **<0.01** | W < E, N |
| L. rotation moment (Nm) | 119 (20) | 123 (23) | 63 (15) | 53 | **<0.01** | W < E, N |
| Muscle endurance (s) | 132 (61) | 125 (69) | 127 (75) | 96 | 0.96 | |

1. %♀: Women's results as a percentage of expert results.

# 4. SESSION II: CONVEYOR-TO-TROLLEY BOX TRANSFERS

## 4.1 Methodology

The participants were instrumented as described in Section 2.3 so the biomechanical body segment model could be used.

### *4.1.1 Experimental procedures*

Once instrumented, the participant stood on the force platform while an assistant identified with a pointer composed of 24 LEDs each of 48 anatomical landmarks required to calculate segment joint centres. Next, the participant assumed the anatomical position and photographs were taken, to be used later to calculate segment parameters with the Jensen method (1978). After that, the subject transferred four boxes from a conveyor (at pallet height, 12 cm from the floor) to a two-wheeled hand trolley 1.5 m away (Figure 4-1). For this stage of the task (conveyor to hand trolley), the conveyor was sloping slightly toward the handler so the boxes moved by gravity on rollers towards him/her. The handler had to pull a first box on the conveyor toward him/her and carry it to the hand trolley. All four boxes had to be stacked on the hand trolley. Once all the boxes were on the trolley, the participant had to move them from the trolley back to the conveyor, which was sloping slightly away from the handler in this stage of the task (trolley to conveyor). For the men, the boxes were as follows: one 15-kg box (weight centred), one 23-kg box (weight centred), one unstable 15-kg box and one off-centre 15-kg box (centre of gravity 27 cm from one side of the box and 8 cm from the other). All the boxes were the same size (26 cm deep, 35 cm wide and 32 cm high). The unstable box contained 12 bottles of sand and water and had no cover, so as to be deformable. For the women, the boxes were identical except for the 23-kg box, which was replaced by a weight-centred 10-kg box. The idea was to give the women handlers a relative load similar to that of the men (15 kg for the men compared to 10 kg for the women). By absolute load, we mean the actual work load; the relative load, on the other hand, is a percentage of maximum capacity. If it is assumed that in general the physical capacity of a woman is about two-thirds that of a man, then for a woman a load of 10 kg requires an effort equivalent to that exerted by a man lifting 15 kg.

A Latin square was used to balance the order of the boxes such that the 15 subjects in each group (experts, novices and women) performed the handling in a different order but all three groups were identical. The boxes were ordered such that each box type was presented to each participant twice at the same height (four heights). In addition, two conveyor positions were studied: one facing the hand trolley (180°) at a distance of 1.5 m and the other at 90° to the hand trolley, the same distance away (1.50 m). The conveyor position was also selected so that half the subjects began in the 180° position and the other half in the 90° position.

The handlers were free to use whatever handling technique they liked and to work at their own pace. They were instructed to remain on the force platform at all times and to stack the boxes on the trolley. To prevent a build-up of fatigue, each round trip (eight box transfers) was followed by a two-minute break, with a seated break for least five minutes after 64 box transfers. After each trip in the going direction (four boxes), there was also a mandatory 30-second pause to reset the system. Additional break time was also planned in case a participant asked for it or seemed tired (based on the Borg scale results), but this did not happen.

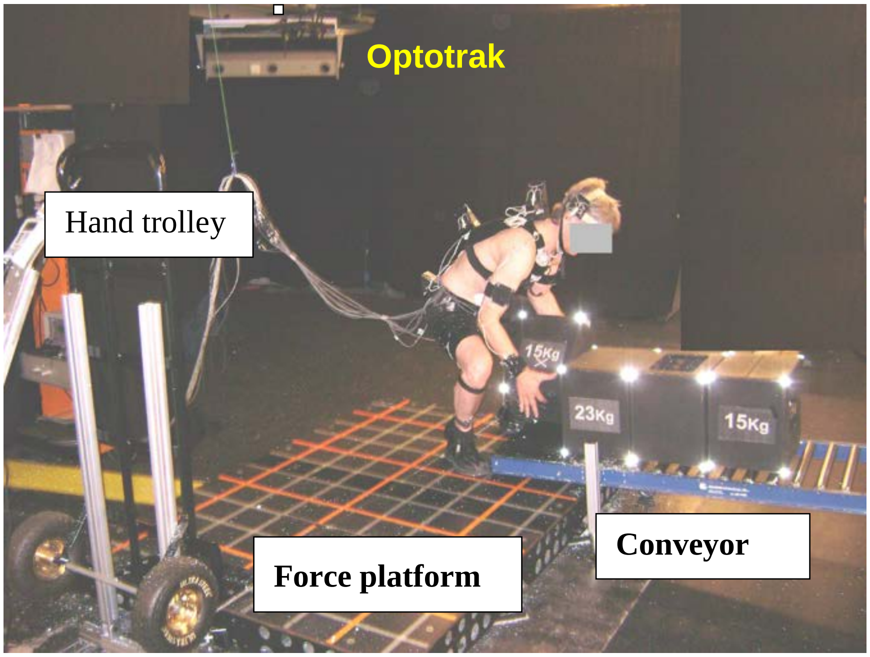


**Figure 4-1: Experimental setup with the conveyor at a 90° angle to the trolley**

### 4.1.2 Signal processing

The processing of data related to the biomechanical segment model is discussed in Section 2.3.

### 4.1.3 Statistical analyses

Each participant performed 128 box transfers [4 boxes x 4 positions/heights x 2 orientations (180° and 90°) x 2 directions (going to the trolley and return to the conveyor) x 2 repetitions]. Separate statistical analyses were performed of the going and return trips. For the 45 subjects, there were a total of 1920 samples (boxes) for the going direction (to the trolley) and the same number for the return trip (back to the conveyor). For analysis purposes, each handling task was broken down into two phases, a lifting phase and a deposit phase (Figure 4-2). The lifting phase includes a pre-lift (gripping), during which the box is brought close to the subject without being lifted, as well as lifting of the box (take-off) and part of the flight. The deposit phase begins after the lifting phase and continues until the box is placed on the trolley or the conveyor. Note that the flight phase (the time during which the weight of the box is completely supported by the subject) is divided into two equal sections, the first of which is included in the lifting phase and the second in the deposit phase.

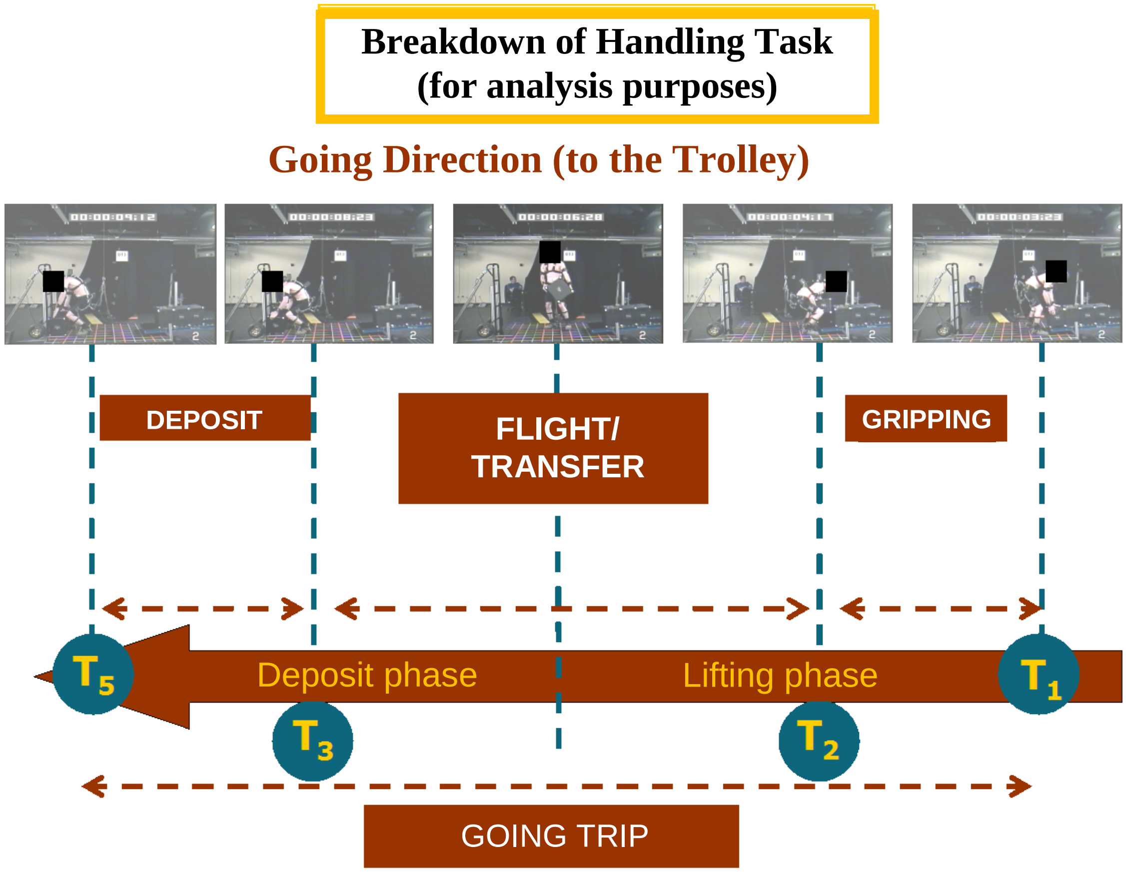


**Figure 4-2: Breakdown of handling task (for analysis purposes). T1 = Start; T2 = Start of flight; T3 = End of flight; T5 = End**

The terms used for the kinetic and kinematic variables are easy to understand, but to prevent any ambiguity, complete definitions are given in Appendix C. The main dependent variables selected as safety and performance criteria were as follows: task duration, box path, resultant and asymmetric moments at L5/S1, awkward postures (extreme bending and asymmetrical upper body positions), knee bending and box distance from L5/S1. Also, as the anthropometric characteristics of the participants have a significant impact on a number of variables, particularly when comparing the sexes, **two data normalization procedures were performed**: 1) the moments at L5/S1 were divided by the moment exerted on L5/S1 by the weight of the horizontal upper body (average values shown in Table 2-1), with the normalized moments thus obtained expressed in units of upper-body weight; 2) certain distances—such as the distance between the box and L5/SI—were divided by the subject's height. **For more information about these normalization procedures, see Appendix D.**

Mixed factorial analyses of variance (ANOVA) were performed to find out if there were significant differences between the male experts, the male novices and the women in each experimental condition (Table 4-1). In a first ANOVA, the three groups were compared handling the three different types of 15-kg boxes. In a second ANOVA, the three groups were compared with the men handling the weight-centred 15-kg boxes and the women handling the weight-centred 10-kg boxes. As the men did not handle the 10-kg boxes, the statistical model was not complete, and the box effect could not be determined. A third ANOVA was performed to compare the women's handling of the centred 15-kg boxes and the 10-kg boxes. This analysis was limited by the lack of group effect and the fact that only the main box effect could be considered. When the main group effect (G) was significant, an a posteriori Tukey-Kramer multiple-comparison test was performed to identify the significantly different group or groups.

**Table 4-1: Session II independent variables**

| Statistical analysis | Independent variables | Comments |
|---|---|---|
| Mixed factorial ANOVA #1 (3x3x4x2) | Between-subject<br>• Three groups (G): Experts (E), Novices (N) and Women (W)<br>Within-subject (repeated measures)<br>• Three boxes (B): 15-kg, off-centred 15-kg, unstable 15-kg<br>• Four positions (P): 1, 2, 3 and 4<br>• Two orientations (O): 180° and 90° | The 23-kg box handled by the men was not included in the statistical analysis. |
| Mixed factorial ANOVA #2 (3x4x2) | Between-subject<br>• Three groups (G): Experts (E), Novices (N) and Women (W)<br>Within-subject (repeated measures)<br>• Four positions (P): 1, 2, 3 and 4<br>• Two orientations (O): 180° and 90° | The box effect (15 kg for the men and 10 kg for the women) was not considered because the model was incomplete. |
| Repeated measures ANOVA #3 (2x4x2) | Women (W) only<br>Within-subject (repeated measures)<br>• Two boxes (B): 10-kg and 15-kg<br>• Four positions (P): 1, 2, 3 and 4<br>• Two orientations (O): 180° and 90° | The main box effect only was considered. |

Given the large quantity of data collected, we decided **to present the data for the going direction only (to the trolley).** For this reason as well, the differences observed between the boxes (B), between the box positions on the conveyor (C) or the trolley (T) and between the two orientations of the conveyor (O) are not discussed in this report but will be examined in future publications. It is the interactions between these factors and the subject groups that interest us here. The differences between the three groups of subjects—experts (E), novices (N) and women (W) are discussed, but we have not focused on the differences between the experts and the novices because this is discussed in an earlier report (Plamondon et al. 2010) which can be consulted on the website of the IRSST (www.irsst.qc.ca/manutention). Accordingly, only the results for the main effect of group (G) and its interaction with the other factors are discussed:

- GB interaction: interaction of group (G) and box type (B)
- GP interaction: interaction of group (G) and box position (P)
- GO interaction: interaction of group (G) and orientation (O).

Often, significant interactions are observed that have little real effect, or an effect that is difficult to evaluate. To simplify this report, such interactions are not discussed. In addition, three-way interactions are also excluded from the analysis because of the complexity of their interpretation. As all the tests were done twice, the statistical analyses were performed by combining the data from the two tests. NCSS software (NCSS 2007, Version 07.1.14, Windows XP: http//www.ness.com) was used to process the statistical data. To perform the parametric analyses, the data were transformed using a transformation that yields normal distributions according to the Wilk-Shapiro test (Van Albada and Robinson, 2007). In addition, to correct for violations of sphericity in the repeated measures ANOVAs, the probability threshold was adjusted using the Geisser Greenhouse Epsilon correction factor.

Last, a colour code was used in some tables to make it easier to see key changes when the load transferred by the women was reduced from 15 kg to 10 kg. Green indicates that the reduction had a positive effect, red indicates a negative effect and grey indicates a negligible effect.

## 4.2 Results

This section describes the results of the box transfers from the conveyor to the trolley: first the results concerning task duration and path are given, then results specific to the lifting and deposit phases are presented. Given the large amount of data in the tables, only the most relevant are examined in the text, to simplify the results interpretation.

### *4.2.1 Task duration and box path*

There were significant differences between the groups with respect to the duration of the different stages of the task, with the women significantly slower in transferring the 15-kg boxes (Table 4-2 and Figure 4-3) in all stages except the pre-flight, when their times were similar to those of the experts and novices. Also, there was a significant interaction in the flight phase (Group × Position, Figure 4-4), but the effect is difficult to determine and seems minor: this interaction is not discussed further in these results.

When the weight of the boxes transferred by the women was reduced from 15 kg to 10 kg, there was a significant decrease in the duration of all stages of the transfer (indicated in green in Table 4-3) which almost completely cancelled out the differences between the subject groups. In other words, when men and women handled similar relative loads, the differences between them in terms of task duration that were noted with an absolute load (Table 4-2) diminished.

**Table 4-2: Task duration with 15-kg boxes**

| Variable | Experts | | Novices | | Women | | *p* value | Interaction (*p*) | | | Post-hoc* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | G | GB | GP | GO | G |
| Total task duration (s) | 4.6 | 1.5 | 4.3 | 1.4 | 5.6 | 1.5 | **<0.01** | 0.73 | 0.74 | 0.78 | W> N, E |
| Pre-flight time (s) | 1.4 | 0.7 | 1.4 | 0.7 | 1.6 | 0.7 | 0.11 | 0.59 | 0.84 | 0.30 | |
| Flight time (s) | 2.2 | 0.7 | 1.9 | 0.7 | 2.4 | 0.5 | **0.05** | 0.18 | **0.03** | 0.33 | W > N |
| Post-flight time (s) | 1.0 | 0.6 | 1.0 | 0.6 | 1.6 | 0.9 | **<0.01** | 0.18 | 0.72 | 0.12 | W > E, N |

M = Mean; SD = Standard deviation; G = Group; GB = Group x box interaction; GP = Group x box position interaction; GO = Group x orientation to conveyor interaction.
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

**Table 4-3: Task duration with weight-centred 10-kg boxes transferred by women and weight-centred 15-kg boxes transferred by men and women**

| Variable | Women | | | | | | | Comparison of men 15 kg vs. women 10 kg | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | 10 kg | | 15 kg | | Δ | *p* value | | *p* value | Interaction (*p*) | | Post-hoc* |
| | M | SD | M | SD | | | | G | GP | GO | |
| Total task duration (s) | 4.7 | 1.1 | 5.5 | 1.5 | 0.7 | **<0.01** | | 0.31 | 0.59 | 0.63 | |
| Pre-flight time (s) | 1.3 | 0.5 | 1.7 | 0.8 | 0.3 | **<0.01** | | 0.99 | 0.51 | 0.30 | |
| Flight time (s) | 2.2 | 0.4 | 2.4 | 0.5 | 0.2 | **<0.01** | | 0.37 | **0.04** | 0.39 | |
| Post-flight time (s) | 1.2 | 0.7 | 1.4 | 0.7 | 0.2 | **<0.01** | | **0.04** | 0.19 | 0.53 | E < W |

Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

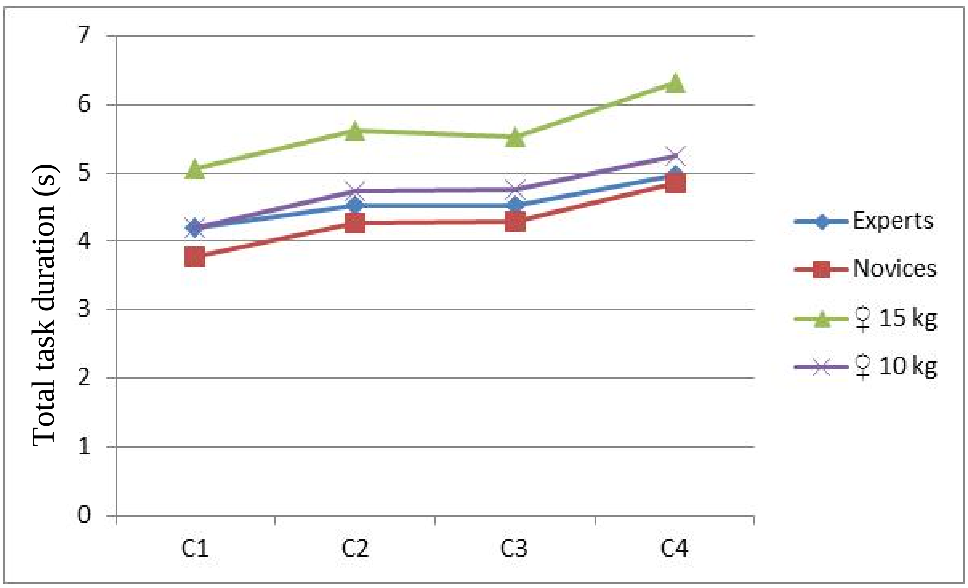


**Figure 4-3: Total task duration for 15-kg and 10-kg boxes as a function of box position on the conveyor (C) on lifting**

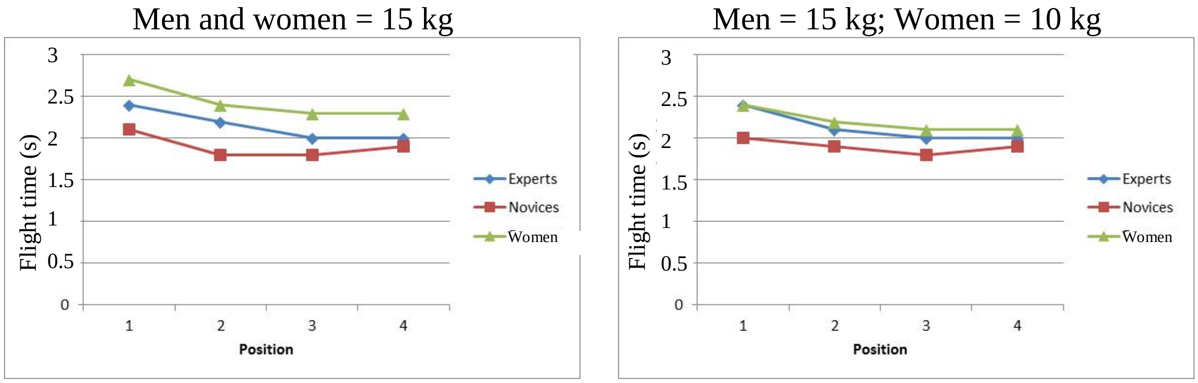


**Figure 4-4: Significant Group x Position interaction affecting flight time with 15-kg and 10-kg loads**

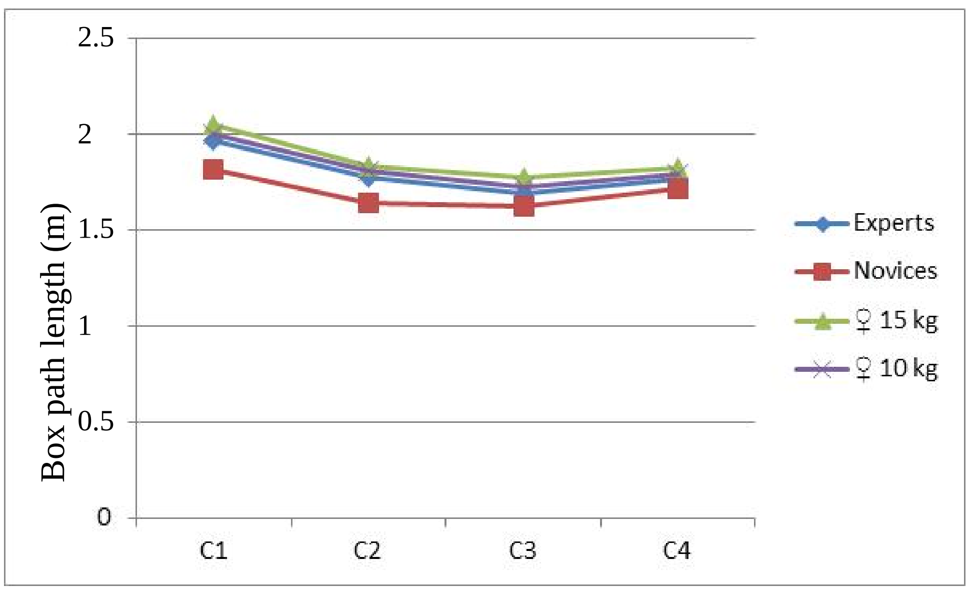


**Figure 4-5: Path length in 15-kg and 10-kg conditions depending on box position on the conveyor (C) on lifting**

The differences between the groups in path length were small, though the path tended to be longer with the women than the men (not significant except the positive vertical path) (Table 4-4). Handling a similar relative load (women 10 kg vs. men 15 kg) also reduced the differences between the groups for path length variables (Table 4-5). Reducing the load handled by the women (10 kg vs. 15 kg) reduced the total path length and slightly reduced the vertical path length (not significantly).

**Table 4-4: Path length of 15-kg boxes**

| Variable | Experts | | Novices | | Women | | *p* | Interaction (*p*) | | | Post-hoc* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | G | GB | GP | GO | G |
| Total path length (m) | 1.80 | 0.30 | 1.70 | 0.28 | 1.87 | 0.21 | 0.09 | **0.01** | 0.16 | 0.14 | |
| Positive vert. length (m) | 0.60 | 0.17 | 0.57 | 0.19 | 0.63 | 0.15 | **0.05** | 0.37 | 0.89 | 0.51 | W > N |
| Negative vert. length (m) | 0.24 | 0.23 | 0.21 | 0.23 | 0.27 | 0.24 | 0.11 | **<0.01** | 0.46 | 0.50 | |
| Horizontal length (m) | 1.39 | 0.13 | 1.37 | 0.15 | 1.43 | 0.10 | 0.30 | 0.96 | 0.08 | 0.05 | |

M = mean; SD = standard deviation
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

**Table 4-5: Path length with 10-kg weight-centred boxes carried by women and 15-kg weight-centred boxes carried by men and women**

| | Women | | | | | | | Comparison of men 15 kg vs. women 10 kg | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 10 kg | | 15 kg | | *Post-hoc** | *p* | | *p* | Interaction (*p*) | | Post-hoc |
| | M | SD | M | SD | | | | G | GP | GO | |
| Total path length (m) | 1.83 | 0.20 | 1.86 | 0.22 | 0.03 | **0.02** | | 0.22 | 0.18 | 0.26 | |
| Positive vert. length (m) | 0.62 | 0.15 | 0.63 | 0.15 | 0.01 | 0.10 | | 0.31 | 0.82 | 0.90 | |
| Negative vert. length (m) | 0.26 | 0.24 | 0.26 | 0.24 | 0.01 | 0.14 | | 0.26 | 0.24 | 0.29 | |
| Horizontal length (m) | 1.41 | 0.09 | 1.42 | 0.11 | 0.01 | 0.09 | | 0.53 | 0.62 | 0.10 | |

M = mean; SD = standard deviation
Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

### 4.2.2 Results: lifting and deposit of 15-kg boxes

Peak resultant moment: The peak resultant moment at L5/S1 in the lifting phase of the transfer of the 15-kg box towards the trolley was significantly smaller in the women (Figure 4-6 and Table 4-6: Experts = 218 Nm, Novices = 219 Nm, Women = 174 Nm). This result was predictable, as women are generally shorter and weigh less than men. When the peak resultant moments are normalized for the moment exerted by the weight of the upper body, the difference between the men and the women is considerably smaller. In fact, not only is the difference no longer significant, but the peak resultant moment at L5/S1 is actually slightly higher in the women (Figure 4-8, Table 4-7: Experts = 2.3 (2.3 × upper-body weight), Novices = 2.3, Women = 2.5). The results for the deposit phase were similar to those of the lifting phase.

As Table 4-6 shows, there were a number of significant differences ($p \leq 0.05$) in other variables at the time of the peak resultant moment, mainly between the experts and the women, with the women adopting many of the postures observed in the novice handlers. Thus in the lifting phase, the lumbar flexion angle (Experts = 55°; Novices = 66°; Women = 66°; Figure 4-8), the lumbar flexibility index (Experts = 83%; Novices = 97%; Women > 99%; Table 4-6) and the trunk flexion angle from the vertical (Experts = 69°; Novices = 83°; Women = 87; Table 4-6) were significantly smaller in the experts than in the women or the novices. In other words, the experts were less bent forward than the women at the time of peak resultant moment. In addition, the experts tended to bend their knees more (Experts ≈ 70°; Novices ≈ 52°; Women ≈ 58°; Figure 4-9) than the other two groups, but this result was not significant. Differences were noteworthy with four other variables. First, peak resultant moment occurred slightly sooner in the experts, just after the start of the flight (Experts = 2%; Novices = 5%; Women = 6%; Table 4-6). Lumbar lateral bending angle in the novices and the women was significantly different (Experts = 0°; Novices = 3°; Women = -2°; Table 4-6), but the difference nonetheless seemed to be quite minor and was difficult to explain (as was the significant interaction). Third, lumbar flexion angular velocity was significantly higher in the experts than in the women (Experts = 26°/s; Novices = 21°/s; Women: 16°/s; Table 4- 6). Interestingly, the distance of the box from L5/S1 was shorter in women and significantly different from this same distance in the novices (Experts = 0.41 m; Novices = 0.43 m; Women = 0.38; Table 4-6). However, when this distance was normalized for participant height, the difference disappeared (Table 4-7). Of note, there was almost no upper body posture asymmetry (lateral bending angle and torsion angle < 4°) in any of the subjects.

Results from the deposit phase were very similar to those of the lifting phase. In the women, lumbar flexion, lumbar flexibility index and trunk flexion angle from the vertical were equivalent to these variables in the novices but significantly greater than these variables in the experts (Table 4-6). The women were closer to the box than the novices, but, unlike in the lifting phase, there was no significant difference in angular velocity of the upper body between the groups. The few significant interactions are of little practical interest, other than the fact that the women must straighten their upper bodies more (trunk inclination) than the novices (and are thus comparable to the experts) in depositing the last box on top of the stack (position 4), probably because they are shorter.

<u>Other moments at L5/S1</u>: In lifting, the peak asymmetrical moment was significantly smaller in the women than the men (Figure 4-10; Table 4-7: Experts = 58 Nm; Novices = 58 Nm; Women = 39 Nm). As with peak resultant moment, size is largely responsible for this difference between the men and the women. When this asymmetrical moment is normalized, the difference disappears. (Figure 4-11; Table 4-7: Experts = 0.6; Novices = 0.6; Women = 0.6). Results in the deposit phase were relatively comparable to those of the lifting phase. Cumulative resultant moment (during box flight) was surprisingly similar (around 220 Nms) in the three groups despite the fact that peak resultant moment was smaller in the women than the men. These results are partly explained by the longer flight time of the women than the men. Normalization of the cumulative resultant moment (Table 4-7) shows that the women are subjected to a significantly greater relative lumbar load than the men (Experts: 2.4; Novices: 2.3; Women: 3.2).

<u>Effects of a similar relative load</u>: The most significant effect when absolute load of the women during lifting was reduced from 15 kg to 10 kg (to provide a relative load equivalent to that lifted by the men) was a significant decrease in all peak and cumulative moments (indicated in green in Table 4-8 and Table 4-9). Although these moments were already lower in the women than the men with the 15-kg load, the normalized values were not lower and indicated equivalent lumbar loading for the peak resultant moment and asymmetrical moment and, in fact, greater lumbar loading for the cumulative resultant moment (Table 4-7). With the load reduced by 5 kg, relative lumbar loading for asymmetrical moment was significantly smaller in the women than in the men and for peak resultant moment and cumulative resultant moment it was similar (Table 4-9). It was expected that with similar relative loads, the peak resultant moment would be significantly smaller for the women than for the men, as the values were already similar at 15 kg. The lesser effect of the similar relative load could be due to an increase in the distance of the box from L5/S1 and in the angular velocity of the trunk (in red in Table 4-8). The peak resultant moment

occurred earlier with the 10-kg box, eliminating the difference between the men and the women (Table 4-8).

In the deposit phase, when the weight of the box was reduced from 15 kg to 10 kg, the resultant and asymmetric moments dropped significantly in the women, but only the drop in asymmetric moment remained significant when the results were normalized (Table 4-9). On the other hand, box distance increased significantly with the 10-kg box when the results were normalized (Table 4-9). Last, knee flexion diminished by 3 to 4 degrees, but the effect was only significant for the left knee and insufficient for distinction from knee bending in the men (Table 4-8).

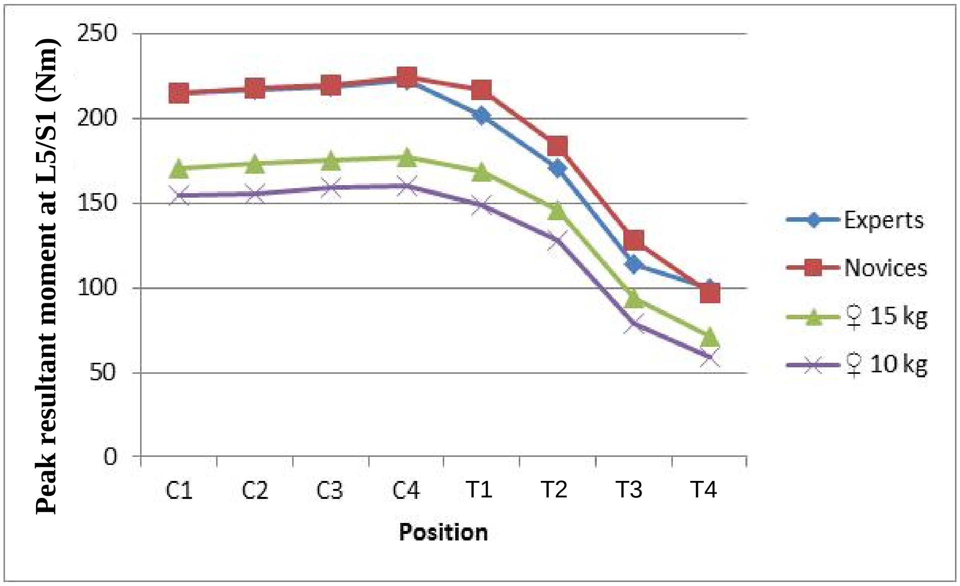


**Figure 4-6: Peak resultant moment at L5/S1 (Nm) when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

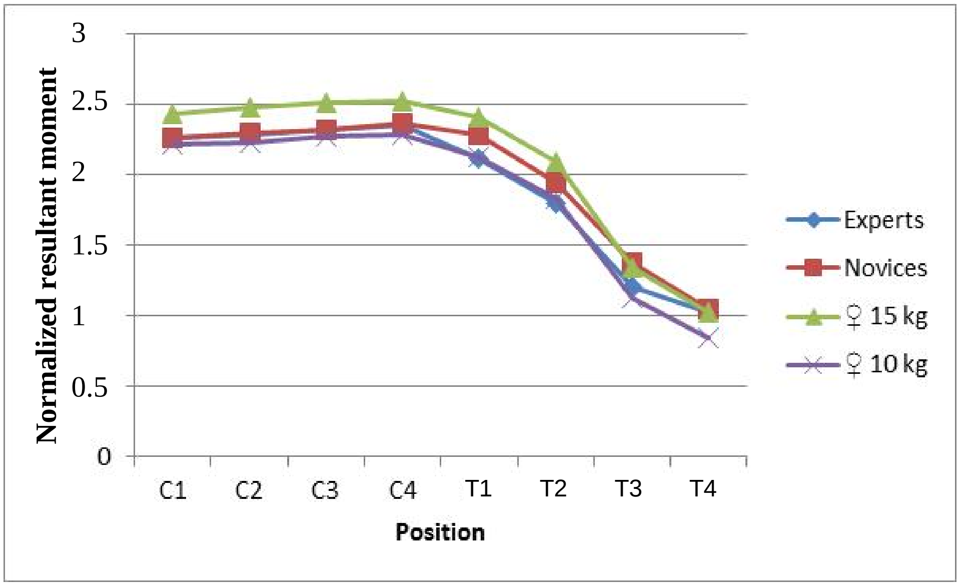


**Figure 4-7: Normalized resultant moment at L5/S1 (per unit of trunk weight) when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

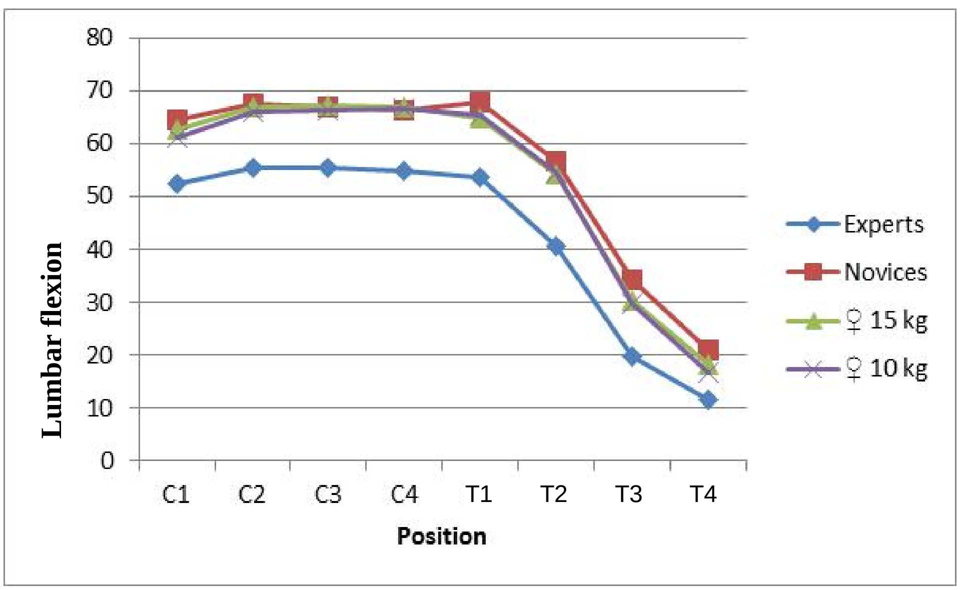


**Figure 4-8: Lumbar flexion (degrees) at time of peak resultant moment when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

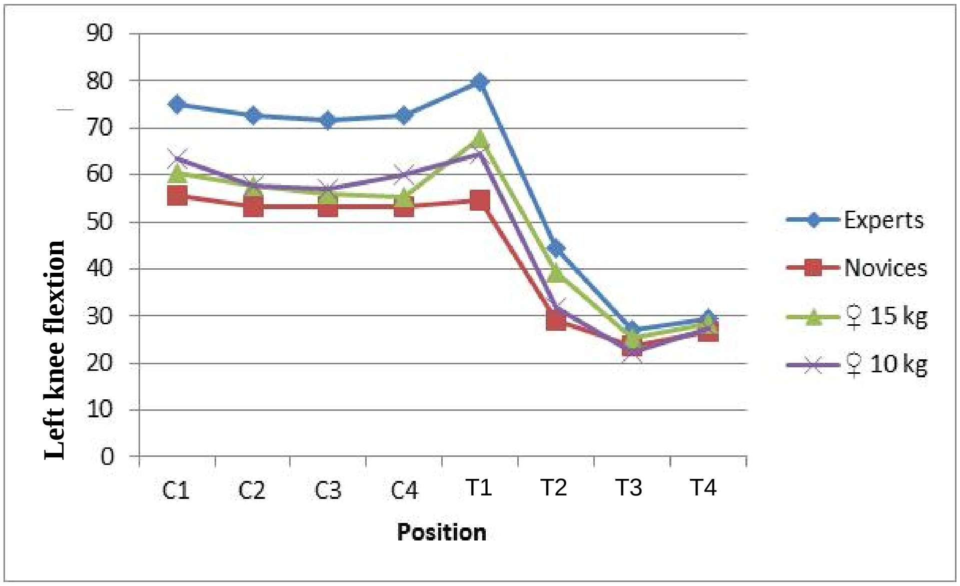


**Figure 4-9: Left knee flexion (degrees) at time of peak resultant moment when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

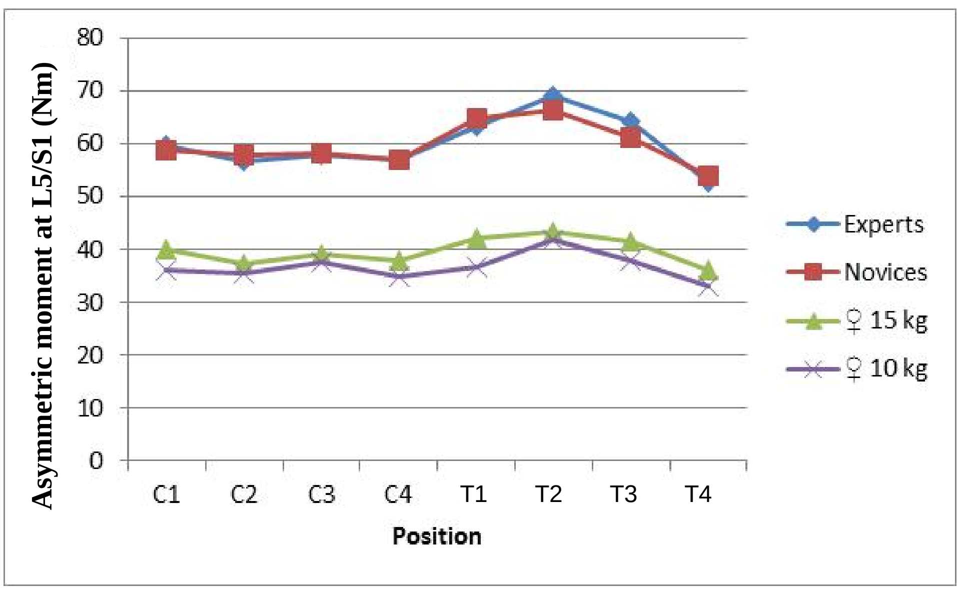


**Figure 4-10: Asymmetric moment at L5/S1 (Nm) when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

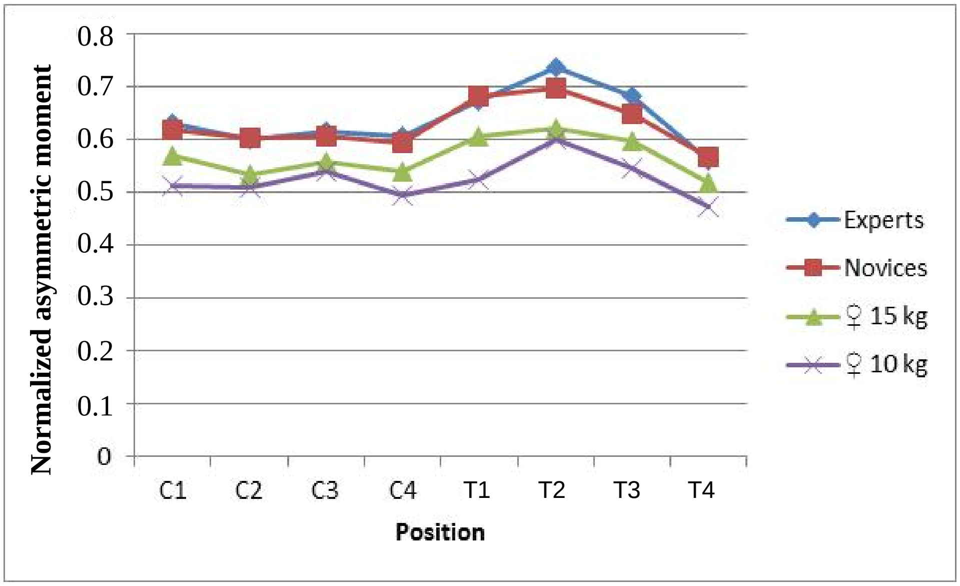


**Figure 4-11: Normalized asymmetric moment at L5/S1 (Nm) when lifting/depositing 15-kg and 10-kg loads as a function of box position on the conveyor (C) when lifting and box position on the trolley (T) when depositing the load**

**Table 4-6: Peak resultant moments at L5/S1 and associated lifting-phase (L) and deposit-phase (D) variables with 15-kg boxes**

| Variable | Phase | Experts (E) | | Novices (N) | | Women (W) | | *p* value | Interaction (*p*) | | | *Post-hoc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | M | SD | G | GB | GP | GO | G |
| Peak resultant moment (Nm) | L | 218 | 34 | 219 | 38 | 174 | 25 | **<0.01** | 0.95 | 0.85 | 0.99 | W < E, N |
| | D | 146 | 55 | 157 | 57 | 120 | 44 | **<0.01** | 0.96 | 0.20 | 0.77 | W < E, N |
| Occurrence of peak resultant moment (%) | L | 2 | 8 | 5 | 9 | 6 | 7 | **<0.01** | 0.56 | 0.39 | 0.84 | W > E |
| | D | 88 | 21 | 86 | 20 | 87 | 26 | 0.71 | 0.30 | 0.64 | 0.90 | |
| Lumbar flexion angle (°) | L | 55 | 11 | 66 | 14 | 66 | 14 | **0.02** | 0.12 | 0.07 | 0.85 | W, N > E |
| | D | 31 | 20 | 45 | 25 | 42 | 22 | **<0.01** | **0.03** | 0.48 | 0.56 | W, N > E |
| Lumbar flexibility index (%) | L | 83 | 18 | 97 | 20 | >99 | 25 | **0.01** | 0.17 | **0.04** | 0.86 | W > E |
| | D | 48 | 31 | 65 | 37 | 70 | 38 | **<0.01** | 0.06 | 0.18 | 0.43 | W, N > E |
| Lumbar lateral bending angle (°) | L | 0 | 5 | 3 | 6 | -2 | 5 | **<0.01** | **<0.01** | 0.89 | 0.42 | W < N |
| | D | -2 | 6 | -1 | 6 | -3 | 6 | 0.46 | **0.01** | 0.49 | 0.08 | |
| Lumbar torsion angle (°) | L | 4 | 5 | -1 | 8 | 1 | 6 | 0.07 | 0.50 | 0.84 | 0.41 | |
| | D | 1 | 6 | 0 | 7 | 1 | 5 | 0.81 | 0.21 | 0.55 | 0.52 | |
| Trunk inclination (°) | L | 69 | 18 | 83 | 18 | 87 | 19 | **<0.01** | 0.54 | 0.12 | 0.88 | W > E |
| | D | 39 | 25 | 53 | 30 | 50 | 30 | **<0.01** | 0.46 | **0.01** | 0.87 | W, N > E |
| Box distance from L5/S1 (m) | L | 0.41 | 0.05 | 0.43 | 0.06 | 0.38 | 0.05 | **0.01** | 0.98 | 0.52 | 0.51 | W < N |
| | D | 0.38 | 0.10 | 0.42 | 0.12 | 0.36 | 0.09 | **0.03** | 0.53 | **0.04** | 0.73 | W < N |
| Right knee flexion (°) | L | 70 | 31 | 49 | 35 | 59 | 35 | 0.08 | 0.90 | 0.46 | 0.62 | |
| | D | 45 | 30 | 41 | 24 | 39 | 27 | 0.40 | 0.15 | 0.39 | 0.83 | |
| Left knee flexion (°) | L | 73 | 29 | 54 | 28 | 57 | 33 | 0.12 | 0.85 | 0.70 | 0.52 | |
| | D | 45 | 30 | 34 | 23 | 40 | 26 | **0.01** | 0.56 | 0.24 | 0.73 | E > N |
| Flexion angular velocity (°/s) | L | 26 | 12 | 21 | 12 | 16 | 10 | **<0.01** | 0.51 | 0.54 | 0.64 | W < E |
| | D | 6 | 23 | 2 | 23 | 6 | 18 | 0.43 | 0.04 | 0.17 | 0.43 | |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

**Table 4-7: Other moments and normalized net moments at L5/S1 as well as box distances from L5/S1 in lifting phase (L) and deposit phase (D) with 15-kg boxes**

| Variable | Phase | Experts (E) | | Novices N) | | Women (W) | | *p* value | Interaction (*p*) | | | *Post-hoc** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | M | SD | G | GB | GP | GO | G |
| Peak asymmetric moment (Nm) | L | 58 | 19 | 58 | 20 | 39 | 11 | **<0.01** | 0.89 | 0.98 | 0.21 | W < E, N |
| | D | 62 | 19 | 62 | 21 | 41 | 10 | **<0.01** | 0.49 | 0.68 | 0.89 | W < E, N |
| Cumulative resultant moment (Nms) | | 226 | 73 | 220 | 66 | 224 | 65 | 0.96 | 0.43 | 0.23 | 0.38 | |
| **Normalized values** | | | | | | | | | | | | |
| Peak resultant moment[1] | L | 2.3 | 0.4 | 2.3 | 0.3 | 2.5 | 0.3 | 0.10 | 0.97 | 0.89 | 0.42 | |
| | D | 1.5 | 0.6 | 1.7 | 0.6 | 1.7 | 0.6 | 0.13 | 0.99 | **0.03** | 0.65 | |
| Peak asymmetric moment[1] | L | 0.6 | 0.2 | 0.6 | 0.2 | 0.6 | 0.1 | 0.37 | 0.81 | 0.98 | 0.18 | |
| | D | 0.7 | 0.2 | 0.7 | 0.2 | 0.6 | 0.2 | 0.26 | 0.49 | 0.63 | 0.89 | |
| Cumulative resultant moment[1] | | 2.4 | 0.8 | 2.3 | 0.7 | 3.2 | 1.0 | **<0.01** | 0.43 | 0.19 | 0.37 | W > E.,N |
| Box distance from L5/S1[2] at time of peak moment | L | 0.24 | 0.03 | 0.24 | 0.03 | 0.24 | 0.03 | 0.60 | 0.98 | 0.56 | 0.50 | |
| | D | 0.22 | 0.06 | 0.24 | 0.07 | 0.22 | 0.05 | 0.29 | 0.57 | 0.12 | 0.79 | |

1. Normalization = moment/trunk gravitational moment; unit of trunk weight
2. Normalization = distance/height; unit of height

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

**Table 4-8: Net peak resultant moments at L5/S1 and related parameters in lifting phase (L) and deposit phase (D) with weight-centred 10-kg boxes and weight-centred 15-kg boxes**

| Variable | Phase | Women | | | | | | Comparison of men 15 kg vs. women 10 kg | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 kg | | 15 kg | | *Post-hoc** | | *p* | Interaction (*p*) | | *Post-hoc** |
| | | M | SD | M | SD | Δ | *p* | G | GP | GO | *G* |
| Peak resultant moment (Nm) | L | 157 | 23 | 175 | 26 | 18 | **<0.01** | **<0.01** | 0.88 | 0.73 | W< E, N |
| | D | 104 | 40 | 119 | 44 | 15 | **<0.01** | **<0.01** | **0.05** | 0.43 | W < E, N |
| Occurrence of peak moment (%) | L | 3 | 4 | 5 | 8 | 1 | **<0.01** | 0.10 | 0.76 | 0.37 | |
| | D | 89 | 22 | 86 | 19 | -2 | 0.45 | 0.97 | **0.01** | 0.98 | |
| Lumbar flexion angle (°) | L | 65 | 14 | 66 | 14 | 1 | 0.14 | **0.02** | **0.02** | 0.74 | E < N |
| | D | 42 | 22 | 42 | 22 | 0 | 0.74 | **<0.01** | 0.31 | 0.41 | W, N > E |
| Lumbar flexibility index (%) | L | +99 | 26 | +99 | 25 | 1 | 0.10 | **0.01** | **0.01** | 0.78 | W > E |
| | D | 70 | 38 | 70 | 38 | 1 | 0.65 | **<0.01** | 0.07 | 0.40 | W, N > E |
| Lumbar lateral bending angle (°) | L | -2 | 4 | -2 | 5 | 0 | 0.86 | **0.01** | 0.22 | 0.40 | W < N |
| | D | -1 | 7 | -2 | 7 | -1 | 0.22 | 0.93 | 0.70 | **0.01** | |
| Lumbar torsion angle (°) | L | 2 | 5 | 1 | 5 | 0 | 0.16 | **0.05** | 0.73 | 0.52 | N < E |
| | D | 0 | 6 | 0 | 5 | 0 | 0.31 | 0.66 | 0.64 | 0.46 | |
| Trunk inclination (°) | L | 86 | 20 | 87 | 19 | 1 | 0.14 | **0.03** | 0.20 | 0.95 | W > E |
| | D | 51 | 31 | 50 | 30 | -1 | 0.82 | **0.01** | **0.00** | 0.65 | W, N > E |
| Box distance from L5/S1 (m) | L | 0.39 | 0.05 | 0.38 | 0.05 | -0.01 | **<0.01** | 0.06 | 0.65 | 0.59 | |
| | D | 0.37 | 0.09 | 0.36 | 0.09 | -0.01 | **0.02** | **0.05** | **0.04** | 0.65 | |
| Right knee flexion (°) | L | 62 | 33 | 60 | 34 | -1 | 0.21 | 0.09 | 0.59 | 0.42 | |
| | D | 36 | 24 | 39 | 28 | 3 | 0.13 | 0.12 | 0.07 | 0.44 | |
| Left knee flexion (°) | L | 60 | 32 | 58 | 32 | -1 | 0.19 | 0.10 | 0.75 | 0.20 | |
| | D | 36 | 24 | 40 | 26 | 4 | **0.01** | **<0.01** | 0.36 | 0.73 | E > N |
| Flexion angular velocity (°/s) | L | 18 | 10 | 16 | 10 | -2 | **0.03** | **0.01** | 0.29 | 0.59 | W < E |
| | D | 6 | 18 | 6 | 18 | 0 | 0.44 | 0.61 | 0.28 | 0.89 | |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.
Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

**Table 4-9: Other moments and normalized net moments at L5/S1 as well as box distances in lifting phase (L) and deposit phase (D) with weight-centred 10-kg boxes and weight-centred 15-kg boxes**

| Variable | Phase | Women | | | | | | Comparison of men 15 kg vs. women 10 kg | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 kg | | 15 kg | | Difference | | *p* | Interaction (*p*) | | *Post-hoc** |
| | | M | SD | M | SD | Δ | *p* | G | GP | GO | G |
| Peak asymmetric moment (Nm) | L | 36 | 11 | 39 | 11 | 3 | **<0.01** | **<0.01** | 0.61 | 0.11 | W < N, E |
| | D | 37 | 11 | 40 | 11 | 3 | **0.01** | **<0.01** | 0.57 | 0.51 | W < E, N |
| Cumulative resultant moment (Nms) | | 170 | 50 | 218 | 65 | 48 | **<0.01** | **<0.01** | 0.13 | 0.23 | W < N, E |
| **Normalized values** | | | | | | | | | | | |
| Peak resultant moment[1] | L | 2.2 | 0.3 | 2.5 | 0.3 | 0.3 | **<0.01** | 0.61 | 0.92 | 0.75 | |
| | D | 1.5 | 0.6 | 1.7 | 0.6 | 0.2 | **<0.01** | 0.23 | 0.23 | 0.34 | |
| Peak asymmetric moment[1] | L | 0.52 | 0.13 | 0.55 | 0.14 | 0.04 | **<0.01** | **0.04** | 0.64 | 0.08 | |
| | D | 0.54 | 0.15 | 0.57 | 0.15 | 0.04 | **0.01** | **0.02** | 0.52 | 0.45 | W < E, N |
| Cumulative resultant moment[1] | | 2.4 | 0.8 | 3.1 | 1.0 | 0.7 | **<0.01** | 0.55 | 0.28 | 0.24 | |
| Box distance from L5/S1[2] at time of peak moment | L | 0.24 | 0.03 | 0.24 | 0.03 | -.01 | **0.01** | 0.64 | 0.61 | 0.67 | |
| | D | 0.23 | 0.05 | 0.22 | 0.05 | -.01 | **0.02** | 0.26 | 0.11 | 0.66 | |

1. Normalization = moment/trunk gravitational moment; unit of trunk weight
2. Normalization = distance/height; unit of height

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

# 5. SESSION III (PALLET-TO-PALLET BOX TRANSFERS): BIOMECHANICAL RESULTS

## 5.1 Methodology

### *5.1.1 Experimental procedures*

**Women**: The first task in this session was to **transfer 24 15-kg boxes from one pallet to another and back three times** (total of 144 box transfers). The boxes (26 cm deep x 35 cm wide x 32 cm high) were arranged on the pallet (height = 16 cm from the floor) as shown in Figure 5-1. This task was followed by a 30-minute break and then **two round-trip transfers of 24 10-kg boxes** (96 box transfers). Back muscle fatigue was tested with a submaximal task that consisted in holding the trunk in horizontal position for five seconds. The experimental session proceeded as follows:

1. Muscle fatigue test 1 (baseline contraction)
2. Two round-trip transfers of 24 15-kg boxes at a self-determined pace (**self-paced**)
3. Muscle fatigue test 2
4. One round-trip transfer of 24 15-kg boxes at a controlled pace (**imposed pace**) of nine boxes/minute
5. Muscle fatigue test 3
6. 30 minutes of rest
7. Muscle fatigue test 4
8. One self-paced round-trip transfer of 24 10-kg boxes
9. Muscle fatigue test 5
10. One round-trip transfer of 24 10-kg boxes at an imposed pace of nine lifts/minute
11. Muscle fatigue test 6

**Men**: The data used were collected as part of an earlier study (Plamondon et al., 2010). The task consisted in **transferring 24 15-kg boxes from one pallet to another and back five times** (total of 240 box transfers) over a period of 30 minutes. The first two round trips (96 box transfers) were self-paced. The other three round trips (144 box transfers) were performed at an imposed pace of nine lifts per minute—a pace that is, according to Garg et al. (1979), an acceptable lifting frequency. Unlike the women, the men did not transfer any 10-kg boxes, and they had to perform three consecutive round trips at the imposed pace.

With the imposed-pace transfers, the participants were regularly informed if they were too fast or too slow. The pallets were 1.65 m apart (edge to edge). The first muscle fatigue test (pre-test) was performed before starting the box transfers. The second was performed after the self-paced trips, (post-test 1), but before the imposed-pace transfers. The last test (post-test 2) was performed after completion of the imposed-pace round trips. Note that for the women the muscle fatigue tests were repeated for the 10-kg loads (six muscle fatigue tests in all). Perception of fatigue was also measured (using the Borg scale) before each muscle fatigue test.


**Figure 5-1: Experimental set-up, pallet-to-pallet transfer**

One of the key aspects of our methodology was to allow the participants to work as they liked, without giving them specific instructions. In other words, the workers were free to use whatever strategies they wanted. The only restrictions were that they could not get off the force platform, put their feet on the pallets (so they would not leave the force platform) or make a 360$^o$ turn (because of the wires of the Optotrak and electromyography systems to which they had to be attached). They were also instructed to stack six boxes wide by four boxes high, but in no particular order.

### 5.1.2 Statistical analyses

Processing of the biomechanical segment model data is discussed in Section 2.3. The dependent variables selected for identification of "safe" as opposed to "efficient" handling practices were the same as those discussed in Section 4.1.3, which the reader can consult for more information. The data processing and statistical analyses were basically the same for Session III as for Session II. Briefly, a first mixed factorial ANOVA was applied to compare the three groups in their handling of identical 15-kg boxes (same absolute load). In a second ANOVA, the three groups were compared when the men were lifting 15-kg boxes and the women 10-kg boxes (similar relative load). A last ANOVA was used to look at the differences in the women when lifting a 15-kg box compared to a 10-kg box (effect of box weight in women). Four main effects were studied in this experiment: the effects of group, box height, horizontal box distance and pace. Table 5-1 summarizes the main statistical analyses performed and the independent variables of the model. Last, as the women differed from the men in terms of weight, height and muscle strength (general test of maximum isometric lifting strength, see Section 3.1), in addition to having fewer years of experience, a mixed-design ANCOVA was performed to test the impact of these co-variables on the main dependent variables considering the group independent variable only.

As there are even more data for Session III than for Session II, we had to restrict our analysis to only the **last self-paced trip in the going direction** (there are two directions in a round trip, a going and a return) and the **last imposed-pace trip in the going direction** for the 15-kg condition in the men and the women and the 10-kg condition in the women. The same colour coding was used in certain tables as in the previous section to facilitate interpretation of the results.

**Table 5-1: Session III independent variables**

| Statistical analysis | Independent variables | Comments |
|---|---|---|
| Mixed factorial ANOVA # 1 (3x4x2x2) | Between-subject<br>• Three groups (G): Experts (E), Novices (N) and Women (W)<br>Within-subject<br>• Vertical height (V): 16, 48, 80 and 112 cm<br>• Horizontal distance (H): close vs. far<br>• Two paces (P): self-paced vs. imposed pace | The complete model was analyzed for the men and the women with a 15-kg load<br><br>**Vertical height was measured from the floor of the force platform. The 16-cm value is for the height of the pallet** |
| Mixed factorial ANOVA #2 (3x4x2x2) | Between-subject<br>• Three groups (G): Experts (E), Novices (N) and Women (W)<br>• Vertical height (V): 16, 48, 80 and 112 cm<br>• Horizontal distance (H): close vs. far<br>• Two paces (P): self-paced vs. imposed pace | Data for the men (15 kg) were compared with data for the women (10 kg). The model was not complete as the men did not handle the 10-kg load. The box effect was thus integrated in the group effect |
| Repeated measures ANOVA #3 (2x4x2) | Women (W) only<br>Within-subject<br>• Box weight: 10 kg vs. 15 kg<br>• Vertical height (V): 16, 48, 80 and 112 cm<br>• Two paces (P): self-paced vs. imposed pace | The horizontal distance was omitted in the model; only the main box effect was considered |

## 5.2 Results

This section is divided into several parts. Pace results are presented first, followed by biomechanical results. As the fatigue tests (Borg scale, heart rate and electromyography) were not part of the main objectives, those results are presented in Appendix F. Once again, given the very large quantity of data in the tables, only the most important results are discussed in the text to simplify interpretation of the results.

### 5.2.1 Pace

Table 5-2 shows the actual paces of the last self-paced and imposed-pace trips in the going direction. The self-determined pace turned out to be very close to the imposed paced, though always significantly slower. The novices did not differ from the experts or the women with the 15-kg box, but the women's pace was significantly slower than the experts. When the women's load was reduced from 15 to 10 kg, their self-determined pace increased significantly, from 7.25 to 9.10 lifts/minute.

**Table 5-2: Averages and standard deviations for actual lifts/min in the self-paced and imposed-pace conditions (n = 15/group)**

| | Self-paced | | Imposed-pace | | *p* group | *p* pace | *p* group-pace |
|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | | | |
| Experts 15 kg | 8.89 | 2.14 | 9.36 | 0.41 | | | |
| Novices 15 kg | 8.45 | 1.99 | 9.51 | 0.86 | [1]**0.03**$^{W<E}$ | **<0.01** | 0.14 |
| Women 15 kg | 7.25 | 1.30 | 9.07 | 0.32 | | | |
| Women 10 kg | 9.10 | 1.00 | 9.22 | 0.30 | [2]0.86 | **0.04** | 0.36 |

1. Repeated measures ANOVA: Group (Experts, Novices, Women) × Pace (self-determined, imposed). Individual pace is the average of the 24 transfers of the last return trip.
2. Repeated measures ANOVA: Group (Experts 15 kg, Novices 15 kg, Women 10 kg) × Pace (self-determined, imposed).

### 5.2.2 Physical fatigue

One way of affecting a participant's lifting strategy and increasing the differences between the three groups was to increase the lifting pace and thus tire out the participants. Physical fatigue was measured by heart rate (HR), Borg CR10 scale score and EMG results. Appendix F shows the results: In sum, with the 15-kg load, heart rate was not significantly different in the three groups but it did increase significantly at the imposed pace of nine lifts/minute. The three groups perceived the imposed pace as more demanding, and the women's perception of fatigue as well as their physiological load was equivalent to that of the men. The level of muscle fatigue measured by EMG varied as a function of time and was highest at the end of the imposed-pace sequence, especially back muscle fatigue, but the difference from the self-paced sequence was not significant. Also, the women did not seem to have more muscle fatigue than the men. The handlers thus accumulated back muscle fatigue throughout the handling task. Dropping the load to 10 kg in the women led to a significant decrease in perceived effort as well as heart rate compared to the 15-kg load. The women thus did not seem to experience marked fatigue with the 10-kg load.

### 5.2.3 Task duration and box path

With the 15-kg load, total task duration as well as two of the three stages of the task (pre-flight and post-flight) were significantly longer for the women—close to a second more than for the male experts and novices (Table 5-4; Figure 5-2). The difference was not significant in the flight stage, but it was significant in the pre-flight and post-flight stages. When the women performed the same task with the 10-kg load, all the differences between the men and the women disappeared, with the women's total task duration dropping by close to a second (Table 5-5; Figure 5-2).

Total length of the box path varied depending on the horizontal and vertical position of the box. Table 5-3 indicates box lifting and deposit positions. Boxes lifted from position 1 (on the floor) were generally deposited to position 4 (21.2%) and vice versa (19%), whereas boxes lifted from position 2 were generally deposited in position 3 (19.2%) and vice-versa (17.7%). Table 5-6 and Figure 5-3 show that the flight path of the box was pretty much the same in all groups, with differences minimal and not significant though the path seemed slightly longer with the novices. Even when the load was reduced to 10 kg for the women, path length remained pretty much the same and improvements (in green in Table 5-7), that is, a shorter path, were noted only in positive vertical path. Last (Figure 5-3), the greater the box lifting or lowering height, the longer the path: in other words, the longest path was when the box was lifted from the bottom of one pallet and deposited in the top position (position 4) on the other pallet. Most of the interactions shown in tables 5-6 and 5-7 had little practical impact; the path of one group was slightly different from those of the other two groups, generating a significant interaction.

**Table 5-3: Vertical box deposit position as a function of vertical box lifting position**

| Deposit / Lifting | 1 | 2 | 3 | 4 |
|---|---|---|---|---|
| 1 | 0.3% | 1.0% | 2.5% | **21.2%** |
| 2 | 1.2% | 2.2% | **19.2%** | 2.4% |
| 3 | 4.5% | **17.7%** | 2.1% | 0.7% |
| 4 | **19.0%** | 4.1% | 1.2% | 0.7% |

### 5.2.4 Results with the 15-kg load

As expected, the peak resultant moment at L5/S1 was significantly smaller in the women than in the men (Figure 5-4; Table 5-8) whether lifting (♀ = 134 Nm; ♂ Experts = 168 Nm; ♂ Novices = 184 Nm) or depositing (♀ = 112 Nm; ♂ Experts = 133 Nm; ♂ Novices = 149 Nm) the load. The significant G×V interaction (Table 5-8; lifting and deposit) was mainly due to the smaller resultant moment in the experts in the upper positions (2, 3 and 4) compared to the other two groups (Figure 5-4). The other interesting interaction, G×H (deposit), stemmed from the women, who differed from the men in having a smaller difference in resultant moment between the front and back row positions of the boxes (smaller resultant moment slope). In other words, the women adjust better than the men to the back row position of the box. When this resultant moment is normalized for trunk weight, there is no statistical difference between the three groups when lifting, though the normalized moment for the women and the novices is higher than that of the experts. On deposit, this moment is statistically higher in the women than the experts. Interactions were not appreciably different from those of the non-normalized resultant moment.

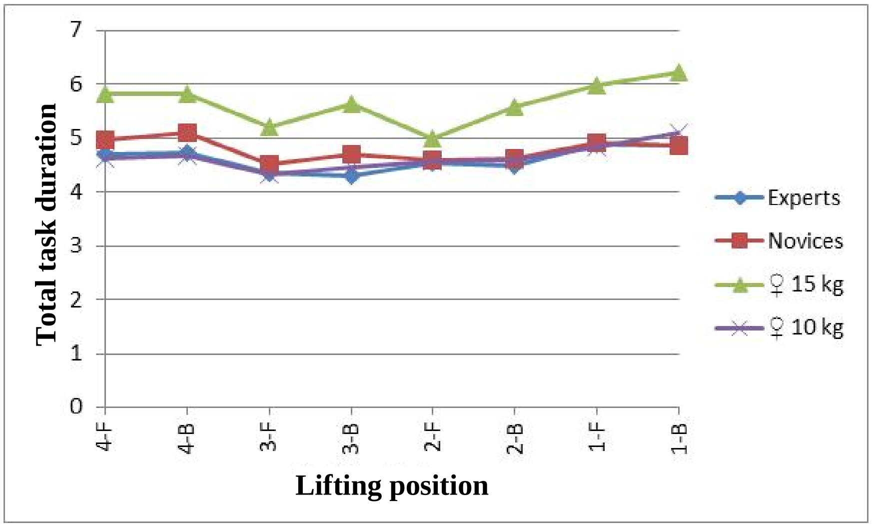


**Figure 5-2: Total task duration for 15-kg and 10-kg conditions as a function of position of the box on the pallet during lifting: numbers 4, 3, 2 and 1 indicate vertical position and letters F (front) and B (back) indicate horizontal position**

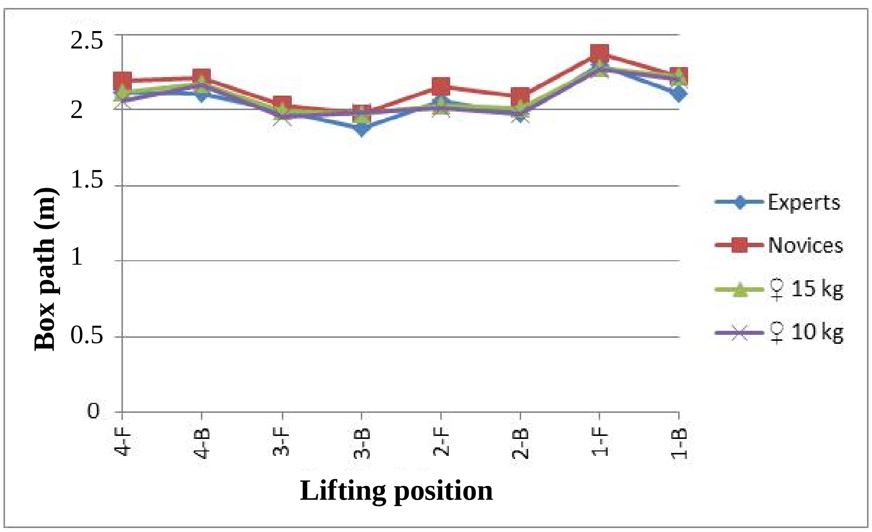


**Figure 5-3: Box path for 15-kg and 10-kg conditions as a function of box pallet position on lifting**

There proved to be major differences between the three groups of handlers in four kinematic variables measured at the time of peak resultant moment, that is, when lumbar load is at a maximum (Table 5-8). First, trunk inclination from the vertical was significantly greater in the women and the novices, about 10° more than in the experts. The same was true of lumbar flexion angle, but the difference between the women and the experts was not significant (Figure 5-6). The horizontal distance of the box from L5/S1 was significantly smaller in the women than in the novices or the experts, by 7 cm and 3 cm respectively, and this was true when lifting as well as depositing the boxes (Figure 5-7). When this horizontal distance was normalized for size, the women remained significantly closer to the boxes than the novices (Table 5-9). The G×H interaction observed with this variable stems from the women remaining closer to the box than the men when the box is lifted from or deposited in the back row position on the pallet. In addition, this interaction remained when the distance was normalized (Table 5-9). Last, lumbar flexion angular velocity (8°/s) was significantly smaller in the women than in the experts on lifting (14°/s) and in the novices on deposit (12°/s). In addition, in the experts and the novices, there was little posture asymmetry when lifting or depositing the boxes, with lumbar torsion and lateral bending angles remaining less than 5° on average. One major significant interaction in lifting, G×V, is caused by greater knee bending in the experts than the women and the novices (Figures 5-8 and 5-9): the closer the box is to the floor, the more the experts bend their knees, which is not the case with the other two groups.

As with resultant moment, peak asymmetrical moment is significantly smaller in the women (Table 5-9). Even when this moment is normalized, the women remain significantly different from the novices when lifting, but not significantly different from the experts (Table 5-9; Figure 5-9). Normalization erases the difference when the boxes are deposited, however. In addition, the cumulative resultant moment is significantly smaller in the women (by close to 30 Nms) than in the novices. Once normalized, however, this variable becomes significantly greater in the women than the men. In other words, in relative terms the women must support a greater lumbar load.

### *5.2.5 Results with the 10-kg load*

Reducing the weight of the boxes lifted by the women from 15 kg to 10 kg had some positive effects (indicated in green), some negative effects (indicated in red) and very often no effect at all (indicated in grey), as shown in tables 5-10 and 5-11 and figures 5-4 to 5-9. First, it is not surprising that peak resultant moment at L5/S1 dropped significantly (more than 15 Nm) with the 10-kg load, as shown so strikingly in Figure 5-4. In addition, as Figure 5-5 shows, women benefitted from a reduced relative loading on the back compared to the men with the 10-kg box. Table 5-11 shows other positive effects: for example, cumulative moment decreased by 37 Nms, a drop of close to 25% (as did the normalized cumulative moment). The effect on the asymmetric moment was much less spectacular: a slight decrease in the deposit phase (Figure 5-9).

Unfortunately, the effects of reducing the load by 5 kg were not all positive. As Table 5-10 shows, the women adapted by significantly increasing the distance of the box from L5/S1 (Figure 5-7), by close to 2 cm in the lifting phase and 4 cm in the deposit phase. With the 15-kg load, the women were significantly closer to the box than the men (Table 5-8), but this was not the case with the 10-kg box, where they performed no better than the novices (Table 5-10). Normalization of this distance eliminated the differences between the men and the women (Table 5-11). The other variable on which the reduced load had a negative effect was knee bending (Figure 5-8). As Table 5-10 shows, there was a significant decrease in knee flexion (about 5°). On the other hand, reducing the load from 15 kg to 10 kg did not significantly affect upper body posture (Table 5-10) and had very little impact on most interactions.

### 5.2.6 ANCOVA results

Table 5-12 shows the ANCOVA results considering the possible effects of four co-variables: weight (W), height (H), experience (E) and strength (S). Interestingly, the data adjustments altered the ANOVA results (tables 5-4, 5-6, 5-8 and 5-9) very little—even increasing significant differences between the groups for certain variables. For example, the experts proved significantly different from the other two groups in box path, trunk inclination, knee flexion and trunk angular velocity. In the women, once adjustments were made, peak resultant moment was equivalent to that of the experts but less than that of the novices. The women remained closer to the box than the men, with a smaller asymmetric moment, but they bent their knees less and inclined their upper bodies more. Cumulative loading was also greater in the women than in the men. Though the conclusions were no different from those of the ANOVA, it is of interest that the anthropometric factors (body weight and height) affected virtually all the dependent variables, whereas experience and strength seemed rather to affect posture-related variables such as knee bending and total task duration.

## Table 5-4: Task duration variables with 15-kg boxes

| Variable | Experts | | Novices | | Women | | *p* | Interaction (*p*) | | | Post-hoc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | G | GV | GH | GP | G |
| Total task duration (s) | 4.6 | 1.2 | 4.8 | 1.5 | 5.7 | 1.8 | **<0.01** | 0.13 | **0.01** | 0.25 | W > E.N |
| Pre-flight time (s) | 1.1 | 0.5 | 1.2 | 0.7 | 1.6 | 0.8 | **<0.01** | 0.15 | 0.07 | 0.09 | W > E.N |
| Flight time (s) | 2.3 | 0.4 | 2.2 | 0.5 | 2.4 | 0.5 | 0.27 | 0.31 | **0.04** | 0.05 | |
| Post-flight (s) | 1.1 | 0.8 | 1.3 | 0.9 | 1.7 | 1.1 | **<0.01** | 0.23 | 0.85 | 0.88 | W > E |

M = mean; SD = Standard deviation; G = Group; GV = Group × Vertical height interaction; GH Group × Horizontal distance interaction; GP = Group × Pace interaction.
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

## Table 5-5: Task duration variables with 10-kg boxes for women and 15-kg boxes for men

| | Women | | | | | | | Comparison of men 15 kg vs. women 10 kg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 10 kg | | 15 kg | | Δ | *P* | | *p* | Interaction (*p*) | | | Post-hoc |
| | M | SD | M | SD | | | | G | GV | GH | GP | |
| Total task duration (s) | 4.7 | 0.9 | 5.7 | 1.8 | 1.0 | **<0.01** | | 0.80 | 0.18 | 0.42 | 0.17 | |
| Pre-flight time (s) | 1.2 | 0.5 | 1.6 | 0.8 | 0.4 | **<0.01** | | 0.77 | 0.08 | 0.71 | 0.08 | |
| Flight time (s) | 2.2 | 0.4 | 2.4 | 0.5 | 0.2 | **<0.01** | | 0.64 | 0.18 | **0.01** | 0.09 | |
| Post-flight (s) | 1.2 | 0.6 | 1.7 | 1.1 | 0.5 | **<0.01** | | 0.40 | 0.44 | 0.63 | 0.28 | |

Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

### Table 5-6: Box path, 15 kg-boxes

| Variable | Experts | | Novices | | Women | | *p* | Interaction (*p*) | | | Post-hoc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | G | GV | GH | GP | G |
| Total distance (m) | 2.07 | 0.22 | 2.16 | 0.28 | 2.10 | 0.24 | 0.19 | 0.62 | 0.06 | **0.01** | |
| Positive vert. distance (m) | 0.34 | 0.34 | 0.37 | 0.37 | 0.37 | 0.37 | 0.21 | 0.14 | 0.26 | 0.24 | |
| Negative vert. distance (m) | 0.28 | 0.27 | 0.30 | 0.29 | 0.28 | 0.27 | 0.84 | 0.22 | 0.64 | **<0.01** | |
| Horizontal distance (m) | 1.86 | 0.18 | 1.96 | 0.24 | 1.88 | 0.20 | 0.06 | 0.13 | **0.05** | **0.05** | |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts

### Table 5-7: Box path, 10-kg boxes for women and 15-kg boxes for men and women

| | Women | | | | | | | Comparison of men 15 kg vs. women 10 kg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | 10 kg | | 15 kg | | Δ | *P* | | *p* | Interaction (*p*) | | | Post-hoc |
| | M | SD | M | SD | | | | G | GV | GH | GP | |
| Total distance (m) | 2.08 | 0.24 | 2.10 | 0.24 | 0.02 | 0.16 | | 0.15 | 0.37 | **0.02** | 0.62 | |
| Positive vert. distance (m) | 0.35 | 0.37 | 0.37 | 0.37 | 0.02 | 0.02 | | **0.05** | **0.03** | 0.39 | 0.88 | W < N |
| Negative vert. distance (m) | 0.28 | 0.27 | 0.28 | 0.27 | 0.01 | 0.06 | | 0.34 | 0.19 | 0.36 | **0.04** | |
| Horizontal distance (m) | 1.89 | 0.21 | 1.88 | 0.20 | -0.01 | 0.78 | | 0.07 | 0.16 | **0.01** | 0.78 | |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.
Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

**Table 5-8: Net peak resultant moment at L5/S1 and associated lifting-phase (L) and deposit-phase (D) variables with 15-kg boxes**

| Variable | Phase | Experts (E) | | Novices (N) | | Women (W) | | *p* | Interaction (*p*) | | | *Post-hoc* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | M | SD | G | GV | GH | GP | G |
| Peak resultant moment (Nm) | L | 168 | 63 | 184 | 64 | 134 | 42 | **<0.01** | **<0.01** | 0.15 | 0.16 | W < E,N |
| | D | 133 | 59 | 149 | 61 | 112 | 42 | **<0.01** | **0.03** | **0.01** | **<0.01** | W < N |
| Occurrence peak moment max (%) | L | 0 | 17 | 2 | 18 | 4 | 24 | **0.01** | **0.03** | 0.09 | 0.60 | W > E |
| | D | 92 | 25 | 90 | 27 | 90 | 28 | 0.18 | 0.68 | 0.82 | 0.15 | |
| Lumbar flexion angle(°) | L | 29 | 21 | 39 | 24 | 37 | 24 | **0.04** | 0.55 | 0.75 | 0.48 | |
| | D | 24 | 19 | 33 | 23 | 29 | 20 | **0.04** | 0.68 | 0.33 | 0.07 | E < N |
| Lumbar flexibility index (%) | L | 45 | 33 | 56 | 35 | 62 | 40 | **0.03** | 0.30 | 0.69 | 0.45 | W > E |
| | D | 37 | 30 | 48 | 33 | 49 | 34 | **0.05** | 0.88 | 0.33 | 0.09 | |
| Lumbar lateral bending angle (°) | L | -2 | 6 | 2 | 7 | -2 | 6 | **0.02** | 0.48 | 0.60 | 0.86 | E < N |
| | D | -2 | 7 | 0 | 7 | -2 | 6 | 0.24 | 0.21 | 0.63 | 0.34 | |
| Lumbar torsion angle (°) | L | 5 | 6 | 4 | 7 | 4 | 6 | 0.44 | **<0.01** | 0.69 | 0.51 | |
| | D | 2 | 6 | 1 | 6 | 0 | 6 | 0.43 | 0.11 | 0.11 | 0.25 | |
| Trunk inclination (°) | L | 36 | 25 | 46 | 29 | 48 | 31 | **<0.01** | **0.01** | 0.94 | 0.27 | E < N,W |
| | D | 32 | 25 | 39 | 28 | 39 | 29 | **0.01** | 0.68 | 0.49 | **<0.01** | E < N,W |
| Box distance from L5/S1 (m) | L | 0.38 | 0.09 | 0.42 | 0.10 | 0.35 | 0.08 | **<0.01** | 0.22 | **0.01** | 0.35 | W < E,N |
| | D | 0.39 | 0.12 | 0.43 | 0.13 | 0.35 | 0.12 | **<0.01** | 0.19 | **0.01** | **<0.01** | W < E,N |
| Right knee flexion (°) | L | 39 | 28 | 30 | 25 | 31 | 24 | 0.13 | **0.01** | **0.03** | 0.07 | |
| | D | 35 | 23 | 32 | 20 | 30 | 22 | 0.30 | 0.67 | 0.46 | 0.25 | |
| Left knee flexion (°) | L | 37 | 28 | 31 | 23 | 30 | 23 | 0.32 | **0.03** | 0.74 | 0.83 | |
| | D | 34 | 22 | 29 | 20 | 29 | 23 | 0.07 | 0.51 | 0.07 | 0.44 | |
| Flexion angular velocity (°/s) | L | 14 | 17 | 11 | 20 | 8 | 17 | **0.03** | **<0.01** | 0.69 | 0.53 | W < E |
| | D | 12 | 17 | 12 | 20 | 7 | 19 | **0.03** | 0.39 | **0.01** | 0.10 | W < N |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.

**Table 5-9: Moments and normalized net moments at L5/S1 as well as box distances from L5/S1 in lifting phase (L) and deposit phase (D) with 15-kg boxes**

| Variable | | Experts (E) | | Novices (N) | | Women (W) | | *p* | Interaction (*p*) | | | *Post-hoc* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | SD | M | SD | M | SD | G | GV | GH | GP | G |
| Peak asymmetric moment | L | 72 | 20 | 82 | 34 | 50 | 16 | **<0.01** | 0.40 | 0.26 | 0.72 | W < E,N |
| | D | 62 | 23 | 69 | 25 | 49 | 18 | **<0.01** | 0.13 | 0.40 | 0.21 | W < E,N |
| Cumulative resultant moment (Nms) | | 178 | 48 | 199 | 53 | 170 | 46 | **0.05** | 0.86 | **0.04** | 0.72 | W < N |
| Normalized values | | | | | | | | | | | | |
| Peak resultant moment[1] | L | 1.77 | 0.68 | 1.94 | 0.63 | 1.91 | 0.57 | 0.09 | **0.01** | 0.15 | 0.25 | |
| | D | 1.40 | 0.61 | 1.57 | 0.63 | 1.61 | 0.58 | **0.01** | 0.27 | **0.03** | **<0.01** | W > E |
| Peak asymmetric moment[1] | L | 0.76 | 0.25 | 0.86 | 0.29 | 0.71 | 0.21 | **0.02** | 0.40 | 0.25 | 0.69 | W < N |
| | D | 0.66 | 0.26 | 0.72 | 0.23 | 0.70 | 0.25 | 0.25 | 0.11 | 0.44 | 0.23 | |
| Cumulative resultant moment[1] | | 1.88 | 0.50 | 2.10 | 0.54 | 2.44 | 0.68 | **<0.01** | 0.81 | **0.04** | 0.77 | W > E,N |
| Box distance from L5/S1[2] at time of peak resultant moment | L | 0.22 | 0.05 | 0.24 | 0.06 | 0.21 | 0.05 | **<0.01** | 0.21 | **0.01** | 0.34 | W < N |
| | D | 0.23 | 0.07 | 0.24 | 0.08 | 0.22 | 0.07 | **<0.01** | 0.16 | **0.03** | **<0.01** | W < N |

1. Normalization = Moment/trunk gravitational moment; unit of trunk weight
2. Normalization = Distance/height; unit of height
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.

**Table 5-10: Net peak resultant moment at L5/S1 and associated lifting-phase (L) and deposit-phase (D) variables with 10-kg boxes and 15-kg boxes**

| Variable | | Women | | | | | | Comparison of men 15 kg vs. women 10 kg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 10 kg | | 15 kg | | Difference | | *p* | Interaction (*p*) | | | Post-hoc |
| | | M | SD | M | SD | Δ | *P* | G | GV | GH | GP | G |
| Peak resultant moment (Nm) | L | 119 | 39 | 134 | 42 | 15 | **<0.01** | **<0.01** | **<0.01** | 0.22 | 0.51 | W < E,N |
| | D | 95 | 39 | 112 | 42 | 17 | **<0.01** | **<0.01** | 0.19 | 0.06 | **0.02** | W < E,N |
| Occurrence of peak moment (%) | L | -1 | 21 | 4 | 24 | 4 | **<0.01** | 0.60 | 0.41 | 0.09 | 0.91 | |
| | D | 92 | 26 | 90 | 28 | -1 | 0.39 | 0.36 | 0.76 | 0.80 | **0.01** | |
| Lumbar flexion angle (°) | L | 35 | 23 | 37 | 24 | 2 | **0.02** | 0.06 | 0.58 | 0.70 | 0.38 | |
| | D | 29 | 20 | 29 | 20 | 0 | 0.45 | **0.04** | 0.72 | 0.43 | 0.57 | E < N |
| Lumbar flexibility index (%) | L | 59 | 40 | 62 | 40 | 3 | **0.03** | 0.08 | 0.36 | 0.72 | 0.34 | |
| | D | 49 | 34 | 49 | 34 | 1 | 0.61 | 0.06 | 0.95 | 0.46 | 0.64 | |
| Lumbar lateral bending angle (°) | L | -1 | 6 | -2 | 6 | -1 | 0.24 | **0.04** | 0.76 | 0.77 | 0.94 | E < N |
| | D | -3 | 7 | -2 | 6 | 1 | 0.13 | 0.17 | 0.20 | 0.61 | 0.48 | |
| Lumbar torsion angle (°) | L | 4 | 6 | 4 | 6 | 0 | 0.80 | 0.44 | **0.01** | 0.75 | 0.69 | |
| | D | -1 | 6 | 0 | 6 | 1 | 0.07 | 0.16 | 0.15 | 0.35 | 0.55 | |
| Trunk inclination (°) | L | 48 | 31 | 48 | 31 | 0 | 0.36 | **<0.01** | **0.02** | 0.93 | 0.37 | W,N > E |
| | D | 40 | 28 | 39 | 29 | -1 | 0.41 | **<0.01** | 0.88 | 0.45 | **0.04** | W,N > E |
| Box distance from L5/S1 (m) | L | 0.37 | 0.08 | 0.35 | 0.08 | -0.02 | **<0.01** | **<0.01** | 0.06 | **0.04** | 0.86 | W,E < N |
| | D | 0.39 | 0.12 | 0.35 | 0.12 | -0.04 | **<0.01** | **0.02** | 0.28 | 0.08 | 0.18 | W,E < N |
| Right knee flexion (°) | L | 26 | 22 | 31 | 24 | 5 | **<0.01** | **0.01** | **0.01** | 0.07 | 0.08 | W < E |
| | D | 25 | 18 | 30 | 22 | 5 | **<0.01** | **0.01** | 0.55 | 0.42 | **0.03** | W < E |
| Left knee flexion (°) | L | 25 | 22 | 30 | 23 | 6 | **<0.01** | **<0.01** | **0.04** | 0.10 | 0.47 | W < E,N |
| | D | 24 | 19 | 29 | 23 | 5 | **<0.01** | **<0.01** | 0.37 | 0.14 | **0.03** | W < E |
| Flexion angular velocity (°/s) | L | 8 | 14 | 8 | 17 | 0 | 0.40 | **0.02** | **0.00** | 0.52 | 0.56 | W < E |
| | D | 8 | 15 | 7 | 19 | -1 | 0.34 | 0.07 | 0.24 | 0.29 | **0.01** | |

*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.
Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

**Table 5-11: Other moments and normalized net moments at L5/S1 as well as box distances in lifting phase (L) and deposit phase (D) with 10-kg boxes and 15-kg boxes**

| Variable | Phase | Women 10 kg M | Women 10 kg SD | Women 15 kg M | Women 15 kg SD | Difference Δ | Difference *p* | | Comparison of men 15 kg vs. women 10 kg: *p* G | Interaction (*p*) GV | Interaction (*p*) GH | Interaction (*p*) GP | *Post-hoc* G |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Peak asymmetric moment (Nm) | L | 49 | 18 | 50 | 16 | 1 | 0.50 | | **<0.01** | 0.50 | 0.08 | 0.52 | W < E.N |
| | D | 45 | 17 | 49 | 18 | 4 | **<0.01** | | **<0.01** | 0.31 | 0.16 | 0.33 | W < E.N |
| Cumulative resultant moment (Nms) | | 133 | 33 | 170 | 46 | 37 | **<0.01** | | **<0.01** | 0.51 | **0.02** | **<0.01** | W < E.N |
| **Normalized values** | | | | | | | | | | | | | |
| Peak resultant moment [1] | L | 1.70 | 0.51 | 1.91 | 0.57 | 0.21 | **<0.01** | | **0.03** | **<0.01** | 0.21 | 0.63 | W < N |
| | D | 1.36 | 0.53 | 1.61 | 0.58 | 0.25 | **<0.01** | | **0.02** | 0.27 | 0.08 | **0.02** | W < N |
| Peak asymmetric moment [1] | L | 0.70 | 0.25 | 0.71 | 0.21 | 0.01 | 0.46 | | **0.03** | 0.47 | 0.08 | 0.48 | W < N |
| | D | 0.64 | 0.23 | 0.70 | 0.25 | 0.06 | **<0.01** | | 0.09 | 0.29 | 0.21 | 0.31 | |
| Cumulative resultant moment [1] | | 1.90 | 0.45 | 2.44 | 0.68 | 0.54 | **<0.01** | | 0.09 | 0.48 | **0.02** | **<0.01** | |
| Box distance from L5/S1[2] at time of peak moment | L | 0.23 | 0.05 | 0.21 | 0.05 | -0.01 | **<0.01** | | **0.05** | 0.09 | **0.05** | 0.85 | E < N |
| | D | 0.24 | 0.07 | 0.22 | 0.07 | -0.02 | **<0.01** | | 0.14 | 0.23 | 0.19 | 0.18 | |

1. Normalization = Moment/ trunk gravitational moment; unit of trunk weight
2. Normalization = Distance/height; unit of height
*A posteriori tests when main effect of group (G) was significant: W = women; N = male novices; E = male experts.
Colour coding for comparison with 15-kg load condition in women: Green = positive effect with 10-kg box; Red = negative effect with 10-kg box; Grey = negligible effect with 10-kg box.

**Table 5-12: Covariance analyses of results of interest, including net peak resultant moments at L5/S1 and associated lifting-phase (L) and deposit-phase (D) variables with 15-kg boxes**

| Variable | Phase | E | N | W | Co-variables | | | | *P group* | *Post-hoc* | *Post-hoc 1* Without normalization | *Post-hoc 2* With normalization |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | M | M | M | w | H | E | S | | | | |
| Total task duration (s) | | 4.9 | 4.7 | 5.5 | ** | ** | * | ** | ** | W > E > N | W > E,N | N.A. |
| Total path (m) | | 2.05 | 2.12 | 2.16 | | ** | | | ** | E < N < W | | N.A. |
| Peak resultant moment (Nm) | L | 153 | 178 | 155 | ** | ** | ** | | ** | W, E < N | W < E, N | |
| | D | 126 | 138 | 130 | ** | ** | | | * | E < N | W < N | E < W |
| - Lumbar flexion angle(°) | L | 32 | 39 | 34 | ** | * | | | ** | E < N | | N.A. |
| | D | 27 | 32 | 27 | ** | ** | | ** | ** | E, W < N | E < N | N.A. |
| - Trunk inclination (°) | L | 33 | 47 | 50 | ** | * | ** | | ** | E < N, W | E < N, W | N.A. |
| | D | 29 | 39 | 42 | ** | ** | * | | ** | E < N, W | E < N, W | N.A. |
| - Box distance from L5/S1 (m) | L | 0.38 | 0.42 | 0.35 | ** | ** | | | ** | W < E < N | W < E, N | W < N |
| | D | 0.39 | 0.42 | 0.36 | ** | ** | | | ** | W < E < N | W < E, N | W < N |
| - Right knee flexion (°) | L | 46 | 29 | 24 | ** | ** | ** | ** | ** | E > N > W | | N.A. |
| | D | 42 | 31 | 25 | ** | ** | ** | ** | ** | E > N > W | | N.A. |
| - Left knee flexion (°) | L | 41 | 31 | 26 | ** | ** | | ** | ** | E > N > W | | N.A. |
| | D | 36 | 26 | 29 | ** | * | | | ** | E > W, N | | N.A. |
| - Flexion angular velocity (°/s) | L | 14 | 11 | 8 | ** | | | | ** | E > N > W | E > W | N.A. |
| | D | 15 | 11 | 6 | ** | | ** | * | ** | E > N > W | N > W | N.A. |
| Peak asymmetric moment (Nm) | L | 67 | 83 | 53 | ** | * | ** | | ** | W < E < N | W < E, N | W < N |
| | D | 60 | 66 | 55 | ** | | | | ** | W < E < N | W < E, N | |
| Cumulative resultant moment Nms) | | 162 | 188 | 197 | ** | ** | ** | ** | ** | W > N >E | W < N | W > E,N |

Note: E = male experts; N = male novices; W = women; M = adjusted mean; w = weight; H = height; E = Experience; S = Strength; N.A. = Not applicable.

**Test significant at $p < .01$; * Test significant at $p < .05$; Post-hoc = Bonferroni comparison tests; Post-hoc 1 = post-hoc tests stemming from Tables 5-4, 5-6, 5-8 and 5-9; Post-hoc 2 = post-hoc tests of normalized values from Table 5-9

Colour = Major difference between post-hoc (ANCOVA) and post-hoc 1 or post-hoc 2

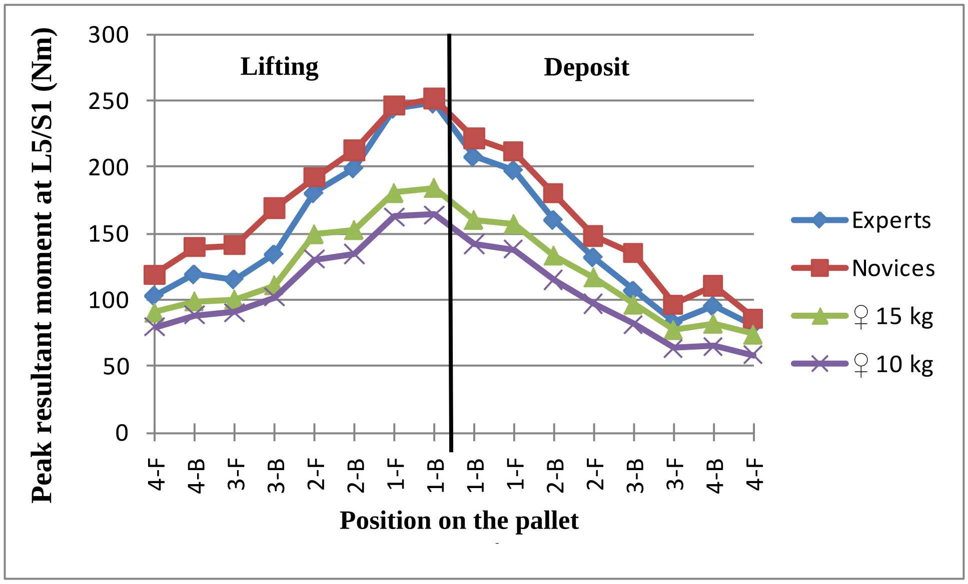


**Figure 5-4: Peak resultant moment at L5/S1 (Nm) for 15-kg and 10-kg conditions as a function of position of the box on the pallet during lifting and deposit: numbers 4, 3, 2 and 1 indicate vertical position and letters F (front) and B (back) indicate horizontal position**

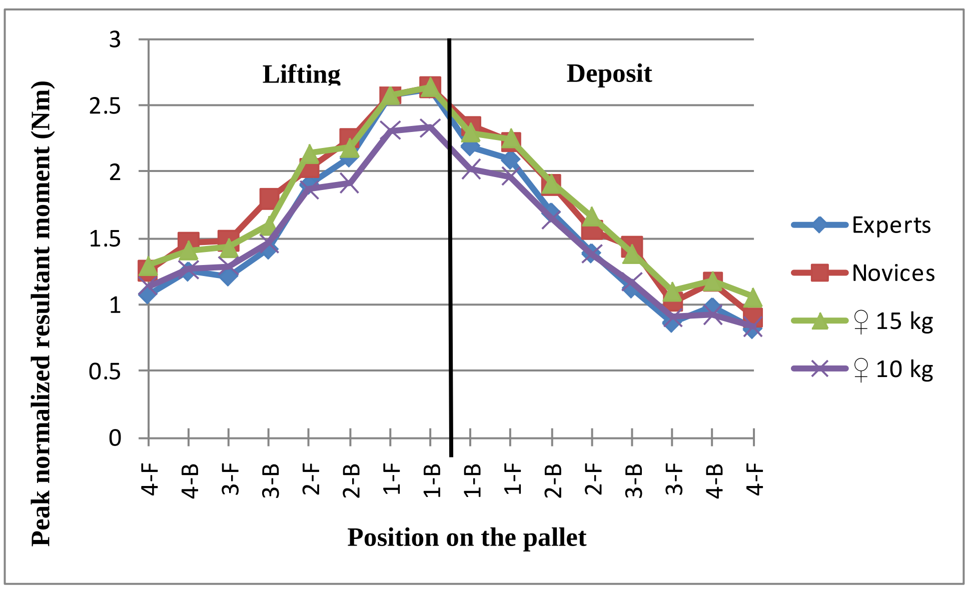


**Figure 5-5: Normalized peak resultant moment (in units of upper body weight) for 15-kg and 10-kg conditions as a function of position on the pallet during lifting and deposit**

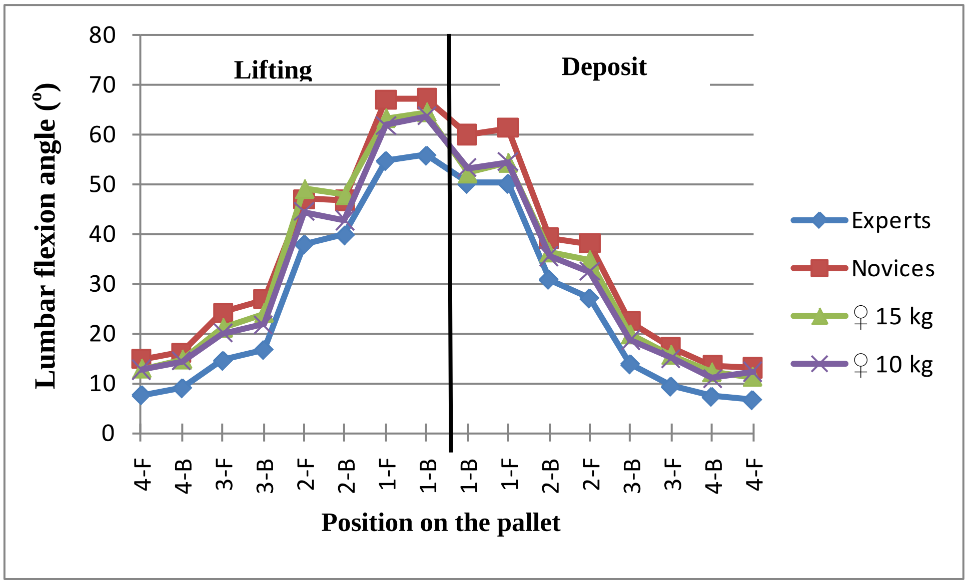


**Figure 5-6: Lumbar flexion (degrees) at time of peak resultant moment for 15-kg and 10-kg conditions as a function of position on the pallet during lifting and deposit**

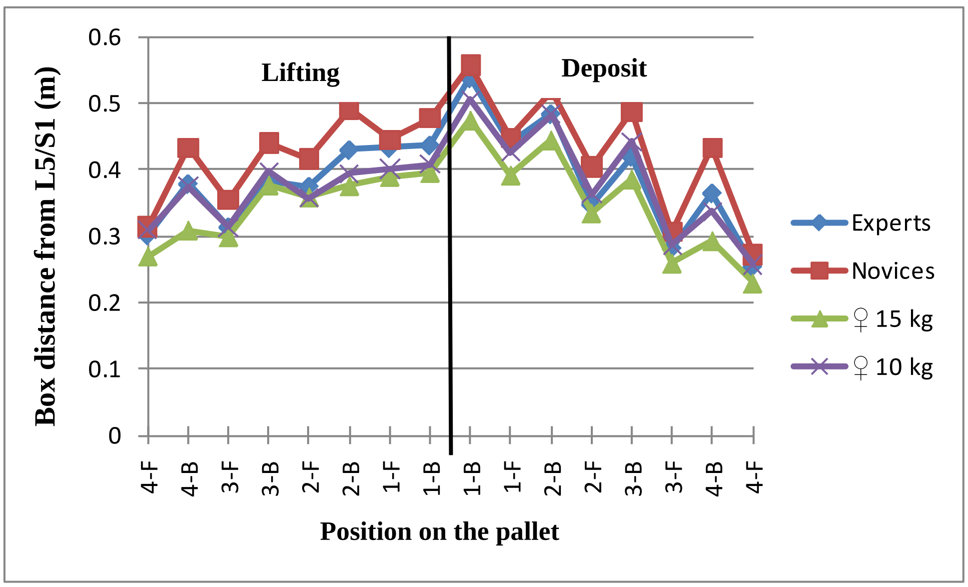


**Figure 5-7: Distance (m) of box from L5/S1 at time of peak resultant moment for 15-kg and 10-kg conditions as a function of position on the pallet during lifting and deposit**

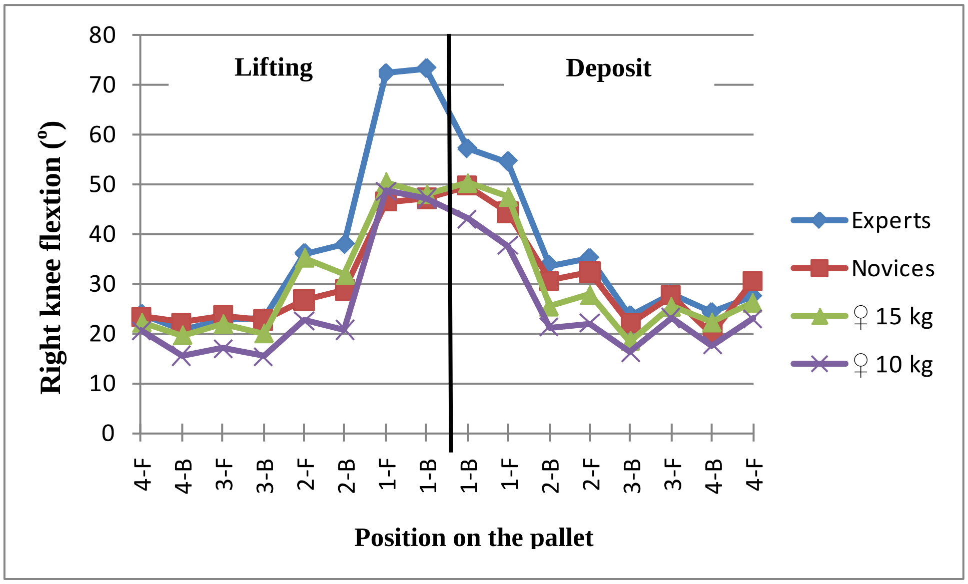


**Figure 5-8: Right knee flexion (degrees) at time of peak resultant moment for 15-kg and 10-kg conditions as a function of position on the pallet during lifting and deposit (similar figure for left knee)**

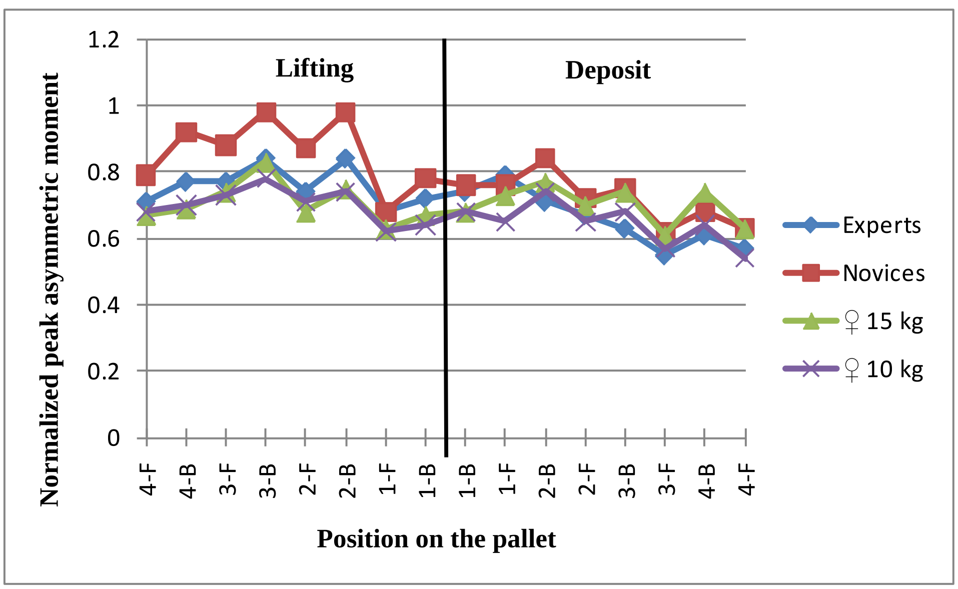


**Figure 5-9: Normalized peak asymmetric moment at L5/S1 (Nm) for 10-kg and 15-kg conditions as a function of position on the pallet during lifting and deposit**

# 6. ERGONOMIC OBSERVATIONS

Ergonomic observations were made from video images recorded during Session III, that is, during box transfers from one pallet to another. These data were analyzed at the same time as the biomechanical data. The main results of the ergonomic observations are outlined in this section.

## 6.1 Methodology

The handling tasks were those described in the preceding chapter (Chapter 5) and are thus not described here.

### *6.1.1 Equipment*

As the amount of data collected is large, the analysis had to be limited to data from the **last self-paced trip in the going direction** and the **last imposed-pace trip in the going direction** for the 15-kg condition in the men and the women and the 10-kg condition in the women. For the 15-kg condition alone there are more than 2,160 observations per variable. The observations were of 45 handlers—15 male experts, 15 male novices and 15 women.

**Observations and data analyses**

Five observation variables were analysed: 1) continuity of box transfer; 2) box tilt in the lifting phase; 3) box tilt in the deposit phase; 4) type of box deposit; and 5) closeness of the box. A detailed description of these five observation variables is given in Appendix G, which includes not only the observation criteria but also images from the videos taken that show the variables observed. The observations were made using the software Observer ™ by two research assistants trained by an ergonomist with extensive observation experience. Most of the variables, or equivalent variables, were used in an earlier study of a population of garbage collectors. The report on this study (in French only) can be downloaded free of charge at the following website: http://www.irsst.qc.ca/media/documents/PubIRSST/R-527.pdf. Raw data entered in Observer™ were transferred to a spreadsheet program for calculation of descriptive data. Chi square ($\chi^2$) tests were performed on the observation data to determine if differences between the groups (experts, novices and women) were sufficient to be significant.

Intraobserver and interobserver reproducibility tests were performed in a preceding study (Plamondon et al., 2010), with all results higher than 80% except for one variable (acceleration). There were three possible categories for this variable, but when the results were sorted into two categories instead, the reproducibility results were above 80%, generally considered an acceptable level.

## 6.2 Results

Table 6-1 shows the data for box transfer continuity. The vast majority of box transfers were performed "in units" or were "continuous with deposit unit" (53% and 36% respectively).[3] Only 7% and 4%, respectively, of the transfers were "continuous" or "continuous with lifting unit." There was not much difference between the groups in terms of frequency of transfers that were performed "in units" or were "continuous with deposit unit." The biggest contribution to the $\chi 2$ (38.89) came from the women, who performed more transfers that were "continuous with lifting unit" than the men. Comparing the 10-kg condition to the 15-kg condition in the women (Table 6-2), the biggest contribution to the $\chi 2$ came from the "continuous with lifting unit" and "continuous" techniques, whose frequency diminished with the 10-kg box.

Observations with respect to box tilt in the lifting phase are presented in Table 6-3. Note that in most cases the box is tilted (36%) or partially tilted (35%). It is the women who tilt the boxes the most and thus contribute most to the $\chi 2$. There was no significant change for the women when the lifted load was decreased from 15 kg to 10 kg. The results were different for box tilt in the deposit phase (Table 6-4), with most of the boxes partially tilted (43%) or not tilted (39%). Once again, the women were the biggest contributor to the $\chi 2$, tilting their boxes much more than the men. Also, the women's technique changed slightly with the 10-kg boxes, which they tilted less than the 15-kg boxes (Table 6-5)

Table 6-6 shows results for type of deposit; the boxes were "held" until they reached the deposit location by half of the participants (51%) and "dropped" there by the other half (49%). The differences between the groups were small, and the biggest contributor to the $\chi 2$ was the group of experts, who generally held the box right to the floor on deposit. The women did not modify their handling technique when the load was decreased from 15 kg to 10 kg. Last, as shown in Table 6-7, most participants held the boxes moderately (55%) or minimally (37%) close to their body, with only 9% bringing the box as close to themselves as possible. The women were different from the men in this, with most working with the box closer to the body than the men. However, the women held the 10-kg boxes significantly farther away than the 15-kg boxes (Table 6-8).

### 6.2.1 A wide variety of techniques

The observations demonstrate that the handlers in our study did not all work in the same way. Though the between-subject differences were more pronounced, the same handler would also vary his/her technique even in identical contexts. Though we were able to identify dominant handling strategies, there was no single standard technique. Apart from a few behaviours adopted by the vast majority of participants, the data show a great deal of variability.

Nonetheless, certain handling strategies were observed more frequently among the handlers in our sample, and it was possible to discern dominant handling profiles. Generally speaking, most of the transfers were performed "in units" or were "continuous with deposit unit" (53% and 36% respectively). This meant that the handler's body was positioned facing the lifting location or the deposit location in the lifting phase, and facing the deposit location in the deposit phase. In

3. See Appendix F for for further explanation of the terms used to describe transfer continuity: "in units," "continuous with lifting unit," "continuous with desposit unit" and "continuous."

addition, most of the handlers tilted the box when lifting it, but not necessarily when depositing it. Furthermore, half of the handlers (in particular the experts) held on to the box till it was on the floor, and the other half dropped it onto the floor.

### 6.2.2 Differences between men and women

The women were different with respect to all variables observed. In terms of continuity, some women worked “in units” when lifting and then deposited the box at the deposit site in open body position. The women tilted the boxes much more than the men in the lifting as well as the deposit phase. For example, in the deposit phase, the women deposited the box without any tilt three to four times less frequently than the men (Table 6-4). The women held onto the box through the deposit phase less frequently than the experts. Last, the women pulled the box close to them more frequently than the men. All these observations indicate that the women used techniques considered safe (working “in units” and bringing the box close to the body) as well as efficient (tilting the box on lifting and deposit) significantly more frequently than the men.

The behaviour of the women changed slightly when the weight of the boxes transferred was reduced from 15 kg to 10 kg, particularly in terms of pulling the box close to the body. In other words, the women brought the 10-kg boxes close to their bodies much less frequently than the 15-kg boxes. This behaviour was also observed in the men, and it reduces the effect of the lighter box on lumbar loading.

**Table 6-1: Observations of all groups: box transfer continuity**

| | **Box transfer continuity** | | | | |
|---|---|---|---|---|---|
| | **In units** | **Continuous with lifting unit** | **Continuous with deposit unit** | **Continuous** | **Total** |
| Experts | 424 | 10 | 258 | 28 | 720 |
| Novices | 387 | 13 | 248 | 72 | 720 |
| Women | 335 | 61 | 269 | 55 | 720 |
| Expected frequency | 382 | 28 | 259 | 52 | 720 |
| Observed frequency (%) | 53 | 4 | 36 | 7 | 100 |
| **Contribution to $\chi 2$** | | | | | |
| Experts | 4.62 | 11.57 | 0.00 | 10.84 | 27.03 |
| Novices | 0.07 | 8.04 | 0.41 | 8.00 | 16.52 |
| Women | 5.78 | 38.89 | 0.44 | 0.22 | 45.33 |
| Total | 10.47 | 58.50 | 0.85 | 19.06 | **88.88** |

**Note: In bold, $\chi 2$ test significant at *p* <0.01; Expected frequency = number of observations for each group if equal.**

**Table 6-2: Observations of women: transfer continuity with 10-kg and 15-kg boxes**

| | **Box transfer continuity** | | | | |
|---|---|---|---|---|---|
| Box weight | **In units** | **Continuous with lifting unit** | **Continuous with deposit unit** | **Continuous** | **Total** |
| 10 kg | 366 | 13 | 337 | 4 | 720 |
| 15 kg | 335 | 61 | 269 | 55 | 720 |
| Expected frequency | 351 | 37 | 303 | 29 | 720 |
| **Contribution to $\chi 2$** | | | | | |
| 10 kg | 0.69 | 15.57 | 3.82 | 22.04 | 42.12 |
| 15 kg | 0.69 | 15.57 | 3.82 | 22.04 | 42.12 |
| Total | 1.38 | 31.14 | 7.64 | 44.08 | **84.24** |

**Note: In bold, $\chi 2$ test significant at *p* <0.01.**

**Table 6-3: Observations of all groups: box tilt in lifting phase**

| | **Box tilt in lifting phase** | | | |
|---|---|---|---|---|
| | **Tilted** | **Partially tilted** | **Not tilted** | **Total** |
| Experts | 239 | 200 | 281 | 720 |
| Novices | 251 | 183 | 286 | 720 |
| Women | 276 | 374 | 70 | 720 |
| Expected frequency | 255 | 252 | 213 | 720 |
| Observed frequency (%) | 36 | 35 | 29 | 100 |
| **Contribution to $\chi 2$** | | | | |
| Experts | 1.04 | 10.85 | 22.21 | 34.10 |
| Novices | 0.07 | 19.05 | 25.56 | 44.68 |
| Women | 1.67 | 58.66 | 95.41 | 155.74 |
| Total | 2.78 | 88.56 | 143.18 | **234.52** |

**Note: In bold, $\chi 2$ test significant at *p* <0.01**

**Table 6-4: Observations of all groups: box tilt in deposit phase**

| | Box tilt in deposit phase | | | |
|---|---|---|---|---|
| | **Tilted** | **Partially tilted** | **Not tilted** | **Total** |
| Experts | 87 | 301 | 332 | 720 |
| Novices | 84 | 235 | 401 | 720 |
| Women | 223 | 398 | 99 | 720 |
| Expected frequency | 131 | 311 | 278 | 720 |
| Observed frequency (%) | 18 | 43 | 39 | 100 |
| **Contribution to $\chi2$** | | | | |
| Experts | 14.97 | 0.34 | 10.78 | 26.09 |
| Novices | 17.06 | 18.72 | 55.14 | 90.92 |
| Women | 63.98 | 24.13 | 114.67 | 202.78 |
| Total | 96.01 | 43.19 | 180.59 | **319.79** |

**Note: In bold, $\chi2$ test significant at $p$ <0.01**

**Table 6-5: Observations of women: box tilt in deposit phase with 10-kg boxes and 15-kg boxes**

| | Box tilt in deposit phase | | | |
|---|---|---|---|---|
| **Box weight** | **Tilted** | **Partially tilted** | **Not tilted** | **Total** |
| 10 kg | 181 | 426 | 113 | 720 |
| 15 kg | 223 | 398 | 99 | 720 |
| Expected frequency | 202 | 412 | 106 | 720 |
| **Contribution to $\chi2$** | | | | |
| 10 kg | 2.18 | 0.48 | 0.46 | 3.12 |
| 15 kg | 2.18 | 0.48 | 0.46 | 3.12 |
| Total | 4.36 | 0.96 | 0.92 | **6.24** |

**Note: In bold, $\chi2$ test significant at $p$ <0.05**

**Table 6-6: Observations of all groups: type of deposit**

| | Deposit type | | |
|---|---|---|---|
| | **Held** | **Dropped** | **Total** |
| Experts | 415 | 305 | 720 |
| Novices | 348 | 372 | 720 |
| Women | 343 | 377 | 720 |
| Expected frequency | 369 | 351 | 720 |
| Observed frequency (%) | 51 | 49 | 100 |
| **Contribution to $\chi2$** | | | |
| Experts | 5.82 | 6.11 | 11.93 |
| Novices | 1.16 | 1.22 | 2.38 |
| Women | 1.79 | 1.88 | 3.67 |
| Total | 8.77 | 9.21 | **17.0** |

**Note: In bold, $\chi2$ test significant at $p$ <0.01**

**Table 6-7: Observations of all groups: pulling the box to the body**

| | **Pulling the box to the body on lifting** | | | |
|---|---|---|---|---|
| | **Max** | **Moderate** | **Min** | **Total** |
| Experts | 53 | 430 | 237 | 720 |
| Novices | 48 | 312 | 360 | 720 |
| Women | 84 | 440 | 196 | 720 |
| Expected frequency | 62 | 394 | 264 | 720 |
| Observed frequency (%) | 9 | 55 | 37 | 100 |
| **Contribution to $\chi 2$** | | | | |
| Experts | 1.22 | 3.29 | 2.83 | 7.34 |
| Novices | 3.03 | 17.07 | 34.62 | 54.72 |
| Women | 8.09 | 5.37 | 17.66 | 31.12 |
| Total | 12.34 | 25.73 | 55.11 | **93.18** |

**Note: In bold, $\chi 2$ test significant at $p$ <0.01**

**Table 6-8: Observations of women: pulling the 10-kg and 15-kg boxes to the body**

| | **Pulling the box to the body on lifting** | | | |
|---|---|---|---|---|
| | **Max** | **Moderate** | **Min** | **Total** |
| 10 kg | 46 | 384 | 290 | 720 |
| 15 kg | 84 | 440 | 196 | 720 |
| Expected frequency | 65 | 412 | 243 | 720 |
| **Contribution to $\chi 2$** | | | | |
| 10 kg | 5.55 | 1.90 | 9.09 | 16.54 |
| 15 kg | 5.55 | 1.90 | 9.09 | 16.54 |
| Total | 11.10 | 3.80 | 18.18 | **33.08** |

**Note: In bold, $\chi 2$ test significant at $p$ <0.01**

# 7. DISCUSSION

## 7.1 Physical capacity of subjects (Session I)

First, there are anthropometric differences between men and women, particularly with respect to size, the women handlers being close to 10 cm shorter than the men handlers. Second, the results of the physical capacity tests of the subjects showed there were no physical differences between the male experts and the male novices except in $VO_2$ max. The differences between the men and the women, on the other hand, were substantial, except in the muscle endurance test (no difference). For the latter test, the subjects had to withstand an absolute load of 150 Nm for the men and 100 Nm for the women for as long as possible. Based on the extension strength test results, the imposed loads were equivalent to about 45% of maximum strength in the men and 54% in the women. The men should therefore have done better in the endurance test, but this was not the case. The physical strength of the women was 49% to 63% of that of the men. It is thus clear that the women handlers were not as strong as the men handlers. These results confirm those of numerous other studies of this question. As indicated by Chaffin et al. (2006), the average strength of a woman is about two-thirds that of a man, but this is an average value for different muscle groups and the values for each muscle group easily range anywhere from 33% to 86% of that of a man (Ayoub and Mital, 1989). Kumar and Garand (1992) measured peak muscle strength in men and in women when stooping (back bent, knees straight) and squatting (back straight, knees bent). The peak strength of the women ranged from 41% to 94% of that of the men and depended on posture and technique. This means that with the same absolute load, a woman will always bear a larger relative load than a man, which generally means that women must make a greater physical effort (closer to their maximum strength).

## 7.2 Factors common to sessions II and III

Whether the boxes were transferred from a conveyor to a trolley (Session II) or from one pallet to another (Session III), the results demonstrate that in general women differ from men handlers in a number of ways (Table 7-1; Figure 7-1). When transferring identical 15-kg boxes, the women take longer to perform the task; bear a smaller absolute back load (moment at L5/S1) but an equivalent relative back load (moment normalized per unit of trunk weight); bear an equivalent cumulative load (cumulative moment at L5/S1) that is greater when normalized; use postures that are more like those of novice male handlers, that is, greater lumbar flexion and trunk inclination than the experts; have a smaller angular velocity; and keep the boxes closer to their bodies. In addition, these results were confirmed considering the co-variables of handler weight, height, experience and strength. When the women transferred a 10-kg load, task duration decreased significantly, as did back loading (absolute as well as normalized resultant, asymmetric and cumulative moments). On the other hand, box distance from L5/S1 increased. In Session III, the women kept the 15-kg boxes significantly closer to their bodies than did the novices, even when the distance was normalized, and they bent their knees less when lifting the 10-kg boxes. A number of these results suggest that the differences between the sexes can be explained by the weight of the load, or, more specifically, muscle strength.

**Table 7-1: Summary of results for women vs. men (N= novices and E = experts) common to Session II and Session III, showing when women's results were higher (+), equal to (=) or lower ( - ) than the men's for 15-kg boxes (absolute load) and 10-kg boxes (relative load)**

| Variable | ♀ 15 kg | ♀ 10 kg | Comments |
|---|---|---|---|
| Task duration | + | = | |
| Box path | = | = | |
| Peak resultant moment | – | – | |
| Normalized peak resultant moment | = | – | 15 kg: ♀ > ♂ $p \approx .10$ ;<br>10 kg:♀ < N Session III |
| Peak asymmetric moment | – | – | |
| Normalized peak asymmetric moment | = | – | 15 kg: ♀ < N lifting Session III |
| Cumulative resultant moment | = | – | 15 kg: ♀ < N Session III |
| Normalized cumulative moment | + | = | |
| | | | |
| Occurrence of peak moment | + | = | 15 kg: ♀ > E |
| Lumbar flexion angle | + | = | 15 kg: ♀ > E Session II<br>10 kg: ♀ > E deposit Session II |
| Lumber flexibility index | + | + | 15 kg: ♀ > E<br>10 kg: ♀ > E Session II |
| Trunk inclination | + | + | 15 kg: ♀ > E<br>10 kg: ♀ > E |
| Box distance from L5/S1 | – | – | 15 kg: ♀ < E, N Session III<br>10 kg: ♀ < N Session III |
| Normalized box distance from L5/S1 | = | = | 15 kg: ♀ < N Session III |
| Knee flexion | = | – | 15 kg: ♀ < E Session III lifting from the floor (significant interaction)<br>10 kg: ♀ < E Session III |
| Angular velocity | – | – | 15 kg: ♀ < E lifting<br>10 kg: ♀ < E lifting |

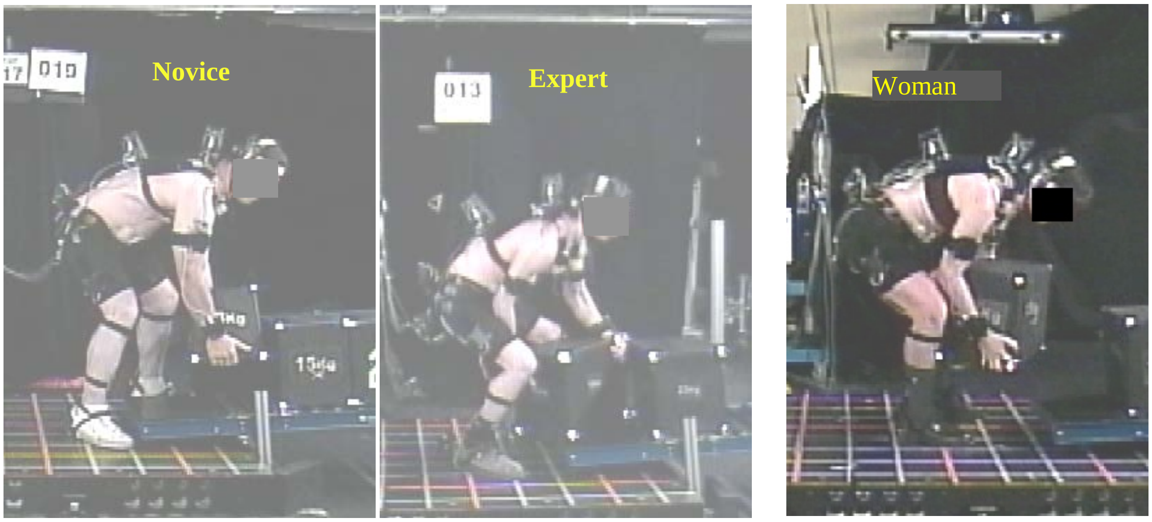


**Figure 7-1: Differences in posture: expert, novice and woman**

### 7.2.1 Task duration

One of the major discoveries of this study was a substantial difference between the men and the women in task duration in transferring the 15-kg boxes: about one second, on average, in both sessions. In addition, trunk angular velocity was significantly smaller in the women. When the women were lifting 10-kg boxes, the differences between the men and the women were considerably smaller—with the difference in task duration no longer significant, though trunk angular velocity remained smaller in the women than in the men. These results seem to indicate that the women have more difficulty transferring the 15-kg boxes than the 10-kg boxes. It is clear, as demonstrated in Chapter 3, that the women do not have the same physical strength as the men, and this can affect the duration and speed of box transfer. Mital (1984) demonstrated in a psychophysical study that men lifted significantly more boxes than women in a 12-hour work shift. Mital (1987) also noted that at an imposed work pace similar to actual working conditions, the men did not experience a physiological overload, which was not the case for the women. The women handlers in our study certainly had more difficulty transferring the 15-kg boxes than the men and seemed more comfortable with the 10-kg boxes.

### 7.2.2 Moments

Resultant and asymmetric moments were significantly lower in the women than in the men. This was anticipated given their anthropometric differences. When the moments were normalized for trunk weight, the differences were no longer significant, as in the ANCOVA. Marras et al. (2002) report the same finding when sagittal moment (flexion axis) was normalized. However, these researchers indicate that there can be significant difference between the sexes in lumbar load (compression force and shear force) because of the differences in handling strategies. The women flexed their hips more than the men in the lifting phase, so there was less flexion in the lumbar region (Marras et al., 2002, 2003). The authors explain that as the women in their study had 30% less extension strength in the back than men, they made kinematic compensations to lift the boxes. For this reason, the women experienced greater lumbar loading than the men, with compression loads of approximately 47% of their compression force tolerance as compared with men—whose compression values represented about 38% of their tolerance. As a result, Marras et al. (2002, 2003) concluded that women are at greater risk of injury than men under identical handling conditions. This interpretation is in keeping with the results of our study.

The cumulative resultant moment (in the flight phase) shows another aspect. When this moment is not normalized, there is generally no difference between the sexes for a 15-kg load. However, normalizing this moment shows that women are subjected to a significantly greater lumbar load. As expected, when the load was reduced from 15 kg to 10 kg, the moments decreased significantly; and when the data were normalized, the women proved to be better off than the men with respect to resultant moment, asymmetric moment and cumulative moment. In other words, reducing the weight lifted substantially reduces lumbar loading in women. According to Marras et al. (2003), adjusting not only the load but also the lifting height will eliminate the difference between the sexes.

Peak resultant moment is affected by box lifting height as well as box distance from L5/S1. When the boxes are lifted from a higher height, resultant moment drops, facilitating handling (Figure 5-4). Plamondon et al. (2012) state that lifting height has a greater effect than expertise on lumbar loading and that reducing lifting height is a more effective intervention than gaining expertise (through training). The women were significantly closer to the boxes than the novices, even when the distance was normalized (Session III only). Ergonomic observations made from a video also showed that the women were closer to the box than the men. Kotowski et al. (2007) demonstrated the same behaviour in women, who would slide the box towards them before lifting it—unlike the men, who lifted up the box immediately. However, despite this technique, the normalized resultant moment was not affected sufficiently in the women to lower it below that of the men. It was only when the women lifted a 10-kg box that the normalized resultant moment was significantly lower than that of the male novices. On the other hand, with the 10-kg box, the women increased their distance from the box significantly. Trunk angular velocity may have played a role, but though it was lower in the women it could only have had a minor impact on the resultant moment.

### 7.2.3 Posture

#### 7.2.3.1 Lumbar flexion

Lumbar flexion and trunk inclination are two major features that distinguish male expert handlers from male novice handlers. In all situations studied, when lifting as well as depositing the boxes, in trips to the trolley as well as to the conveyor, the difference between the two groups in lumbar flexion or trunk inclination (at the time of peak moment at the back) was at least 10°. The experts bent forward less than the novices and this is believed to be a key characteristic of expertise (Plamondon et al., 2010). The current results indicate that the behaviour of the women is similar to that of the novice male handlers, that is, they bend the trunk and the lumbar region more than the experts. In addition, as the women were on average older than the male experts, lumbar flexibility (which can decrease with age) cannot explain the difference. Furthermore, the lumbar flexibility indices of the women (which take age into account, Appendix E) were much higher than those of the experts. Interestingly, Marras et al. (2003) as well as Davis et al. (2003) found that women adopt a straighter trunk posture during handling tasks than men (less lumbar flexion). The reasons for this contradiction between study results are not easy to explain, but two major factors may have played a role: the selection of the novice subjects and the highly controlled laboratory context of the Marras et al. (2003) and Davis et al. (2003) studies. Additional research is required to better explain these contradictory results.

To what extent, then, is lumber flexion or lumbar flexibility index a factor to be considered in preventing back injury? There are two schools of thought in the literature (Dolan et al., 1994a). One school advocates close to full lumbar flexion to stretch passive lumbar structures and the thoracolumbar fascia, thus increasing the contribution of passive elements to balance the external moment and reduce the internal compressive force on the disk (Dolan et al., 1994a; Gracovetsky et al., 1981; Gracovetsky et al., 1989). Dolan et al. (1994a) indicate that most participants in their study bent the lumbar spine by about 80% to 95% of full flexion when lifting weights from the floor and that the contribution of passive elements to the external moment could be as high as 30%. Maduri et al. (2008) suggest that stretching passive tissue is a method of energy transfer that promotes storage of energy during the stretch and its release during the subsequent shortening during lifting (stretch-shortening cycle). By stretching these structures, the women might be making use of a powerful method of energy transfer that allows application of greater force as well as conservation of energy. However, this technique can increase the risk of injury, especially when lifting boxes from the floor.

The second school of thought recommends maintaining the lumbar spine in a neutral posture (close to lordosis) so as to limit stretching of the passive elements of the spine (McGill, 2002; McGill, 2009). A number of reasons are cited in support of this recommendation. With pronounced flexion of the lumbar spine, especially beyond static capacity (100%), the risk of ligaments tearing increases (Adams et al., 1980); shear loads on the lumbar spine are much higher, approaching maximum tissue tolerance (about 1000 N); the ligaments must support much of the shear load—which is not the case with a neutral posture, where the muscles play a bigger role; disks are 20% to 40% less capable of supporting loads than with a neutral posture (McGill, 2002). Also, the creep induced by stretching (prolonged or cyclic) of the ligaments desensitizes the mechanoreceptors, resulting in diminished reflexive activation of the muscles (Solomonow et al., 1999). More recently, Solomonow (2011) presented a model for development of musculoskeletal disorders (MSDs or cumulative trauma disorders (CTDs), and one of the key aspects of the model is the scope of creep. As creep and associated micro-damage develop, muscular responses first increase (spasms) and then diminish relative to normal responses, which in turn reduces lumbar stability. Without appropriate periods of rest, pain and injuries become chronic over time. The risk of developing back pain is high with prolonged exposure to creep, that is, exposure to high loads, many repetitions, short rest and high loading velocity (frequency). Handlers whose lifting strategy involves frequent stretching of the passive elements of the spine induce greater creep in passive tissue, which can prove damaging to the back in the long term.

Between the two schools of thought, there is the viewpoint of Adams et al. (2002), who state that moderate lumbar flexion makes it possible to 1) stretch passive structures without too great a risk of intervertebral disk herniation; 2) reduce muscular activity, stabilizing the vertebral column and associated fatigue; and 3) take advantage of the elastic energy of passive tissue. A number of authors (Burgess-Limerick, 2006; Adams et al., 2002; McGill, 2007; Marras, 2008) recommend that extreme postures be avoided, in particular extreme flexion, but also extreme lateral bending or axial rotation. The posture adopted by the experts seems most like that advocated by Adams et al. (2002), that is, moderate flexion of the lumbar region to take advantage of the mechanical benefits of stretching passive structures while maintaining a safety margin. Burgess-Limerick (2006) indicates there is no reason to avoid postures with moderate lumbar flexion. A safety margin can be important for any handler in case of fatigue or unexpected events. For example, Dolan and Adams (1998) observed an increase in lumbar flexion (from 83.3% to 90.4%) in participants after 100 box lifts. Fatigue caused the subjects to work closer to their flexibility limit, with the advantage that passive tissue supported more of the load (energy saving) and the drawback of considerably reducing the safety margin of this tissue and thus increasing the risk of damage to the tissue. The experts seem thus to give themselves a larger safety margin.

According to our results, women rely more on the passive structures, stretching them more than the experts, especially when lifting loads from the floor. Burgess-Limerick et al. (1995) say that the distal-to-proximal pattern of coordination of the extension of the knee, then the hip and last the lumbar vertebral joints is exaggerated as load mass increases. In fact, we did observe that a greater number of women and novice handlers used this type of sequential movement, that is, bending of the knees when lifting a box from the floor, followed by very rapid extension of the knees (from squat to stoop) and then extension of the hips and the spine to lift the box. What looked like a squat lift at the start in certain handlers was followed in fact by a stoop lift. To validate these observations, knee flexion at the time of peak resultant moment (Table 7-2) was subtracted from peak knee flexion when lifting. The difference for the right knee was 10°, 14° and 30° for the experts, novices and women respectively. The women used rapid extension of the knee (at the start of the lifting) to delay rapid shortening of the hamstrings and thus facilitate hip extension (Burgess-Limerick et al., 1995; Toussaint et al., 1992; de Looze et al., 1993). During this rapid knee extension, the quadriceps contribute to the hip extension, allowing the hamstrings (biarticular muscles) to act to some degree as a tendon that pulls on the pelvis through leg action. According to Burgess-Limerick et al., 1995, this mechanism can reduce muscular effort and thus delay the effects of fatigue. However, this technique delays extension of the lumbar vertebral column, or, in other words, increases the duration of lumbar flexion, which means, in turn, greater contribution of the posterior passive tissue of the vertebral column. By stretching these structures, the women benefit from a very powerful energy transfer that allows them to apply greater force and conserve energy, but there are risks.

**Table 7-2: Difference between maximum right knee angle (maximum angle) and angle at time of peak resultant moment at L5/S1 (angle at peak resultant moment) in lifting boxes from the floor of the pallet**

| Right knee variable | Experts (E) | | Novices (N) | | Women (W) | | *p* |
|---|---|---|---|---|---|---|---|
| | M | SD | M | SD | M | SD | |
| Maximum angle (°) | 83 | 29 | 61 | 35 | 79 | 36 | **0.02**$^{E>N}$ |
| Angle at peak resultant moment (°) | 73 | 30 | 47 | 38 | 49 | 32 | **<0.01**$^{E>N,W}$ |
| Difference (°) | 10 | 9 | 14 | 13 | 30 | 23 | **<0.01**$^{W>E,N}$ |
| Occurrence of maximum angle (%) | -6.8 | 18.2 | -0.7 | 25.7 | -7.5 | 25.9 | |
| Occurrence of peak resultant moment (%) | 1.4 | 4.4 | 3.7 | 4.4 | 5.8 | 4.9 | |

Davis and Troup (1965) as well as Schipplein et al. (1990) noted a change in technique from squat lifting to stoop lifting with heavier weights. The relative strength of the back and the leg muscles may explain this change in technique. Li and Zhang (2009), for example, note that subjects stronger in the legs than the back preferred a strategy that relied more on knee flexion. It is possible that the relative strength of the hip extensors compared to the back extensors is greater in women than in men. This would explain this strategy, which seems to clearly demand more of the hip extensors than the technique used by the men. Though we found no data in the literature to support this hypothesis, we do have a database (11 women and 11 men) of maximum strength (static effort) of back extensor muscles and hip extensor muscles measured with a dynamometer, results not published in the original article (da Silva et al., 2009). Two positions were considered, both of which can be generalized to load lifting: (1) hip at 90° and knee at 90°; and (2) hip at 90° and knee at 135°. The hip/back strength ratio was in fact higher ($p = 0.019$) in the women (1.10 ± 0.21) than the men (0.91 ± 0.21), confirming our hypothesis. In addition, the ratio (1.08 ± 0.19) was higher ($p = 0.003$) in position 2 than in position 1 (0.92 ± 0.25), additional support for the technique used by the women, that is, straightening the knees (as in position 2), before lifting the load.

Given the current state of our knowledge, it is reasonable to assume that the women developed a motor coordination technique that is highly advantageous for them and that differs from that of male experts. On the other hand, there is every reason to believe that the women put themselves at greater risk of injury by adopting a posture similar to that of novice handlers. Dolan et al. (1994b) state that even with 100% static flexing of the lumbar spine, there is a safety margin, as the point of injury is around 130%. In addition, as soon as the box is lifted up, particularly when lifted from the floor, lumbar flexion decreases rapidly (Figure 5-6), thereby increasing the safety margin for excessive stretching of passive elements. In addition, the women handlers in this study had many years of experience. That the experts and the women differed here leads us to be cautious, to reiterate that there is no "ideal posture" and to affirm that the individual and the working conditions can lead to selection of a less ideal posture that is nonetheless better suited to the situation. Davis et al. (2003) noted less lumbar region flexion in women (novices) than men (novices as well) when lifting boxes from different heights. Why, in this situation, did the women differ from the men in this way? We don't really know. It is of interest, however, that when the load was reduced from 15 kg to 10 kg, lumbar flexion decreased slightly, but not significantly, in the women in our study.

#### 7.2.3.2 Asymmetry

Interestingly, there was little posture asymmetry in the three subject groups at the time of peak moments. As mentioned by Gagnon (2003, 2005), feet mobility (no restrictions on feet positioning) considerably reduces posture asymmetry, and the laboratory context probably encouraged handlers to avoid risky positions. Our ergonomic observations are consistent with these findings. The vast majority of the box transfers were performed "in stages" throughout the transfer or with a "deposit stage" (53% and 36% respectively), promoting a posture facing the box. This may not always be the case in the field, however, where asymmetric postures are frequently observed. Baril-Gingras and Lortie (1995), for example, estimate that about 15% of lifting efforts in material handling include trunk twisting and that this occurs in close to 50% of material handling activities. However, this torsion was not objectively measured, and no information is given on whether feet mobility was restricted.

#### 7.2.3.3 Knee flexion (at time of peak moment)

Knee flexion remained greater in the experts than in the women, particularly when the box had to be lifted from the floor. The lower the box on lifting, the more the experts bent their knees; however, differences between the groups diminished and then disappeared as lifting height increased to waist and then chest height (Session III). One key finding of Plamondon et al. (2010) was that experts bent their knees significantly more than novices, especially during the lifting phase, and a little less so during the deposit phase. Interestingly, when only the 15-kg boxes in this study are considered (excluding the 23-kg box from the data), the significant difference between the experts and the novices in knee flexion in the lifting phase is considerably smaller (especially in Session II). There is good reason to assume that the 23-kg box (of the earlier study) intensified the difference in knee flexion between the experts and the novices. Nonetheless, at 15 kg, the experts on average bent their knees more, and the difference, mainly from the novices, was close to significant. The difference between the experts and the women was about ten degrees (not significant: Session II). In this particular case, we cannot conclude that knee bending is a determining factor between the men and the women, though the ANCOVA results (Table 5-12) suggest the women bend their knees significantly less. When the load was decreased from 15 to 10 kg, there was little change in Session II, but in Session III, a significant decrease in knee bending by the women compared to the experts was noted. In other words, box weight and muscle strength seem to play a role in knee bending.

Note that the experts stayed with the boxes to completion of the deposit more often than the women or the novices, according to our ergonomic observations. This is probably why the experts bent their knees more when depositing boxes on the floor. Note as well that the women tilted the boxes more than the men, in lifting as well as depositing them. For example, the women deposited the box in an untilted position three to four times less frequently than the men did. These observations explain some of the differences in knee flexion between the groups.

### *7.2.4 Closeness to the box*

The women kept the boxes closer to them (box-L5/S1 distance) than the novices. Their smaller size seems to be largely responsible for this, as the differences become smaller (Session II) with normalization, though they did not disappear completely (Session III), especially in the ANCOVA (Table 5-12). When the 15-kg boxes were replaced by 10-kg boxes, the distance increased significantly, by 1 cm to 4 cm. Though the increase was small, it shows that handlers will often behave in a way opposite to what is desired when load is reduced. Davis and Marras (2000), for example, found that the participants in their study held the box farther away from their bodies when lifting lighter boxes. This is not desirable as, according to Marras (2006), the most important rule in avoiding occupational back injuries concerns the external moment on the vertebral column: it is crucial that this external moment be as small as possible and that no matter what the lifting strategy used it works to bring the centre of gravity of the load as close as possible to the vertebral column. As they are smaller, women have a certain advantage here, and our results show they bring the boxes closer to them than do the men. However, they did not take advantage of the reduced load by remaining close to the boxes.

## 7.3 Limitations of the study

### 7.3.1 Subjects

All the women were recruited from different warehouse stores of a large beverage distribution company. Nine of the fifteen participants had never taken a training course, three were more or less familiar with safe handling techniques and three had taken part in a training course. Probably all of the women participants as well as the men had been informed at one time or another of the recognized “safe” technique for lifting a box: back straight, knees bent. It is thus unlikely that one group of subjects in particular (the women, for example) was more influenced than the other groups by these recommendations, which would have biased the results of our study. All the women met the study inclusion criteria, though they were not without musculoskeletal injuries (Appendix A: Table A.3): injuries to all joints, including the back, were reported. In addition, the women seem to have had more musculoskeletal injuries than the male experts (Table A.1 and Table A.2). However, we must be very cautious with this interpretation, as it cannot be considered valid without a more extensive investigation of the physical health of the participants. On the other hand, none of the subjects presented musculoskeletal disorders that might affect how they normally carry out their work, and the problems mentioned were minor. We do not, as a result, believe that musculoskeletal injuries played any role whatsoever in our research results.

The protocol for the women differed from that of the men in the pallet-to-pallet transfer session, as the women first transferred 15-kg boxes and then switched to 10-kg boxes. The fact that the women had to transfer the 15-kg boxes only once at an imposed-pace, compared to three times for the men, and that the women always transferred the 10-kg boxes after completing the transfer of the 15-kg boxes, may have affected the results, but not enough to alter the main conclusions of the study.

The women who participated in the study had many years of experience. Bias is nonetheless possible, as the male experts had twice as much experience as the women (♀= 7.3 years vs. ♂= 15.5 years). However, this bias was considered in the ANCOVA and the results were substantially the same. In addition, all the women participants were able to perform the tasks without major difficulty and even had an aerobic capacity ($VO_2$ max) superior to that of the experts. Most of the women participants could very probably be classified as experts. In this respect, their lifting strategies were as valid as those of the male experts. Given current knowledge and the results of this study, our hypothesis is that the women handlers used a technique to lift boxes from the floor that seemed less safe than that used by the men. However, it would be a mistake to think that the men had “the best lifting technique” and that this technique should necessarily be copied by the women without understanding the reasons for these differences. Further studies are required to validate these differences and, above all, to understand the reasons for them.

### 7.3.2 Biomechanical results

A number of sources of error can affect biomechanical results, including human error; inaccurate photogrammetric and force platform measurements; errors in identification of anatomical landmarks and in installing markers; movement of the skin and of the markers on the skin during the lifting activities; and errors in the biomechanical models. However, everything was done to minimize these errors, from calibration of the measuring instruments to instructions for properly installing the clusters of markers. All the photogrammetric data were checked visually, for example, to ensure accuracy.

The lifting technique specific to the women was not analyzed in depth. To do so would have meant tracking the sequence of knee, hip and back movements in the three groups of subjects. The data collected did not allow for this in this particular project. We are confident, however, that the analyses performed are sufficient to highlight the technique particular to women, especially when lifting boxes from the floor. In-depth analyses should be performed to validate the technique. It could be of interest to consider moments at the knees and hips as well as moments at L5/S1, and to show the relationship between these moments and the strength of the subjects.

### *7.3.3 Generalization of results*

One concern was to allow study participants as much freedom as possible so they would work the way they usually do. Experimental constraints were therefore minimized so as not affect these usual methods. However, we cannot claim that we succeeded completely in meeting this objective for a number of reasons: the subjects were only partially clothed; markers and electrodes were attached to their skin; wires may have interfered with their movement; they could not put their feet on the pallets; cameras were filming them; the work environment was not the same as their workplace; etc. All these factors affected the subjects' technique to a lesser or greater extent, and they may not have behaved as they usually do. We believe that the two experimental work contexts (Session II and Session III), though very specific, placed the handlers in familiar conditions and that the handlers transferred the boxes in the same way that they do at work. State-of-the-art instrumentation was used. The large force platform did not restrict foot positioning and the optoelectronic system was not so cumbersome as to interfere with movements. In other words, handling situations much closer to reality than those of most earlier studies were studied. As a result, we believe, despite certain experimental constraints, that our results can be generalized to all handlers transferring boxes.

## 7.4 Women handlers

In terms of experimental design, neither the dimensions of the experimental setup nor the load were adjusted to the individual in order to exclude the effect of the main variables that differentiate the sexes: size and muscle strength. In effect, in the application of knowledge to the workplace, this study took a pragmatic approach by simulating the only intervention actually possible in the workplace, that is, adjustment of the absolute load of the boxes. More specifically, the men and the women were compared not only with the same absolute load (15 kg) but also with the same relative load (men = 15 kg; women = 10 kg). The 10-kg load was selected because it gave the women a relative load approximately equivalent to that of the men, not on an individual basis but on the basis of a group average (given that the strength of a woman, on average, is two-thirds that of a man: 10/15 kg = 2/3).

The results of this study show that women work differently from male experts, more like male novices. They are less physically strong, but they compensate by keeping the box closer to their bodies and employing a lifting technique that makes use of a powerful method of energy transfer that enables application of greater force and energy conservation. On the other hand, this technique may increase the risk of injury due to continued excessive stretching of passive structures of the vertebral column when lifting boxes from the floor. There may be a conflict between efficiency and safety with this technique. What then should be done, given what we now know? One of the first elements to consider with women handlers (as well as men) is knee bending in the lifting phase. Just because the knees are bent more than 90º as in a squat, it does not necessarily mean that the handler performs a squat lift. One must check if the knee extension that initiates the lift contributes to accentuation of lumbar flexion (trunk inclination) as in a stoop. If so, the trunk flexion must not be so accentuated as to overstretch the passive structures of the spine. It is important to leave the handler a safety margin, even if this means a less efficient lift. The problem only arises when lifting boxes from the floor, at which point lumbar flexion and lumbar loading are at a maximum. This happens frequently, but it is only a fraction of the task of a handler.

One question that deserves consideration is why the women seem to prefer a technique different from that used by experts. If muscle strength is largely responsible, then training alone would be limited as a form of intervention. Plamondon et al. (2012) conclude that raising the height from which the boxes are lifted or reducing box weight are much more effective interventions in terms of reducing lumbar loading than expertise (training) in handling. With training alone (in a work context similar to that studied), the effect on physical exposure, that is, lumbar loading and task duration, would likely be small, with a greater impact on posture. On the other hand, physical exposure of the handlers drops significantly when the load is reduced to 10 kg, but posture does not change much. When the lifting height is raised to hip height, the effect is significant in terms of lumbar loading as well as posture. Thus, when lifting height is raised by the height of a single box (about 32 cm), lumbar flexion angle drops more than 10º (Figure 5-6) and lumbar load decreases as well Figure 5-4). Ideally all three types of intervention would be used to reduce exposure as much as possible.

Another issue that merits consideration is the safety margin for women. Though many women have a physical capacity close to or even superior to that of some men and are thus capable of performing the same physical tasks as men, we cannot conclude that the level of risk is the same for men and the women (Mital et al., 1997). It has been noted that when handling intensity increases (continuous load of more than 22.7 kg), the number of back injuries increases, but male sex and older age are protective factors (Kraus et al., 1997). Given their muscle strength, women definitely have a smaller safety margin than men, but is this important? It all depends on the work situation. Lifting a 40-kg box from the floor leaves very little safety margin for any group of material handlers, and the major factor in carrying out such a task is the worker's muscular strength. However, when it comes to lifting a 15-kg box from the ground, as our results demonstrate, a woman can very well perform this handling task with a smaller safety margin than a man, provided she stays within this safety margin. We must not, therefore, conclude that women are always at greater risk of injury. By raising the height from which the boxes are lifted, the safety margin is increased, for men as well as women. When the load is reduced to 10 kg, and the boxes are lifted from a higher height, box handling conditions are improved for women. In some sense, this is what Snook and Ciriello's psychophysical tables do (1990), as well as the ISO-11228 standard, specifying conditions that should ensure an adequate safety margin. The challenge is to personalize such standards.

Last, Denis et al. (2011) identified eight handling rules, outlined in Appendix H. The results of our study validate several of these rules, which could be useful in training novice handlers. For example, the women hold the boxes closer to their bodies than their male co-workers and they perform the box transfer “in units” of movement. In terms of postural alignment, there is general consensus in the literature: stick to symmetric postures as much as possible and avoid extreme postures. The load/body distance rule (keep the load as close to the body as possible to reduce effort) was extensively applied by the women and the experts. Gender played a role in application of the weight-bearing rule (hold the load in the hands for as little time as possible), with the women holding the 15-kg loads longer than the men. When the load was reduced to 10 kg, however, the results for the women were more like those of the men. There was no difference between the experts and the novices in the application of the transfer rule (appropriate path between lifting and deposit), as anticipated, except in the adjusted values ANCOVA (Table 5-12). The minimal differences between the groups were probably due to the work context, which was not very complex. Last, current data do not allow conclusions to be drawn with respect to the other four rules (load use, body balance, body use and rhythm of movement). Other analyses are to be performed and are necessary if any conclusions are to be drawn about the rules as a whole.

## 7.5 What remains to be done

As with the report of our last study (Plamondon et al., 2010), this report describes essential ergonomic and biomechanical results, as we anticipated from the start that we would not be able to analyze all the data we would be collecting. For example, more in-depth biomechanical and ergonomic analyses are to be performed to confirm that women do indeed have a motor coordination technique that is different from that of men. In addition, the revision of an internal biomechanical model has been completed (Gagnon et al., 2011) and should make it possible to find out more about our handlers’ internal back load and to get a better understanding of the impact on tissue of the differences between men and women. All of which is to say our project will not end with the filing of this report.

# 8. CONCLUSION

The purpose of this research project was to understand how women handlers differ from male handlers in the way they work. The results of physical tests confirm that women handlers are not as strong as male handlers. Our biomechanical and ergonomic results demonstrate that women work differently from male expert handlers, using techniques more like those employed by novice male handers. Back loading (resultant moments at L5/51) was significantly smaller in the women than the men, but when these moments were normalized for trunk weight, the difference disappeared. When lifting boxes from the floor, the women bent their upper bodies more and their knees less and used a very efficient lifting technique that allows application of greater force as well as conservation of energy. On the other hand, this lifting strategy increases the risk of injury because of continuous excessive stretching of the passive structures of the spine. This was only the case, however, when boxes were lifted from the floor, only a fraction of the work performed by a material handler. With the design of our study, we were able to demonstrate that the 15-kg load partially explains the differences observed between men and women, and that these differences diminish when the women handle a 10-kg load. A number of possible interventions are discussed, including increasing box height and reducing box weight, solutions that can significantly decrease the load on the back and increase the handler’s safety margin. Last, more in-depth biomechanical and ergonomic analyses are to be performed to validate the hypothesis that women have a motor pattern different from that of men and that internal tissue load may be affected by this difference.

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# APPENDIX A: MUSCULOSKELETAL HEALTH OF THE 45 SUBJETS

**Table A.1: Musculoskeletal health[4] of men in the past 12 months**

| Musculoskeletal health | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Novices** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | | | L N N | | | | | | |
| 2 | | R N N | R N N | | | | | | Y N N |
| 3 | | | | | | | | Y N N | Y N N |
| 4 | | R N N | | | | Y N N | | Y N N | |
| 5 | | | R N N | R N N | | | | | R N N |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | Y N N |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 10 | | | | | | Y N N | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | | | | | | | | Y N N | |
| 14 | | Y Y Y | | | | | | Y | |
| 15 | | | | | | | | Y | |
| **Experts** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | Y N N | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | | | |
| 4 | | | | Y N N | | | | | |
| 5 | | | | | | | | | |
| 6 | | | | | Y N N | | | | |
| 7 | | | | | | | | | |
| 8 | | | | | | | | | |
| 9 | | R N N | | | | | | | |
| 10 | | | | | | | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | Y N N | | R N N | L N Y | | | | | |
| 14 | | | | | | | | | |
| 15 | | | | | | | | | |

Three questions

**Question 1**: Have you at any time in the past 12 months had trouble (ache, pain or discomfort) in ________?

**Question 2**: Have you at any time during the last 12 months been prevented from doing your normal work because of the trouble?

**Question 3**: Have you had trouble at any time during the last seven days?

**Responses**: Empty box = no to all three questions; first letter = response to Question 1; second letter = response to Question 2; third letter = response to Question 3.

**Codes: Y = Yes; R = Yes, right side; L = Yes, left side; N = No**

4. From the Nordic questionnaire developed by Kuorinka, I., Jonsson, B., Kilbom, A., Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K. Adapted by Lina Forcier, UQAM, Claire Lapointe, IRSST, Sylvie Beaugrand, IRSST, Monique Lortie, UQAM, Ilkka Kuorinka, Peter Buckle, University of Surrey.
For more information about the use of the questionnaire, from planning to dissemination of results, please see guide RG-270 published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), www.irsst.qc.ca.

**Table A.2: Musculoskeletal health[5] of men over their lifetimes**

| Musculoskeletal health | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Novices** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | | Y N N | Y N N | | | Y Y N | | Y N N | Y N N |
| 2 | | Y N N | Y N N | Y N N | Y Y Y | Y Y N | | | Y Y N |
| 3 | | | | | | | | Y N N | Y N N |
| 4 | | Y N N | | | | Y N N | | Y N N | |
| 5 | | | R N N | | | | | | R N N |
| 6 | | | | | | | | | |
| 7 | | | | | | | | | R N N |
| 8 | | | | | | | | | |
| 9 | | | | | | | | | |
| 10 | | | | | | Y N N | | | |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | | | | | | | | R Y N | |
| 14 | | Y N N | | | | | | Y N N | |
| 15 | | | | | | | | Y N N | |
| **Experts** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | Y N N | | | | | | | | |
| 2 | | | | | | | | | |
| 3 | | Y Y N | | | | | | | Y Y N |
| 4 | | | | Y N N | | Y Y N | | | |
| 5 | | Y Y N | | | | | | | |
| 6 | | | | | Y Y N | | | | |
| 7 | Y N N | Y N N | | | | Y Y N | | | |
| 8 | | | | | | | | | |
| 9 | | Y Y N | | | | | | | |
| 10 | Y N N | L Y N | | | | | R Y N | | R Y N |
| 11 | | | | | | | | | |
| 12 | | | | | | | | | |
| 13 | Y Y N | | R N N | L | | | | | |
| 14 | | Y N N | | | | | | | |
| 15 | | | | | | | | | |

<u>Three questions</u>
**Question 1**: Have you ever had ______ trouble (ache, pain or discomfort)?
**Question 2**: Have you ever hurt your ______ in an accident?
**Question 3**: Have you ever had to change jobs or duties because of ______ trouble?
**Responses**: Empty box = no to all three questions; first letter = response to Question 1; second letter = response to Question 2; third letter = response to Question 3.

**Codes: Y = Yes; R = Yes, right side; L = Yes, left side; N = No**

5. From the Nordic questionnaire developed by Kuorinka, I., Jonsson, B., Kilbom, A, Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K. Adapted by Lina Forcier, UQAM, Claire Lapointe, IRSST, Sylvie Beaugrand, IRSST, Monique Lortie, UQAM, Ilkka Kuorinka, Peter Buckle, University of Surrey.
For more information about the use of the questionnaire, from planning to dissemination of results, please see guide RG-270 published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), www.irsst.qc.ca.

**Table A.3: Musculoskeletal health[6] of women in the past 12 months**

| In the past **12 months** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Women** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | | R N N | | | Y N N | | | | |
| 2 | | | | | | | | | |
| 3 | | | | | | | R N N | | |
| 4 | Y N N | | R N N | | | | | | |
| 5 | | | | Y N Y | | Y N N | | | Y N Y |
| 6 | | | | | | Y N N | | | |
| 7 | Y N N | | | | | Y N Y | | | |
| 8 | | | | | | | | | Y N N |
| 9 | Y N N | L N N | | | Y N N | | | Y N Y | |
| 10 | Y N Y | R N Y | | | | | | | |
| 11 | | | | | | | | | Y N N |
| 12 | | | R N Y | | Y N Y | | | | |
| 13 | Y N Y | | R N N | | Y N N | Y N Y | | Y N N | |
| 14 | | | Y N N | | | Y N N | | | |
| 15 | Y Y N | | | | | Y Y N | | | |

Three questions
**Question 1**: Have you at any time in the past 12 months had trouble (ache, pain or discomfort) in _______:
**Question 2**: Have you at any time during the last 12 months been prevented from doing your normal work because of the trouble?
**Question 3**: Have you had trouble at any time during the last seven days?
**Responses**: Empty box = no to all three questions; first letter = response to Question 1; second letter = response to Question 2; third letter = response to Question 3. **Codes: Y = Yes; R = Yes, right side; L = Yes, left side; N = No**

**Table A.4: Musculoskeletal health of women over their lifetimes**

| Lifetime | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Women** | Neck | Shoulders | Elbows | Wrists | Upper back | Low back | Thighs | Knees | Ankles |
| 1 | | Y N N | | Y L N | Y N N | | | | |
| 2 | | | | | | Y Y Y | | | |
| 3 | Y Y N | | Y R N | Y R N | | | Y N N | | |
| 4 | Y N N | Y N N | Y N N | | | | | | |
| 5 | Y N N | | | Y Y N | | Y N N | | | Y Y N |
| 6 | | | | | | Y N N | | | |
| 7 | Y N N | | | | | Y N N | | | |
| 8 | | | Y N N | Y N N | | Y Y Y | | | Y N N |
| 9 | Y N N | Y L N | | | Y Y Y | Y Y N | Y Y Y | Y N N | |
| 10 | Y N N | Y R N | | | | | | | |
| 11 | | Y N Y | | | | | | | Y R N |
| 12 | Y Y Y | Y Y Y | Y N N | | Y Y Y | Y Y Y | | | |
| 13 | Y N N | | Y N N | | Y N N | Y Y Y | | Y N N | Y Y N |
| 14 | | Y L Y | Y L Y | Y L Y | | Y N N | | | |
| 15 | Y N N | | | | | Y N N | | | Y R N |

Three questions
**Question 1**: Have you ever had ______ trouble (ache, pain or discomfort)?
**Question 2**: Have you ever hurt your ______ in an accident?
**Question 3**: Have you ever had to change jobs or duties because of ______ trouble?
**Responses**: Empty box = no to all three questions; first letter = response to Question 1; second letter = response to Question 2; third letter = response to Question 3. **Codes: Y = Yes; R = Yes, right side; L = Yes, left side; N = No**

6. From the Nordic questionnaire developed by Kuorinka, I., Jonsson, B., Kilbom, A, Vinterberg, H., Biering-Sørensen, F., Andersson, G., Jørgensen, K. Adapted by Lina Forcier, UQAM, Claire Lapointe, IRSST, Sylvie Beaugrand, IRSST, Monique Lortie, UQAM, Ilkka Kuorinka, Peter Buckle, University of Surrey.
For more information about the use of the questionnaire, from planning to dissemination of results, please see guide RG-270 published by the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST), www.irsst.qc.ca.

# APPENDIX B: MEASUREMENT SYSTEMS

Several measurement systems were used during the three experimental sessions: two dynamometers, a surface electromyography system and two photogrammetric measuring systems (video and optoelectronic cameras).

Dynamometers: The dynamometers were used to measure the subjects' physical capacity and the foot force exerted during handling tasks. The physical capacity of the back muscles was measured on an apparatus in which the subject was positioned (Figure 3-1) and on which AMTI load cells (model MC3A-6-1000, Watertown, Massachusetts) were used to record the L5/S1 extension moments exerted by the subjects. External foot forces during handling tasks were obtained through an in-house force platform (1.90 m x 1.30 m) mounted on an AMTI 6-axis load cell (model MC3A-6-1000, Watertown, Massachusetts). This type of force platform has been validated.

Surface electromyography: Pairs of preamplified surface electrodes (active electrodes with a gain of 1000 and a bandwidth of 20-450 Hz, manufactured by Delsys, Boston, MA) were positioned on the back and abdominal muscles. The signals were recorded at a minimum frequency of 1024 Hz and digitized by a 12-bit analog/digital data acquisition device (National Instrument DAQ-E).

Photogrammetric systems: Two photogrammetric measuring systems were used to record the 3D coordinates of the markers affixed to the main body segments. The first was made up of infrared LEDs whose signals were captured by four Optotrak columns (Northern Digital Inc., Waterloo, Ontario). The sampling frequency of the Optotrak system was 30 Hz, and the 3D marker reconstruction error was generally less than 1 mm. The advantage of this system is that it requires no manual digitization; however, the wiring connected to each LED makes it unwieldy, and it cannot generate video images. To solve the latter problem, a second system made up of three video cameras was used to verify the Optotrak data, correct missing data and perform an ergonomic analysis of the handling tasks. Synchronization of all measurement systems (video, electromyography and Optotrak) was done by means of a Horita time code generator (model FP-50, Mission Viejo, CA).

# APPENDIX C: DEFINITIONS OF KINETIC AND KINEMATIC VARIABLES

**Table C.1: Definitions of kinetic and kinematic variables**

| Variable | Description |
|---|---|
| Peak resultant moment at L5/S1 (Nm) | Highest value of resultant moment (m) at L5/ S1.<br>Resultant moment = $\sqrt{m_{extension}^2 + m_{lateral\ bending}^2 + m_{twisting}^2}$ |
| Occurrence (%) | Occurrence of resultant moment: negative value = pre-flight; 0 to 50% = flight in lifting phase; 51 to 100% = flight in deposit phase; 100% = post-flight; lifting phase = -200% to 50%; deposit phase = 51% to 200%; flight = 0% to 100%. |
| Lumbar flexion angle (°) | Flexion angle of the lumbar region (°) calculated using the Grood & Suntay sequence (1983). |
| Lumbar flexibility index (%) | Lumbar flexion angle divided by typical peak lumbar flexion in subjects of the same age (based on data from Intolo, 2009). |
| Lumbar lateral bending angle (°) | Lumbar lateral bending angle (°) calculated using the Grood & Suntay sequence (1983). |
| Lumbar torsion angle (°) | Lumbar twisting angle (°) calculated using the Grood & Suntay sequence (1983). |
| Trunk inclination (at T11) from vertical (°) | Angle of flexion of trunk from vertical at T11 (°). |
| Box distance from L5/S1 (m) | Horizontal distance (m) from box to L5/S1. |
| Right knee flexion (°) | Angle of flexion of right knee (°). |
| Left knee flexion (°) | Angle of flexion of left knee (°). |
| Flexion angular velocity (°/s) | Angle of velocity of lumbar region along transverse axis of trunk (°/s). |
| Peak asymmetric moment at L5/S1 (Nm) | Highest value for asymmetric moment (Nm) at L5/ S1.<br>Resultant moment = $\sqrt{m_{lateral\ bending}^2 + m_{twisting}^2}$ |
| Cumulative resultant moment at L5/S1 (Nms) | The sum of the resultant moments at L5/S1 during the flight phase. |

# APPENDIX D: DATA NORMALIZATION

The normalization procedure consists in adjusting a variable according to a standard value. We know that a subject's height and weight have an influence on certain variables. To take this effect into account, we divide the variable in question by the subject's weight or height so that groups can be compared on a common basis. For example, we know that women are generally shorter than men; therefore it can be expected that segments such as arms will also be shorter and that women will hold the box closer than men. To factor in this effect, we divide the box–L5/S1 distance by the subject's height. The unit is no longer in metres but in number of times the subject's height, and we thus obtain a better response to the question of whether women hold the box closer than men. For example, in Table 5-9, the box-L5/S1 distance for women is 0.21 units of height (1 = height) while for novices it is 0.24 units of height.

For moments, normalization consists in dividing the moment at L5/S1 by the moment created by the weight of the trunk when horizontal (Figure D.1). Once normalized, the moment is expressed in units of trunk weight. For example, an L5/S1 resultant moment of 150 Nm is divided by the subject's horizontal trunk moment (100 Nm), yielding a normalized moment of 1.5 times the trunk weight (Figure D.1).

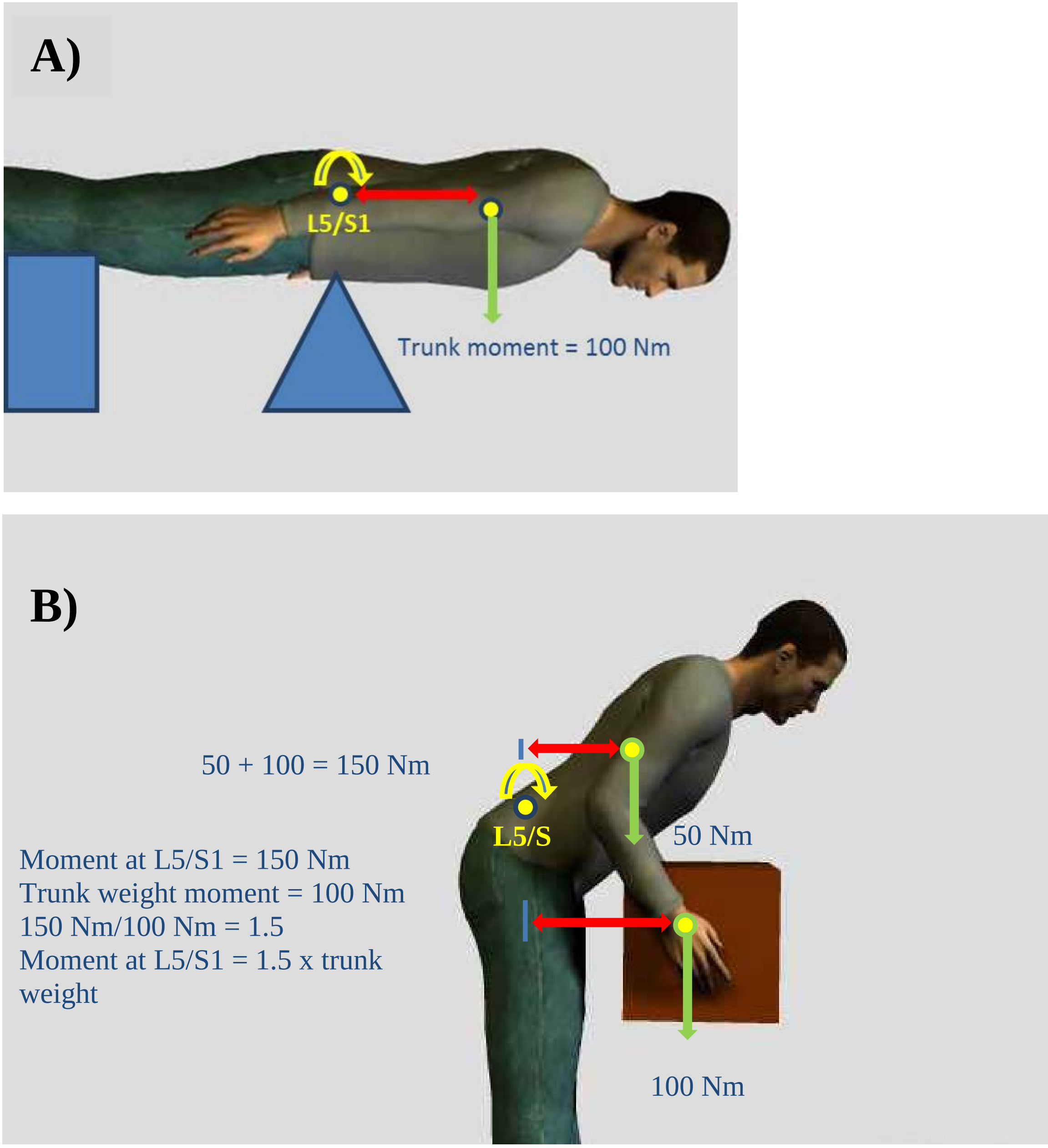



Figure D.1. Illustration of normalization procedure. In this example, the L5/S1 moment exerted by the horizontal trunk weight is 100 Nm (A). Normalization consists in dividing the resultant or asymmetric moment by the moment exerted by the trunk weight: here (B), 150 Nm/100 Nm = 1.5 x trunk weight.

# APPENDIX E: MAXIMUM LUMBAR FLEXIBILITY

**Table E.1: Maximum lumbar flexibility of subjects based on data by Intolo (2009)**

| Subject ♂ | Age | Maximum flexibility | Subject ♀ | Age | Maximum flexibility |
|---|---|---|---|---|---|
| 1 | 43 | 61 | 1 | 31 | 63 |
| 2 | 30 | 67 | 2 | 42 | 73 |
| 3 | 30 | 67 | 3 | 44 | 47 |
| 4 | 37 | 64 | 4 | 52 | 63 |
| 5 | 52 | 57 | 5 | 44 | 43 |
| 6 | 25 | 69 | 6 | 44 | 42 |
| 7 | 34 | 65 | 7 | 39 | 67 |
| 8 | 31 | 66 | 8 | 50 | 49 |
| 9 | 51 | 57 | 9 | 49 | 53 |
| 10 | 27 | 68 | 10 | 51 | 55 |
| 11 | 24 | 69 | 11 | 46 | 68 |
| 12 | 41 | 62 | 12 | 35 | 80 |
| 13 | 44 | 60 | 13 | 39 | 80 |
| 14 | 24 | 69 | 14 | 25 | 69 |
| 15 | 22 | 70 | 15 | 26 | 68 |
| 16 | 42 | 61 | | | |
| 17 | 27 | 68 | | | |
| 18 | 24 | 69 | | | |
| 19 | 20 | 71 | | | |
| 20 | 18 | 72 | | | |
| 21 | 27 | 68 | | | |
| 22 | 24 | 69 | | | |
| 23 | 25 | 69 | | | |
| 24 | 27 | 68 | | | |
| 25 | 20 | 71 | | | |
| 26 | 21 | 71 | | | |
| 27 | 50 | 58 | | | |
| 28 | 51 | 58 | | | |
| 29 | 30 | 67 | | | |
| 30 | 26 | 68 | | | |

# APPENDIX F: FATIGUE TESTS DURING PALLET-TO-PALLET SESSION (SESSION III)

Task difficulty tests were conducted during the pallet-to-pallet session (Session 3) to determine the subjects' level of fatigue. The results of these tests are presented below.

## Measurement techniques

The following measurement techniques were used to assess task difficulty.

**Back muscle fatigue**: Muscle fatigue was assessed by testing sub-maximal contraction of back muscles (longissimus) and hamstrings (semitendinosus) after a series of box transfers. This required electromyographic recordings, for which surface electrodes were positioned bilaterally on the lumbar longissimus at L3 (3 cm lateral) and on the hamstrings halfway between the originating point and the muscle insertion point. Fatigue level was indicated by differences between pre-test, mid-test and post-test EMG signals from the back muscles and hamstrings in terms of amplitude (RMS) and spectral content (median of the frequency range).

**Heart rate**: We used a Polar S810i heart-rate monitor to directly measure the subjects' heart rates and to indirectly assess their physiological load during the box transfer operations.

**Psychophysical fatigue**: This type of measurement does not require any instruments. The Borg CR-10 scale was used to assess perceived muscle and overall fatigue after a series of box transfers. The subject was questioned (after the series of self-paced transfers and again after the series of imposed-pace transfers) about his/her level of fatigue on a scale of 0 to 10, with 0 indicating total absence of fatigue and 10 maximum fatigue. Perceived fatigue in the back and leg muscles was measured, as well as perceived overall fatigue.

## Processing of EMG signals

An 8th-order digital bandpass filter (30-450 Hz) was applied to the EMG signals, mainly to subtract the electrocardiographic signal and remove the ECG. The RMS value and the median of the frequency spectrum of the EMG signal were estimated over a period of three seconds. The median frequency was extracted using the MATLAB Signal Processing Toolbox (Mathworks, Natick, MA).

## Results and discussion

Three fatigue tests were conducted. The Borg CR-10 scores, used to measure perceived muscular and overall fatigue after the two series of box transfers, are presented in Table F.1. The subjects perceived a higher level of fatigue and greater overall and back-specific muscular intensity at the imposed pace than at the self-determined pace. The perceived level did not differ between the experts, novices and women.

Table F.1 also shows that heart rate (HR) did not differ significantly between the three groups ($p > 0.05$), but increased significantly ($p < 0.05$) under the imposed pace of nine lifts/min. However, when the HR was divided by the theoretical maximum HR (220 – age), there was a significant difference between the experts and the novices but not between the men and the women. The interaction on heart rate (Group x Pace) is due to the greater increase in heart rate in the male novices (compared with the male experts and the women) in the imposed-pace compared to the self-paced transfers. The same explanation applies to the interaction on the normalized heart rate. For a 15-kg load, the women had perceived fatigue levels and physiological loads similar to those of the men. Switching to a 10-kg load had the effect of significantly decreasing perceived effort and heart rate in the women, compared with the 15-kg load (Table F.2). Pace was also a significant factor in the perception of effort, but the interaction (Load x Pace: L×P) on overall fatigue meant that pace had virtually the same effect on fatigue with the 10-kg load as with the 15-kg load.

The level of muscle fatigue measured by the EMG varied over time (T0 = pre-test vs. T1 = post-test 1 or T2 = post-test 2; Table F.3). The amplitude of the EMG signal from the longissimus increased with fatigue for all three groups, being significantly higher at the end of the second post-test (T2) and sometimes after the first post-test (T1). Median frequency of the right and left longissimi (under a 15-kg load) decreased significantly in all three groups by the end of the imposed-pace series (T2), but in the novices (right and left longissimus) and the women (right longissimus only) it had already decreased by the end of the self-paced series (T1). There was no significant difference between T1 and T2. For the hamstrings, the effect of fatigue was much less present. There was even an increase in median frequency in the three groups and stabilization of the EMG signal amplitude (non-significant difference). As for the 10-kg load for women, it did not yield any significant difference between the three tests (in green). Thus, women do not seem to tire noticeably under this load.

**Table F.1: Fatigue and effort intensity according to Borg scores (ψ) and heart rate (average with standard deviation in parentheses) in experts, novices and women with a 15-kg load**

| Variable | Self-paced | | | Imposed-pace | | | Group $p$ | Pace $p$ | GxP $p$ |
|---|---|---|---|---|---|---|---|---|---|
| | Experts | Novices | Women | Experts | Novices | Women | | | |
| Overall fatigue (ψ) | 4 (1.7) | 3.9 (1.6) | 3.4 (1.6) | 5.4 (2.1) | 5.1 (2.5) | 4.4 (1.7) | [1]0.45 | **<0.01** | 0.77 |
| Back fatigue (ψ) | 3 (2.2) | 4 (1.8) | 3.0 (2.2) | 5.1 (2.4) | 5.1 (2.7) | 3.8 (2.6) | 0.37 | **<0.01** | 0.07 |
| Overall intensity (ψ) | 3.7 (1.8) | 3.8 (1.9) | 3.5 (1.8) | 4.9 (2.2) | 5 (2.3) | 4.0 (1.6) | 0.55 | **<0.01** | 0.44 |
| Back intensity (ψ) | 3.6 (2.2) | 4.3 (1.7) | 3.2 (2.1) | 5.1 (2.5) | 5.2 (2.5) | 4.0 (2.0) | 0.34 | **<0.01** | 0.24 |
| Heart rate (bpm) | 141 (23) | 126 (27) | 139 (16) | 152 (19) | 148 (20) | 144 (13) | 0.36 | **<0.01** | **<0.01** |
| Normalized HR (%) | 78 (14) | 65 (14) | 78 (9) | 84 (12) | 76 (11) | 80 (8) | **0.02$^{N<E}$** | **<0.01** | **0.01** |

1. Repeated measures ANOVA: Group (Experts, Novices, Women; 15-kg load), Pace (self-determined, imposed). Borg scores were recorded after the self-paced series and again after the imposed-pace series.

**Table F.2: Fatigue and effort intensity according to Borg scores (ψ) and heart rate (average with standard deviation in parentheses) in experts, novices and women with 15- and 10-kg loads**

| Variable | Pace for 15 kg | | Pace for 10 kg | | Box $p$ | Pace $p$ | BxP $p$ |
|---|---|---|---|---|---|---|---|
| | Self-determined | Imposed | Self-determined | Imposed | | | |
| Overall fatigue (ψ) | 3.4 (1.6) | 4.4 (1.7) | 2.9 (1.2) | 3.2 (1.2) | **0.03**[1] 15> 10 | **<0.01** | **<.05** |
| Back fatigue (ψ) | 3.0 (2.2) | 3.8 (2.6) | 2.9 (1.7) | 3.3 (1.5) | 0.40 | **0.02** | 0.23 |
| Overall intensity (ψ) | 3.5 (1.8) | 4.0 (1.6) | 3.0 (1.4) | 3.4 (1.1) | 0.07 | **0.02** | 0.74 |
| Back intensity (ψ) | 3.2 (2.1) | 4.0 (2.0) | 3.2 (1.6) | 3.3 (1.6) | 0.25 | **0.03** | 0.09 |
| Heart rate (bpm) | 139 (16) | 144 (13) | 123 (13) | 127 (13) | **<0.01** 15 > 10 | **0.05** | 0.41 |
| Normalized HR (%) | 78 (9) | 80 (8) | 69 (8) | 71 (8) | **<0.01** 15 > **10** | **0.05** | 0.40 |

1. Repeated measures ANOVA: Loads (15 kg vs. 10 kg), Pace (self-determined, imposed). Borg scores were recorded after the self-paced series and again after the imposed-pace series.

**Table F.3: *p* values for EMG tests in men and women**

| | | Experts 15 kg | | | | Novices 15 kg | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | T0 | T1 | T2 | $p^a$ | T0 | T1 | T2 | $p$ |
| L. long. | Amp. (mV) | 0.096 | 0.115 | 0.126 | **<0.01**$^{0<2}$ | 0.119 | 0.138 | 0.165 | **0.05**$^{0<2}$ |
| | Freq. (Hz) | 85 | 79 | 76 | **<0.01**$^{0>2}$ | 91 | 83 | 82 | **0.01**$^{0>1.2}$ |
| R. long. | Amp. (mV) | 0.092 | 0.109 | 0.113 | **<0.01**$^{0<1.2}$ | 0.143 | 0.154 | 0.177 | **0.01**$^{0<2}$ |
| | Freq. (Hz) | 85 | 81 | 77 | **<0.01**$^{0>2}$ | 94 | 83 | 82 | **<0.01**$^{0>1.2}$ |
| L. hamstring | Amp. (mV) | 0.123 | 0.140 | 0.138 | 0.27 | 0.147 | 0.151 | 0.148 | 0.96 |
| | Freq. (Hz) | 92 | 91 | 94 | 0.16 | 82 | 92 | 96 | **<0.01**$^{0<1.2}$ |
| R. hamstring | Amp. (mV) | 0.121 | 0.138 | 0.132 | 0.13 | 0.112 | 0.120 | 0.169 | 0.08 |
| | Freq. (Hz) | 90 | 94 | 97 | **0.02**$^{0<2}$ | 92 | 96 | 92 | 0.63 |
| | | | | | | | | | |
| | | **Women 15 kg** | | | | **Women 10 kg** | | | |
| | | T0 | T1 | T2 | $P$ | T0 | T1 | T2 | $p$ |
| L. long. | Amp. (mV) | 0.067 | 0.074 | 0.080 | 0.28 | 0.080 | 0.087 | 0.089 | 0.27 |
| | Freq. (Hz) | 74 | 71 | 68 | **0.04**$^{0>2}$ | 72 | 71 | 69 | 0.19 |
| R. long. | Amp. (mV) | 0.075 | 0.098 | 0.101 | **<0.01**$^{0<1.2}$ | 0.089 | 0.091 | 0.098 | 0.18 |
| | Freq. (Hz) | 76 | 70 | 71 | **0.01**$^{0>1.2}$ | 72 | 72 | 70 | 0.43 |
| L. hamstring | Amp. (mV) | 0.304 | 0.367 | 0.307 | 0.31 | 0.215 | 0.320 | 0.297 | 0.35 |
| | Freq. (Hz) | 96 | 104 | 104 | **0.01**$^{0>1.2}$ | 98 | 107 | 103 | 0.13 |
| R. hamstring | Amp. (mV) | 0.097 | 0.109 | 0.100 | 0.39 | 0.078 | 0.079 | 0.086 | 0.47 |
| | Freq. (Hz) | 103 | 106 | 110 | 0.23 | 105 | 109 | 107 | 0.66 |

a. Repeated measures ANOVA: Test variable (T0 = Pre-test; T1= Post-test 1; T2= Post-test 2).

The women did not seem to experience more muscular fatigue than the men. The handlers accumulated back muscle fatigue throughout the box transfer operations. For the women, switching to a 10-kg load significantly reduced perceived effort and heart rate compared with the 15-kg load. Women thus do not seem to tire noticeably under the 10-kg load.

It should be emphasized that the women had only one round trip to make with the 15-kg boxes at the imposed pace; if they had had to make the same number of trips as the men (3), they would probably have been much more tired. We had two reasons for choosing this protocol: (1) we feared that the women would be too much at risk of injury at the imposed paced, and so we acted out of caution; and (2) we wanted to measure the effect of reducing the load to 10 kg for women without increasing the total number of transfers (5 in all). Based on the fatigue test results, it is certain that the women could have continued working at the imposed pace beyond the first series of 15-kg box transfers. In terms of the effects of fatigue on work methods, it does not seem to have affected any group in particular. A few significant interactions (Group x Pace) were noted but were not of any magnitude.

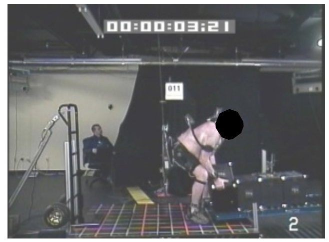
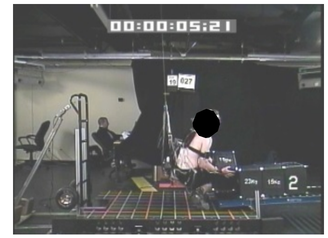
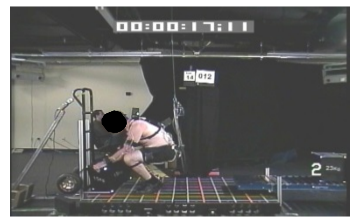
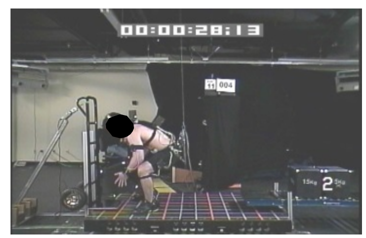
# APPENDIX G: OBSERVATION CRITERIA

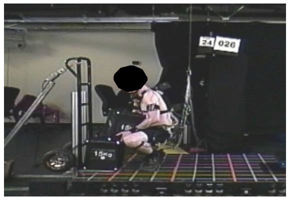
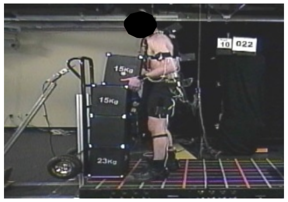
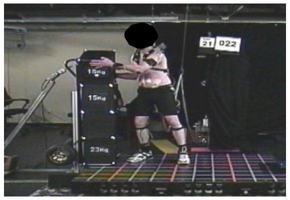
| Variable | Category | Observation criteria |
|---|---|---|
| Continuity | In units | The box is handled in units, i.e., not continuously. There are stops, hesitations and changes in direction: for example, the box is set down and lifted back up. The handler may work in units, stopping between the lift and the flight and again between the flight and the deposit. |

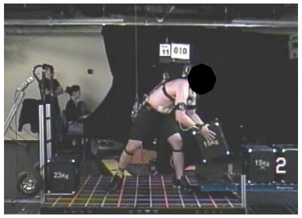
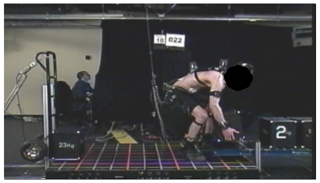
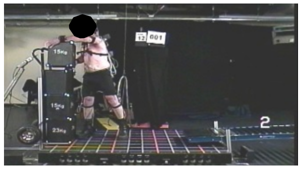
| | | |
|---|---|---|
| | Continuous with lifting unit | Movement is segmented during the lift phase. Typically, the handler faces the load during the lift but is in a more open position for the deposit phase. |

| | | |
|---|---|---|
| | Continuous with deposit unit | Movement is segmented during the deposit phase. Typically, the handler faces the load during the deposit but is in a more open position for the lifting phase. |


| | | |
|---|---|---|
| | Continuous | The handling is done in a single continuous movement from lift to deposit. |

| Variable | Category | Observation criteria |
|---|---|---|
| Load tilting | Tilted | Load completely tilted onto one edge to obtain the highest height for lifting from the picking surface. The handler rolls or tilts the load to change the lifting height.     |
| | Partially tilted | Load tilted to some degree on the picking surface. The handler tilts the load but could have obtained a higher lifting height with additional manoeuvring.   |
| | Not tilted | Load is not raised above the picking surface. It is lifted from a flat position.   |

| Variable | Category | Observation criteria |
|---|---|---|
| Closeness to the body | Maximum | The load is brought as close as possible to the edge of the pallet or conveyor and is lifted only when the back edge is at the edge of the pallet. The handler slides, pivots or tilts the box to move it to the edge, maintaining box contact with the picking surface as long as possible. With the trolley and when lifting from the conveyor, the box is considered to be in takeoff position when on the conveyor platform.  |
| | Moderate | The load is at some distance from the edge of the pallet or conveyor. The box is lifted before its back edge reaches the edge of the picking surface. The handler slides or tilts the box, but could have maintained contact with the picking surface for longer with additional manoeuvring.  |
| | Nil | The load is picked up from its original position with no manoeuvring to bring it closer to the edge.  |

| Variable | Category | Observation criteria |
|---|---|---|
| Post-deposit adjustment | Yes | The handler makes adjustments after depositing the box by sliding or tilting it to change the contact with the deposit surface, etc. |
| | No | The handler makes no adjustments after depositing the box: the position in which the box is set down is the final position. Touching the box to stabilize it does not constitute a post-deposit adjustment. By convention, if the box is pushed along the conveyor rollers, that does not constitute a post-deposit adjustment; in this case, the zone under consideration is before the conveyor. |
| Speed of deposit | Fastest | The handler deposits the load as quickly as possible: as soon as the deposit surface is encountered. It all happens very quickly. |
| | Moderate | The handler does not deposit the load as soon as the surface is encountered; he/she could have deposited it sooner. |
| Tilting on deposit | Tilted | The load is tilted on the deposit surface. The first contact between the box and the surface may be one edge, one corner or the edge of a side.  |
| | Partially tilted | The load is tilted to some degree on the deposit surface. The first contact between the box and the surface may be half of one side.  |
| | Not tilted | The load is deposited flat on the deposit surface, on one of its rectangular or square sides.  |

# APPENDIX H: THE EIGHT RULES OF MANUAL HANDLING

**Table H.1: The eight rules of manual handling (IRSST report R-690, Denis et al., 2011[7])**

| | Principle | Note | Description |
|---|---|---|---|
| 1 | Postural alignment | The human spine is designed and adapted for working in alignment. | Refers to the best spinal postures to adopt during effort. It is important to respect the natural curvature of the spine, without excessive forward bending, and to work symmetrically. |
| 2 | Load/body distance | Greater distance from the load means greater effort. | The lower back is already subjected to considerable effort to support the upper body; now a load is added, and the farther it is from the person holding it, the greater its weight. The load should therefore be held as close to the body as possible. |
| 3 | Weight bearing | The less time is spent holding the load, the less the effort. | The phase in which the load is entirely supported is the most demanding: this should be reduced to a minimum. |
| 4 | Load use | The load can be used to work in one's favour | It is preferable to work WITH the load rather than against it, using its position in space or its inherent properties. |
| 5 | Body balance | Being in balance and ready to react to avoid unpleasant surprises | The addition of an external load influences balance, as does the floor surface. Having to recover from loss of balance or from an unforeseen event requires sudden and brusque movements, which are unnecessary and harmful and should be avoided. |
| 6 | Body use | The body can be used to reduce effort. | The body can be used in handling activities. Body use consists first and foremost in the use of the lower limbs, which do most of the work. |
| 7 | Transfer from pickup to delivery | The handler must choose how to cover the space between pickup and delivery. | The route selected for going from pickup to delivery has a major influence on how long the load has to be supported. The most appropriate form of transfer must be selected. |
| 8 | Rhythm of movement | Pattern and quality of movement. | Speed and fluidity have an impact on back stress and on how long the load must be supported. The handler must know how to choose the appropriate rhythm and avoid jerky movements. |

7. Denis, D., Lortie, M., St-Vincent, M., Gonella, M., Plamondon, A., Delisle, A., Tardif, J. (2011) Participatory Training in Manual Handling. IRSST report R-690, p.34.