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Baggage handling in an airplane cargo hold: An ergonomic intervention study

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Abstract

Incidence rates of lost time back and shoulder injuries in the airline industry are some of the highest in all of private industry. Commonly, risk factors associated with such injuries include overexertion, repetitive lifting, and awkward postures. These factors are found in combination in the airline baggage handler job. Twelve male subjects performed a simulated baggage handling task in a kneeling posture under a low ceiling, to test the effects on spinal loading, muscle activity, and trunk motion of (1) providing baggage weight information on the routing tag, and (2) an alternative method for handling and stowing bags. Providing weight information did not alter the biomechanical characteristics of the handling exertions in these subjects. However, it was shown to reduce cumulative spinal loading if used to organize stowing of baggage. The alternative stowing method, tipping bags and storing them on their short sides (like books on a shelf), was found to reduce spinal loads and trunk muscle activity.

Relevance to industry

Airline baggage handler injuries cost millions of dollars, annually. Two low-cost administrative means of changing their working conditions were explored, and showed promise, in terms of reducing biomechanical loads on the baggage handlers when performing some of their most strenuous activities.
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Keywords: Airline baggage handler; Manual materials handling; Kneeling; Spinal load; Intervention study; Administrative control

1. Introduction

The airline industry in the US has some of the highest rates of work-related lost time injuries in all of private industry. The overall incidence rate is 3.5 times the rate for private industry as a whole; rates of back and shoulder injuries are four and five times the respective rates for private industry as a whole. A comparison of 2002 US Bureau of Labor Statistics (BLS) incidence rates in various sectors of private industry in the USA is provided in Table 1 (BLS, 2002). "Air transportation, scheduled" (airline passenger service) had the second highest rate of lost time back injuries, among the hundreds of industries listed by the BLS. The incidence rate of back pain injury for "air transportation, scheduled" exceeded that of coal mining and nursing and personal care facilities, and almost all other industries for which the BLS maintains statistics.

Musculoskeletal back pain and disorder has been linked to work involving lifting and forceful movements (Bernard, 1997). Shoulder musculoskeletal disorders (MSDs) have been associated with work postures and repetitive work (Bernard, 1997), and more specifically with lifting with one or two hands (10 kg), lifting at or above shoulder level (9 kg), and pushing/pulling (32 kg); working with hands above shoulder and monotonous work, and any other body part pain (Harkness et al., 2003).

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Table 1
2002 BLS lost time work injury incidence rates, per 10,000 full time employees, for various industry sectors and some specific industries (BLS, 2002)

	Overall (R5)	Event/exposure: overexertion (any body part) (R8)		Nature of injury: back pain, hurt back only (R5)	Part of body affected (any event) (R6)	
		Total	Lifting		Back	Shoulder
Private industry	162.6	43.1	23.6	5.3	39.1	9.5
Agricultural production	217.9	33.7	17.3	9.7	40.5	13.6
Mining	198.8	53.6	19.8	1.9	43.3	10.0
Coal mining	463.2	156.3	57.7	6.6	116.2	22.3
Construction	276.8	57.2	30.3	9.3	58.6	13.3
Manufacturing	174.5	42.9	22.2	3.8	34.7	11.6
Services	133.8	41.2	20.8	0.8	37.2	7.7
Health services: nursing and personal care facilities	411.3	203.5	91.2	25.9	152.5	31.3
Transportation and public utilities	270.6	74.2	37.3	10.3	68.4	19.9
Trucking terminal facilities	515.4	225.2	119.3	—	177.3[a]	63.0
Transportation by air	520.4	200.4	107.9	33.9	142.8	41.0
Air transportation, scheduled	**576.9**	**227.6**	**122.5**	**39.4**	**161.6**[b]	**47.7**

Specific BLS reference (R) tables are noted in parentheses in each column heading.
Bold signifies the industry subgroup in which airline baggage handling job is included.
[a] Industry with highest rate of injuries to backs.
[b] Industry with second highest rate of injuries to backs.

One airline industry job that requires repetitive manual handling of heavy materials is that of airline baggage handler. Dell's surveys of airline safety professionals and baggage handlers revealed that one in 12 baggage handlers suffers a back injury each year (Dell, 1997, 1998). On average, in the time period 1992–1994, baggage handler back injuries cost each of the surveyed companies $1.25 million annually. Both sampled groups identified working inside narrow-body aircraft as the top work location likely to cause back injuries. The top two tasks identified by both groups as most likely to cause injury were "pushing baggage from the doorway into the baggage compartment of narrow body aircraft" and "stacking baggage inside the baggage compartment of narrow body aircraft".

Narrow-body aircraft include airplanes such as the Boeing B737 and Fokker F100. Ceiling height for the Boeing 737 cargo hold is 112 cm, which forces baggage handlers to work in squat, stooped, kneeling, or seated postures and often handle luggage at or above shoulder level. On average, a piece of luggage weighs 15 kg (de Looze et al., 2001); however, baggage handlers are typically required to handle bags weighing more than 32 kg (the notional industry weight limit) (Dell, 1997). This load exceeds the National Institute for Occupational Safety and Health (NIOSH) lifting equation limit for working in *optimum* working postures and conditions (Waters et al., 1993).

Stålhammara et al. (1986) performed a laboratory simulation of baggage handling in a DC-9 (100 cm ceiling height) to study effects of different working postures. Participants were professional aircraft loaders. Bags weighed 9–19 kg. Based on their biomechanical assessment, no one posture was better or worse across all of their measures. There was somewhat of a tradeoff between muscle activities, in that postures with higher erector spinae activity tended to have somewhat lower trapezius activity and vice versa. Additionally, luggage-handling times were significantly shorter (by 10%) when kneeling than when sitting or squatting.

When adverse work conditions exist, engineering and/or administrative means of changing the conditions should be explored. One engineering solution that is being used in over 2500 narrow-body aircraft at this point is the Sliding Carpet System (Telair). The system still requires manual handling and stacking of baggage, but it eliminates much of the manual movement of baggage along the length of the plane. Johansen (1995), cited in Dell (1997), reported reductions in sick rates, damage to luggage and luggage compartment lining, and numbers of baggage handlers required to load a plane, as well as $2 million in savings in the first 3 years of operation of 17 B737s with the systems. The baggage handlers surveyed by Dell were also favorably inclined toward "in-plane" baggage systems (Dell, 1998).

The baggage handlers also identified a number of administrative solutions that might be useful. At the top of the list was adding warning tags to heavy bags and improving baggage handling training. Dell (1997) also examined the option of enforcing the weight limit, but unless this was adopted by all countries and airlines simultaneously, those that adopted the rule would be at a commercial disadvantage. Currently, luggage is not routinely weighed, so bags exceeding 32 kg are only tagged if they are spotted by check-in personnel. Lighter bags may also be problematic if their weight is disproportional to their size. A study by Butler et al. (1993) showed spinal moments are elevated for unexpectedly small loads.

The purpose of the current study was to evaluate two administrative interventions for their capacity to reduce some of the risk factors to which baggage handlers are exposed. The interventions were based on consideration of worker biomechanics and acceptance, as well as cost to employers. Both interventions could be used in conjunction with a Sliding Carpet System.

The first intervention is the addition of weight information on the existing routing tag of all luggages. This would ensure that all heavy bags are so identified, and would help workers to avoid unexpected loading situations when a bag weighs more or less than anticipated. The second intervention is an alternative to the current methods of stowing bags. Some carriers now lay bags flat and stack them into several layers, from floor to ceiling of the cargo hold, while others place bags on their long sides in fewer layers. The proposed alternative stowing method requires bags to be stored upright on their short sides, in order to further reduce the number of layers (and consequently the number of lifts a baggage handler must perform). This strategy could be implemented with minimal training required for the workers, and at minimal cost to airlines. Fig. 1 shows both stowing methods. A key element of the new storage method is that most bags are slid into place and then tipped upright, as opposed to being lifted into place. These interventions are intended to reduce the forces exerted by the back and shoulder muscles in baggage handling scenarios, and reduce the amount of the spinal loading to which baggage handlers are exposed. The following two hypotheses were tested:

1. Providing categorical information on bag weight will significantly reduce muscle activity and spinal loading, when compared to the current condition of providing no weight information.
2. Tipping bags upright will significantly reduce muscle activity and spinal loading, when compared to stacking horizontal bags.

2. Methods

2.1. Subjects

Twelve healthy male college students with no prior history of back, knee, or shoulder problems volunteered to participate in the study. Males were chosen, because currently the vast majority of baggage handlers are men. None of the participants had professional manual

Table 2
Anthropometric data ranges of participants ($n = 12$)

Variable	Units	Mean	SD	Min	Max
Age	Years	24.6	3.2	19.0	30.0
Stature	cm	180.8	6.9	170.5	195.4
Weight	kg	74.7	10.0	54.4	93.0
Body mass index (BMI)	—	22.9	2.5	18.8	26.9
Trunk breadth at xyphoid	cm	30.0	2.5	26.4	35.1
Trunk depth at xyphoid	cm	21.5	2.4	17.4	25.1
Trunk breadth at pelvis	cm	27.6	1.8	24.4	31.4
Trunk depth at pelvis	cm	19.4	1.4	16.9	21.2

Stacked horizontal bags.

Stow bags tipped upright

Fig. 1. (a) Current method employed by baggage handlers and (b) tipping intervention.

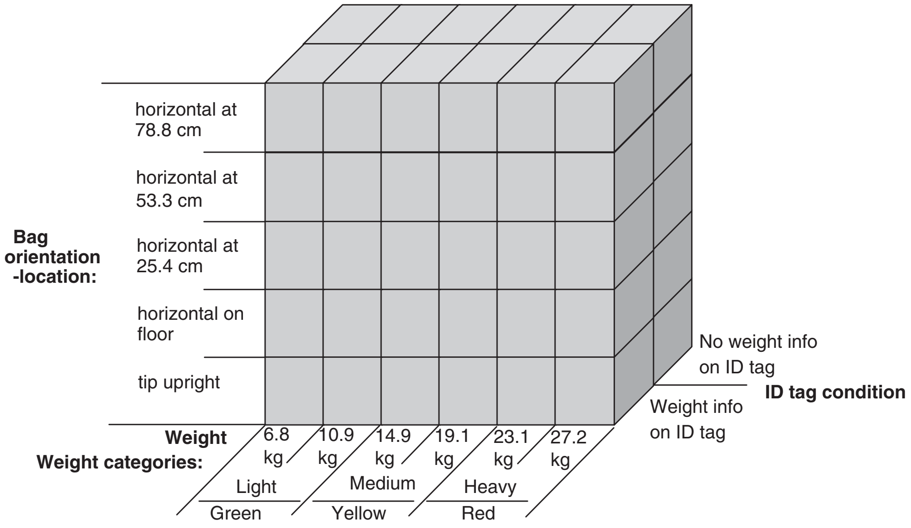


Fig. 2. Schematic layout of experimental design. Each participant performed 60 lifts, 30 with bags marked with a weight class code on the routing tag and 30 bags without. Bag weight (six levels) was fully crossed with bag orientation–location (five levels), within each ID tag condition.

materials handling experience. Participant anthropometrics are summarized in Table 2.

The number of subjects was based on the variability associated with spinal compression estimates. A power calculation indicated that 11 subjects would result in a statistical power of about 0.99 with an $\alpha = 0.05$ for the treatment combinations used in this study.

2.2. Experimental design

Effects of two administrative interventions were examined. Both were hypothesized to reduce muscle activity and spinal loading during simulated in-plane baggage handling. The experimental design is depicted in Fig. 2.

2.2.1. Task

Subjects performed a task that simulated stowing luggage within a Boeing 737 baggage compartment. The height of the ceiling was 1.07 m above the floor. Subjects knelt on two knees to perform the task. Six identical suitcases were used, each containing a different amount of weight. Weights were located in the same space in each bag, so the center of gravity was in the same place in all bags. Bags measured $45 \times 25.4 \times 66\,\text{cm}^3$ ($L \times W \times H$), had two wheels, and an extendable handle that was retracted for the experiment. Bag order was randomized, with regards to weight and storage orientation–location (O–L). The experiment was conducted in two blocks of 30 lifts. Blocks were based on weight ID tag condition. Half the subjects experienced the *with weight class on ID tag* condition first, and half experienced the *without weight class on ID tag* condition first. To offset fatigue, short breaks were provided after every fifth lift, and a longer break was provided between experimental blocks. Lift rate was paced at one bag every 6 s. Bags that were stowed horizontally were slid into place at floor level and then lifted to the appropriate predetermined storage height. Bags that were to be stowed upright, when first received, were angled up to utilize their wheels, rolled into place and then tipped vertically upright into their storage location.

2.2.2. Independent variables

In the experimental trials, the independent variables were bag weight, ID tag condition, and bag O–L (Fig. 2). Weights represented almost the full range of bag weights handled by most airlines before additional fees are imposed. The top weight in the study was set so as not to pose undue risk to subjects. Weights were divided into three weight categories, each compromised of two weights. Information on weight class ID was provided on the existing routing tag during half of the lifts, in the form of text (“light”, “medium”, or “heavy”) and color (green, yellow, or red, respectively). Tags were devised based on previous research (Braun et al., 1995), which described the use of bold text and color to draw the attention of users and elicit behavioral changes in users. The four locations (0, 25.4, 53.3, and 78.7 cm) were chosen to represent heights at which luggage of the size used in this study could be stacked within a Boeing 737 cargo hold.

2.2.3. Dependent variables

Dependent variables included trunk and shoulder muscle activity, spinal loading (compression and shear), and trunk kinematics. Electromyographic (EMG) data were collected from seven bilateral muscle pairs: latissimus dorsi (LAT-R and -L), erector spinae (ERS-R and -L), internal oblique (IOB-R and -L), external oblique (EXO-R and -L), rectus abdominus (RAB-R and -L), anterior deltoid (ADL-R and -L), and trapezius (TRP-R and -L). The dependent variables examined in the statistical analyses were the peak normalized EMG activity for each muscle.

A whole-body free-dynamic model that utilizes EMG data as input was used to determine spine loading. Peak compression, anterior–posterior (AP) shear, and lateral shear were determined for each lift. Peak trunk kinematic variables were derived for each lift, based on continuous collection of trunk posture measurements recorded with a lumbar motion monitor (LMM) (Chattexc Corp, Chattanooga, TN). Trunk position, velocity, and acceleration were derived in each plane (sagittal, frontal (lateral), and transverse (twist)).

2.3. Apparatus

2.3.1. EMG monitoring

Surface EMG data were collected from bipolar surface electrodes over the aforementioned muscle pairs. Descriptions of trunk electrode locations can be found in Mirka and Marras (1993). Electrode locations for the trapezius muscle were based on Jensen et al. (1993) and the anterior deltoid electrodes were positioned per Cram et al. (1998) and Sommerich et al. (2000). EMG signals were bandpass filtered between 30 and 1000 Hz, with a notch filter at 60 Hz, and then integrated over a 20 ms window. Data were normalized to maximum contraction values. Prior to performing the baggage handling tasks, static maximum voluntary contractions (MVCs) were performed in six directions (trunk flexion, extension, right lateral, left lateral, right twist, and left twist) while standing in a structure that immobilized the pelvis and lower extremities. Standing MVCs were collected even though the handling task was performed in a kneeling posture, because peak trunk muscle activity has been shown to be equivalent in standing and kneeling postures (Gallagher, 1997). The MVC for the shoulder was collected based on the method of Cram et al. (1998). However, as this luggage-handling task was relatively strenuous, activity from some of the muscles exceeded the static MVCs. Therefore, maximum values were taken from the experimental task data files and used for normalization when necessary (adjusted MVC).

2.3.2. Lumbar motion monitor

An LMM (Marras et al., 1992) was used to obtain the trunk kinematics. These data were also used in the EMG-assisted model, in order to estimate instantaneous trunk muscle length, as well as the geometric relationship between the thorax and the pelvis throughout each exertion.

2.3.3. Force plate

Each subject knelt on a force plate during the lifting tasks. A proprietary system (Fathallah et al., 1997) interfaced with the force plate in order to determine the moment of the torso about the L5/S1 disk throughout each exertion. The force plate was modified by adding a 1.25 cm thick wooden plate, which extended beyond the back edge of the force plate. This allowed subjects to kneel and still be fully supported by the force plate.

All data channels were monitored simultaneously using proprietary software, a National Instruments PCI-6031 E A/D board, and a 2 GHz Pentium IV computer. Muscles were sampled at 1000 Hz and the other data were sampled at 100 Hz.

2.4. EMG-assisted biomechanical model

An EMG-assisted biomechanical model employed the EMG, kinetic, and kinematic data as input to compute the dynamic loads on the spine (Marras and Granata, 1997). The model incorporated the normalized muscle activities, dynamic trunk motion, and external loads to determine the contractile forces of the 10 trunk muscles. Spinal compression, lateral shear, and AP shear forces were computed from the vector sums of the muscle forces, providing three-dimensional dynamic spinal loads for each lifting exertion. The data collection methods, biomechanical model structure, and validation were published previously (Marras and Granata, 1997).

In order to adapt the model for the restricted kneeling posture used in this research, a number of modifications were applied. As previously mentioned, subject muscle MVC values were replaced with maximum values observed during the experimental conditions, where experimental maximums exceeded recorded MVCs. In addition, model muscle gain was calculated using the average of four sagittal lifts performed while the subject knelt without the low ceiling overhead. (Model muscle gain is the value that affords conversion of normalized EMG to muscle force estimates, and is a function of muscle length, velocity, cross-sectional area, and strength per unit of area.) In order to keep the muscle force contribution within the active portion of the length–strength relationship, in the model muscle length was not allowed to exceed 160% of resting muscle length (Elftman, 1966; Kroemer, 1999; Kroemer et al., 1997, 1990).

2.5. Statistical analysis

2.5.1. Hypothesis #1

Providing categorical information on bag weight will significantly reduce muscle activity and spinal loading, when compared to the current condition of providing no weight information.

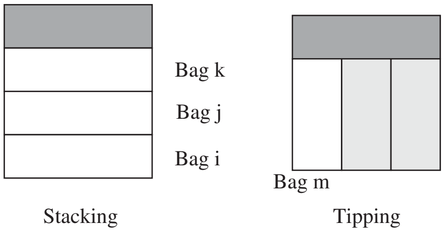
Effectiveness of providing weight class information was evaluated in two ways. Evaluation 1: a standard ANOVA was performed. The unit of analysis was a single exertion, and each exertion was included as a separate entry in the statistical analysis. The effect of providing weight class information was assessed on the peak values of the normalized muscle activity, spine kinematics, and spinal loading. The independent variables included in the models were subject (a blocking factor), bag weight, bag weight class, and bag O–L.

Evaluation 2: Baggage stacking strategies that utilized (or did not utilize) the weight class information were assessed for their effect on cumulative spinal loading. A subset of the data was used to perform this analysis: data from the trials in which weight class information was

Table 3
Description of sequencing/bag placement scenarios

Sequencing scenario	No. combinations	Description
(1) Randomized scenario	81	All combinations of three weights and four height levels
(2) Conservative scenario	15	All combinations of equal or lesser weight on top
(3) Optimistic scenario 1	12	All combinations with "heavy" weight on at least one of bottom two levels
(4) Optimistic scenario 2	9	All combinations with "heavy" weight on bottom level only

provided and in which the bags were stowed horizontally (Fig. 2). The goal was to compare the effect of stacking horizontal bags in a random order to stacking them based upon strategies in which the heavier bags were placed in the lower locations. Cumulative spinal loads, defined as the sum of four maximum spinal loads (one at each height), were compared across four different stacking scenarios: (1) randomized scenario; (2) conservative scenario; (3) optimistic scenario 1; and (4) optimistic scenario 2. Scenarios are described in Table 3. For comparison purposes, averages of all cumulative spinal load combinations within scenarios 2, 3, and 4 were each contrasted with the average of all cumulative spinal load combinations within the randomized scenario.



Maximum value calculations

Stacking : [Max (Bag i) + Max (Bag j) + Max (Bag k)]/3 Eqn. 1

Tipping : Max(Bag m) Eqn. 2

Fig. 3. Depiction of baggage handling scenarios and calculations of dependent variables. The darkened fourth bag on top of each stack is common to each, so it was excluded from this part of the analysis.

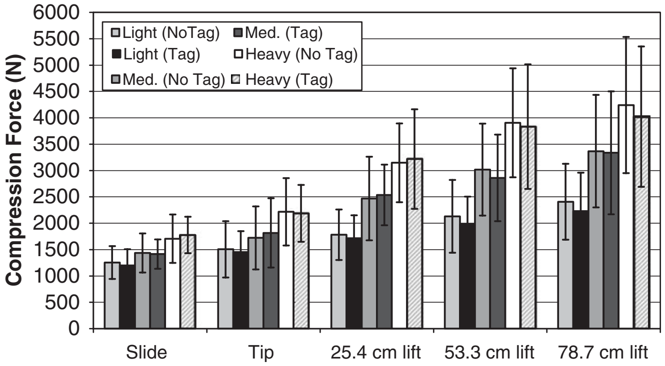


Fig. 4. Compression as a function of trial condition.

2.5.2. Hypothesis #2

Tipping bags upright will significantly reduce muscle activity and spinal loading, when compared to stacking horizontal bags.

A subset of the data was used to test this hypothesis: data from the trials for which weight class ID information was not provided. The unit of analysis was a set of three bags of equal weight, either stacked horizontally as a single three-row column or tipped upright as a single three-column row (see Fig. 3). For the stacking method, the maximum values of the dependent variables were calculated as the average of the maximums for each of the three lifts (Fig. 3, Eq. (1)). By contrast, for the tipping method, the analysis was based on data from tipping one bag. The maximum values of the dependent variables were taken to be the maximum for the one tip of interest (Fig. 3, Eq. (2)). The independent variables were subject (a blocking factor), stowing method (tip vs. stack), and baggage weight.

Diagnostics were performed across all data to ensure statistical model assumptions were not violated. Natural log transformations were performed on spinal load data in order to improve model validity. Once significance was determined, the data were transformed back into original form for means comparison.

3. Results

3.1. Evaluation of weight class ID

3.1.1. Hypothesis 1, evaluation 1

Spinal loads as a function of weight class ID (on tag vs. not on tag), baggage weight class, and bag O–L are presented in Figs. 4–6. Overall, there were no significant differences in spine loads attributable to baggage weight class ID tags. There were no interaction effects between the tags and the actual bag weight or the bag O–L that affected spine loads or trunk kinematics ($p > 0.05$). Overall, the use of weight class ID did not have a significant effect on normalized EMG of 12 of the 14 measured muscles ($p > 0.05$). Only a few scattered effects were observed. With such small effects on so few measures and no effects on the majority of the measures taken, the hypothesis that presence of weight class ID tag alone would significantly affect trunk biomechanics and resulting spinal loads was not supported in this study.

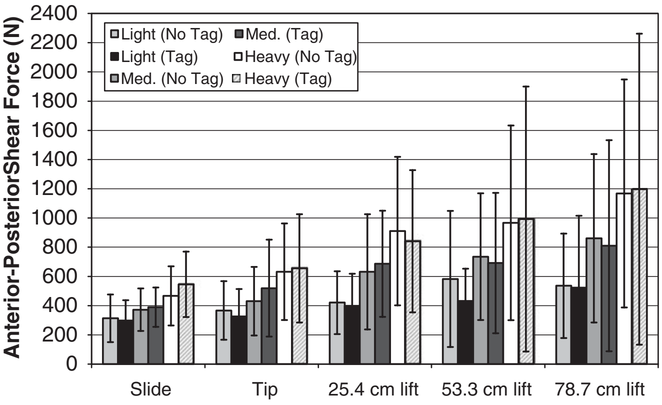


Fig. 5. Anterior–posterior (AP) shear as a function of trial condition.

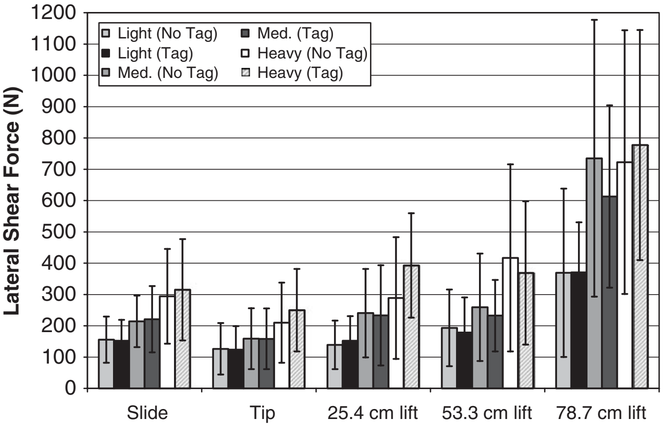


Fig. 6. Lateral shear as a function of trial condition.

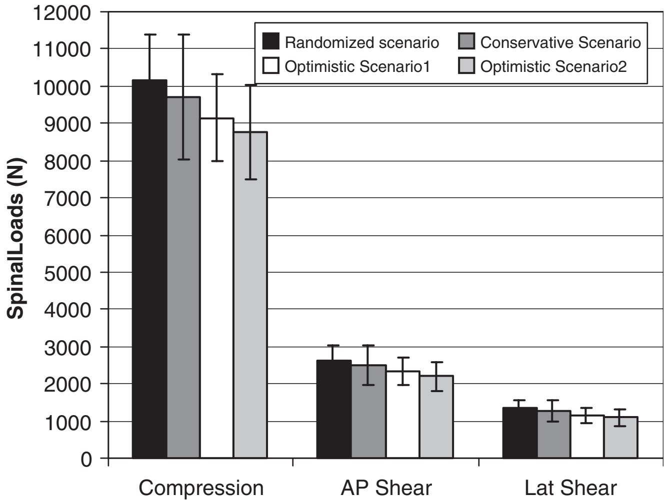


Fig. 7. Cumulative spinal loads by stacking scenario.

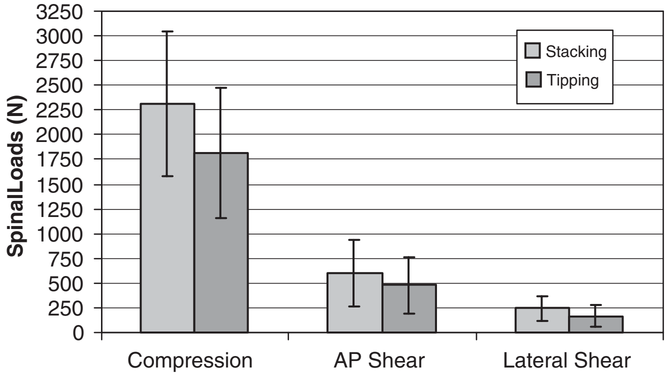


Fig. 8. Spinal loads as a function of stowing method.

3.1.2. Hypothesis 1, evaluation 2

The evaluation of the four bag stacking scenarios showed that alternatives to random sequencing offer the potential of reduced cumulative spinal loading if adopted. Fig. 7 illustrates that if weight class ID were used to inform the conservative stacking scenario, average reductions of 423 N (4.2%) of cumulative compression, 128 N (4.9%) of cumulative AP shear, and 79 N (5.9%) of cumulative lateral shear over four lifts would be expected when compared to the randomized sequence. Likewise, the first optimistic scenario resulted in an average reduction of 1005 N (9.9%), 307 N (11.7%), and 173 N (13.0%) in cumulative compression, AP shear, and lateral shear, respectively. The second and most favorable optimistic stacking scenario resulted in an average reduction of 1369 N (13.5%), 424 N (16.2%), 234 N (17.5%) in cumulative compression, AP shear, and lateral shear exposures, respectively, relative to the randomized stacking of sequenced baggage.

3.2. Evaluation of baggage stowing method (hypothesis 2)

The tipping method significantly lowered spinal loads when compared with the standard stacking method (Fig. 8). Peak compression, AP shear, and lateral shear values for tipping averaged over all subjects and baggage weights resulted in reductions of 21.4% (494 N), 20.4% (122 N), and 32.4% (79 N), respectively, compared to stacking. There was no interaction with baggage weight, showing that the intervention was essentially equally effective across the bag weights tested.

Fig. 9 illustrates the differences in trunk kinematics between stowing methods averaged across all subjects and weights. Only sagittal position, twist position, lateral velocity, and lateral acceleration were not statistically significant. Sagittal velocity and acceleration resulted in reductions of 2.9°/s (14.2%) and 12.2°/s^2 (17.6%), respectively, with tipping as compared to stacking. However, tipping increased lateral position, twist velocity, and twist acceleration by 2.2° (19.6%), 3.6°/s (12.7%), and 10.8°/s^2 (14.7%), respectively. There was no interaction with baggage weight. Stowing method and baggage weight interaction was not significant for the kinematic data ($p > 0.05$).

Significant changes were observed in the EMG data as a function of stowing method. Figs. 10 and 11 illustrate

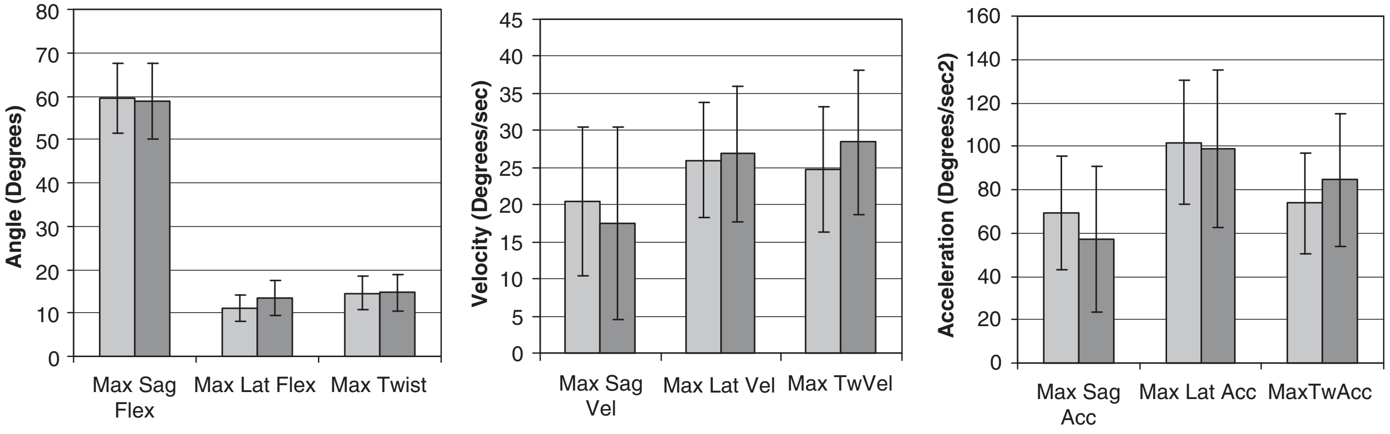


Fig. 9. Maximum kinematics as a function of stowing method (stacking on left, tipping on right).

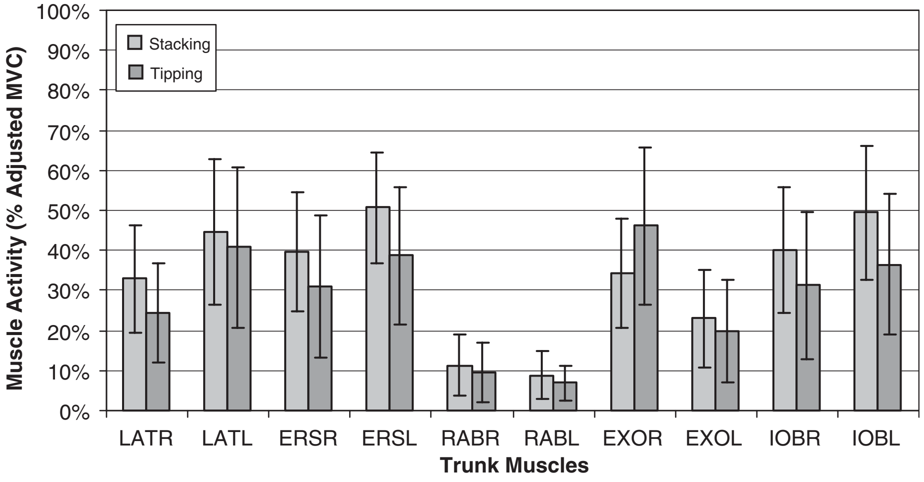


Fig. 10. Normalized trunk muscle activity as a function of stowing method.

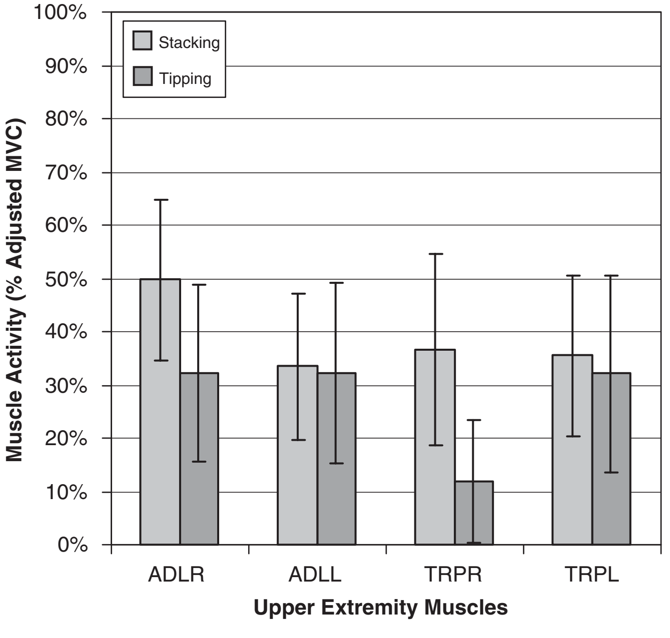


Fig. 11. Normalized upper extremity muscle activity as a function of stowing method.

normalized trunk and shoulder muscle activities as a function of stowing method. With the exception of ADLL, each muscle showed a significant effect. Tipping reduced the following: LATR and LATL by 8.5% and 3.9% adjMVC, ERSR and ERSL by 8.9% and 12.1% adjMVC, RABR and RABL by 1.8% and 1.9% adjMVC, EXOL by 3.0% adjMVC, and IOBR and IOBL by 8.7% and 12.9% adjMVC, respectively. EXOR increased by 11.9% adjMVC, which was consistent with the increased twisting motion noted with tipping.

In the shoulder muscles, significant reductions were found in the normalized activity of ADLR (17.6% adjMVC), TPRR, and TPRL (24.5% and 3.3% adjMVC, respectively) when using the tipping method. A few interactions between stowing method and baggage weight were statistically significant: RABL ($p = 0.0056$), IOBL ($p = 0.0048$), ADLR ($p = 0.0315$), and TRPR ($p < 0.0001$).

Further, analysis showed decreasing trends of muscle activity across all weights with tipping as compared to stacking for the IOBL, ADLR, and TPRP. However, the spread of the muscle activity according to baggage weight was somewhat greater for stacking as opposed to tipping, suggesting an interaction. Only the RABL showed an increase in average EMG with the tipping method, yet this occurred only with the 6.8 kg weight.

4. Discussion

4.1. Weight class ID

The average compressive loads determined in this experiment were found to be above the NIOSH 3400 N recommended materials handling lifting limit for lifting the heavy bags and for lifting all bag weights to the two highest lifting heights (Waters et al., 1993). AP shear loads were also found to be higher than the 1000 N shear limit proposed by McGill (1997) for the heavy bags. Lateral shear loads, while not as high as the AP shear loads, were still high, especially for lifts to the highest height.

The presence of weight class ID tags as an intervention was not found to significantly reduce these spinal loads. It was expected that the ID tags would allow subjects to better prepare for the task by giving them an early indication of the effort necessary to handle each bag. The lack of a significant reduction could be a result of the experimental task parameters. Subjects were instructed to initially slide the bag next to the lift destination before lifting it into place in order to remain consistent between trials. This sliding motion may have allowed the subject to judge the approximate weight of the bag in order to prepare for the lift. Studies have shown that subjects have some ability to perceive box weight during pushing and pulling tasks (Straker, 1997). Perception of the bag weight would have negated the effect of the ID tags, by preventing unexpected loading conditions.

Weight class ID tags were shown to be useful in determining a better sequential placement for stacking horizontally stowed bags. With weight class ID tags in place, handlers could place heavier bags on the bottom and stack lighter bags on top. This would result in an overall reduction in the load experienced, as only the lighter bags would be lifted while heavier bags would be slid into place on the bottom. This would be preferable, since sliding resulted in the lowest average loads for the heavy bags. In addition, presence of weight class ID tags could aid in proper sequencing of bags by the handlers sending the bags up the conveyor into the airplane. In this study, using a conservative strategy, the average reduction in cumulative compression would be 423 N for each set of four bags, with reductions in cumulative AP and lateral shear of 128 and 79 N, respectively, a significant reduction in the loads on the spine considering the large number of bags handled each day. Using a more preferable stacking scenario would reduce the cumulative loads even further. While the specific effect of these strategies would depend on the set of bags on a given flight, results suggest that this simple procedure could result in a significant reduction in the cumulative loads on a baggage handler's spine over the course of a workday, which should, in turn, reduce the risk of developing low back pain (Kumar, 1990).

Due to subject safety concerns, this study only examined bag weights between 6.8 and 27.2 kg. However, luggage weighing more than 27.2 kg are routinely encountered. It is presumed that heavier bags would result in greater spinal loads, based on trends seen in this study. The use of weight class ID tags on bags that weighed more than 27.2 kg would most likely be beneficial, since the heavier bags would be relegated to the bottom row rather than lifted on top of other bags as in an untagged, random placement. This would further differentiate the tagged and untagged conditions.

Consistent with the spinal load results, there was little difference in muscle activity with the use of weight class ID tags. It was expected that some preparation strategies might have become apparent in the recruitment of specific muscles when the subjects were presented with tagged weights. However, only the deltoid muscles showed any significant change with the presence of weight class ID tags. These changes were mixed, with the ADLR decreasing and ADLL increasing. Since the ADLR was typically much higher than the left and the changes primarily occurred in the higher weights, this result could be an attempt to offset some of the higher load on the ADLR by passing it off to the ADLL for the higher weights. Once again, these changes were relatively minor. The TRPL showed an increase in activity at the highest lift height with the use of weight class ID tags. This modest increase was unexpected, since the height of the lift was known, regardless of the presence or absence of the weight class ID tags.

Overall, the use of weight class ID tags had little practical effect on spinal and muscular loads and kinematics, in this experiment. However, their use as a procedural intervention to minimize the lifting of the heaviest bags was shown to have considerable potential benefit.

4.2. Baggage stowing method

The data quantitatively demonstrated the benefit of the tipping method. Compared with stacking, tipping imposed lower compressive and shear spinal loads, per bag, and could be expected to lower daily cumulative spinal loads. An average reduction of 494 N of spinal compression per bag handled is significant, considering the hundreds of bags handled by a baggage handler in a typical day. The average reductions in AP and lateral shear of 122 and 79 N, respectively, while less than the reduction in spinal compression, are still significant given the spines' lower tolerance of shear forces (McGill, 1997). There is evidence that reducing cumulative spinal loads could result in a significantly lower amount of spinal deterioration, reducing the risk of low back MSDs (Kumar, 1990). The lower loads are a result of the subject having to directly support less of the bag, allowing the bag's wheels (or edge) to support the majority of the load while the bag was pushed, rather than lifted, into place. Compared to sliding the bags, tipping results in less lateral shear, because friction between the wheels and the floor was less than between the surface of the bag and the floor.

Tipping bags weighing more than 27.2 kg, the largest weight examined in this study, would most likely also be beneficial. Lifting bags over 20.9 kg resulted in average compressive loads over the 3400 N NIOSH limit, while none of the bags that were tipped were found to exceed the limit. Thus, it is expected that lifting bags heavier than those studied in this experiment would also result in compressive loads over the NIOSH limit, while tipped bags would continue to be significantly less.

While tipping reduced the overall maximum spinal loads, it came at a cost. The subjects' lateral position, twist velocity, and twist acceleration all increased. These were only modest increases though, and most likely occurred as a result of the lower load supported by the subjects. The lower load allowed subjects to move the bag more rapidly horizontally, taking advantage of the bag's wheels. The lower load also may have caused subjects to assume more extreme postures, and greater velocities and accelerations as the subjects, recognizing the decreased difficultly of the task, moved more rapidly in order to work ahead and be prepared for the next bag sooner. While the greater inertial loads as a result of the rapid movement would result in greater forces on the spine, the lower load directly supported by the subjects in the tips offset these modest increases. Further, the subjects' sagittal velocity and sagittal acceleration decreased with the use of the tipping strategy. This is most likely a result of the primarily axial movement required to tip the bags as opposed to the lift, which mainly occurred in the sagittal plane after the initial slide. The decreases in sagittal velocity and acceleration correspond with the decreases in the muscle activity of the trunk extensors and the overall reduction in spinal loads.

The kinematic results are dependent on the experimental conditions in this study. Within the height restrictions of a baggage compartment, baggage handlers are normally free to choose their work postures. In this experiment, however, subjects were restricted to working on two knees. One would expect similar results if kneeling on one or two knees, as previous studies found similar lift capacities in subjects lifting on one and two knees (Gallagher et al., 1988). However, the change in posture may result in different kinematics that could also significantly alter spinal and muscular loads. Results from this study cannot be extrapolated to standing, stooping, squatting, or sitting.

The effect of the baggage stowing method was significant in the activity of 13 of the 14 muscles measured; only ADLL was not found to be significantly different. The reduction in the weight directly supported when using the tipping method resulted in lower muscle activity in all but two muscles. The greatest reductions in the trunk muscles occurred in the ERSR and ERSL and the IOBR and IOBL. This was expected, as these extensor muscles would be very active during lifts. The LATR and LATL also showed moderate reductions in activity. The RABR and RABL and EXOL showed very small reductions and low overall activity owing primarily to the fact that they mainly function as flexors. The one muscle that showed an increase in activity was the EXOR. This increase could be due to inertial forces as a result of the increased axial velocity and acceleration seen with tipping. This increase resulted in an peak activity of 46% adjMVC, which was comparable to the activity of other muscles (Fig. 10).

In the shoulder muscles, the largest reductions occurred in the ADLR and TRPR. These, too, are most likely the result of the lower load supported in the tips. Due to the experimental setup, with bag presentation to the subjects' right and destination to the left, subjects used the right arm for lifting the majority of the load, with the left arm providing support and guidance in bag placement. Thus, the reduction in load lifted was of greatest benefit to the ADLR and TRPR. In addition, during lifting, the subject was required to exercise a significant amount of control on the bag to properly place it at the correct destination. This control would require greater muscle activity to support the bag during placement compared to tipping, in which the bag could be moved into place and then reoriented correctly without the subject having to support the load. The reduced muscle activity seen in the majority of the muscles examined would allow the baggage handler to work at a lower percentage of his/her work capacity, resulting in less muscle fatigue and susceptibility to injury.

The RABL, IOBL, ADLR, and TRPR all exhibited an interaction with baggage weight. Each showed less differentiation between baggage weights with the tipping as opposed to the stacking strategy. This suggests that with greater weights, the difference between the two methods would become increasingly larger, further differentiating the two and lending validation to the use of the tipping method in actual baggage handling with weights greater than those examined in this study.

The fact that the use of the tipping method resulted in lower average spinal and muscular loads, with only modest increases in EXOR activity, lateral position, axial velocity, and acceleration as tradeoffs, shows that adoption of the tipping method would be a desirable intervention that could potentially protect baggage handlers without exposing them to other risks.

5. Limitations and suggestions for future research

The limitations of this study should be acknowledged. First, subjects were university students with no baggage handling experience. In order to minimize the effect of inexperience on the experiment, subjects were provided instruction and training, in order to replicate the techniques used in actual aircraft baggage handling. It is expected that the trends would be similar and that both the use of weight class ID tags to determine bag location placement and the adoption of a tipping strategy would be beneficial if employed in actual aircraft baggage handling. Both interventions result in lower overall loads placed on the body due to the lower weight directly supported during the tipping and the lower cumulative weight lifted with weight class ID tags used to determine bag location. However, it may be that experienced baggage handlers would react differently to the interventions than did the study subjects. In Dell's survey, baggage handlers favored similar interventions, as ones they thought would be effective in reducing back injuries (Dell, 1998). This study should, therefore, be replicated with professional baggage handlers as the subjects.

This study only examined a single style of bag, which was selected as being representative of the typical bag lifted by a baggage handler. However, luggage is extremely variable. Handle size and location, presence or absence of wheels, wheel size, and the overall size and rigidity of the bags could affect lifting dynamics and the effect of a particular stowing method. Even though it is believed that the overall trend would be similar to the results of this study, it is unknown exactly how the kinematics and resultant loading might change with different bag styles.

Another limitation was that subjects handled sets of five bags presented in 6-s increments with breaks between each set, during which they were permitted to stand up and rest. Actual baggage handlers often handle large numbers of bags in short amounts of time (several minutes in length), followed by longer breaks between airplanes. Thus, fatigue effects not present in this study could play a role in actual baggage handling. This could result in greater muscle activity in order to compensate, resulting in greater spinal loads. Given the significantly lower muscle activity exhibited with tipping, fatigue effects may be delayed, further differentiating tipping from stacking.

This study was conducted in a laboratory setting. Actual baggage handling takes place outside, exposing baggage handlers to inclement weather. Aircraft baggage compartments are not typically heated, requiring baggage handlers to wear heavy coats and gloves in cold weather. Inclement conditions and cold temperatures could not be replicated in the laboratory, nor were the subjects permitted to wear large bulky clothing, as it would interfere with data collection. It is expected that actual working conditions would increase spinal loading, as bulky clothing would restrict movement and make baggage handling more difficult.

Lastly, the biomechanical model used in this experiment was originally developed to examine spinal loads while lifting from a standing position. Its use in examining kneeling exertions has not been tested previously. In order to determine the validity of using the model for this experiment, each subject performed a number of calibration lifts to determine how well the model was performing with the subjects kneeling. The calibration lifts consisted of sagittally symmetric lifts of a 4.5 kg box to chest height from a platform 10 cm above the surface on which subjects knelt. The measured torque curve, calculated by translating torque measured at the force plate up to L5/S1, was compared to the predicted torque curve, which was the sum of the individual moments contributed by each of the measured trunk muscles. In order for the model to be considered valid, the two curves should follow one another closely while still maintaining a physiologically valid value for force per unit of cross-sectional area of the muscle. The valid range is between 30 and 100 N/cm^2 (Marras and Granata, 1997). For each subject, the R^2 coefficient for the two curves was 0.90 or above and the calculated muscle force per unit area fell within physiologic limits. This close agreement of the two curves suggests that the model, as adapted for this study, has the ability to correctly analyze kneeling exertions.

6. Conclusion

The study demonstrated the potential benefit of two ergonomic interventions in aircraft baggage handling within the baggage compartment of a Boeing 737. Weight class ID tags to help prepare the baggage handler for the effort necessary for each lift, while not found to significantly reduce spinal loads, could act as a procedural aid helping to determine bag storage location, so that heavier bags could be slid into place on the bottom with lighter bags being stacked on top, thus reducing the cumulative load experienced by the baggage handler. The use of a tipping motion rather than sliding or lifting the bags was also shown to result in a reduction in spinal loads experienced by the baggage handler. The lower spinal loads resulting from both interventions would help reduce the risk of low back injury to airline baggage handlers. This study helped to demonstrate that even simple, low-cost solutions that could be readily incorporated into current baggage handling practices could result in potentially significant benefits to airline baggage handlers.

References

Bernard, B.P., 1997. Musculoskeletal Disorders and Workplace Factors. DHHS (NIOSH) Publication No. 97-141. US Department of Health and Human Services, Public Health Service, Centers for Disease Control and Prevention, National Institute for Occupational Safety and Health.

BLS, 2002. Bureau of Labor Statistics: Annual survey of occupational injuries and illnesses. US Department of Labor. 〈http://www.bls.gov/iif/oshcdnew.htm〉 (accessed on 04/25/05).

Braun, C.C., Kline, P.B., Silver, N.C., 1995. The influence of color on warning label perceptions. International Journal of Industrial Ergonomics 15, 179–187.

Butler, D., Andersson, G.B.J., Trafimow, J., Schipplein, O.D., Andriacchi, T.P., 1993. The influence of load knowledge on lifting techniques. Ergonomics 36, 1489–1493.

Cram, J.R., Kasman, G.S., Holtz, J., 1998. Introduction to Surface Electromyography. Aspen Publishers, Inc., Gaithersburg, MD.

Dell, G., 1997. The causes and prevention of baggage handler back injuries: A survey of airline safety professionals. 〈http://www.ipso.asn.au〉 (accessed on 04/25/2005).

Dell, G., 1998. Airline baggage handler back injuries: A survey or baggage handler opinion on causes and prevention. Safety Science Monitor 1998; Article 6.

de Looze, M.P., Urlings, I.J., Vink, P., van Rhijn, J.W., Miedema, M.C., Bronkhorst, R.E., van der Grinten, M.P., 2001. Towards successful physical stress reducing products: An evaluation of seven cases. Applied Ergonomics 32, 525–534.

Elftman, H., 1966. Biomechanics of muscle with particular application to studies of gait. Journal of Bone and Joint Surgery–American 48, 363–377.

Fathallah, F.A., Marras, W.S., Parnianpour, M., Granata, K.P., 1997. A method for measuring external spinal loads during whole body free dynamic lifting. Journal of Biomechanics 30, 975–978.

Gallagher, S., 1997. Trunk extension strength and muscle activity in standing and kneeling postures. Spine 22, 1864–1872.

Gallagher, S., Marras, W.S., Bobick, T.G., 1988. Lifting in stooped and kneeling postures: Effects on lifting capacity, metabolic costs, and electromyography of eight trunk muscles. International Journal of Industrial Ergonomics 3, 65–76.

Harkness, E.F., Macfarlane, G.J., Nahit, E.S., Silman, A.J., McBeth, J., 2003. Risk factors for new-onset low back pain amongst cohorts of newly employed workers. Rheumatology 42, 959–968.

Jensen, C., Vasseljen, O., Westgaard, R.H., 1993. The influence of electrode position on bipolar surface electromyogram recordings of the upper trapezius muscle. European Journal of Applied Physiology 67, 266–273.

Johansen, T., 1995. Evaluation Report—sliding Carpet Loading System Servicing Braathens Safe's 17 b737-500. SAFE, Braathens, Oslo.

Kroemer, K.H.E., 1999. Human strength evaluation. In: Karwowski, W., Marras, W.S. (Eds.), The Occupational Ergonomics Handbook. CRC Press, Boca Raton, FL (Chapter 11).

Kroemer, K.H.E., Marras, W.S., McGlothlin, J.D., McIntyre, D.R., Nordin, M., 1990. On the measurement of human strength. International Journal of Industrial Ergonomics 6, 199–210.

Kroemer, K.H.E., Kroemer, H.J., Kroemer-Elbert, K.E., 1997. Engineering Physiology. Bases of Human Factors/Ergonomics. 3rd ed. Van Nostrand Reinhold, New York, NY.

Kumar, S., 1990. Cumulative load as a risk factor for back pain. Spine 15, 1311–1316.

Marras, W.S., Granata, K.P., 1997. The development of an EMG-assisted model to assess spine loading during whole-body free-dynamic lifting. Journal of Electromyography and Kinesiology 7, 259–268.

Marras, W.S., Fathallah, F.A., Miller, R.J., Davis, S.W., Mirka, G.A., 1992. Accuracy of a three-dimensional lumbar motion monitor for recording dynamic trunk motion characteristics. International Journal of Industrial Ergonomics 9, 75–87.

McGill, S.M., 1997. The biomechanics of low back injury: Implications on current practice in industry and the clinic. Journal of Biomechanics 30, 465–475.

Mirka, G.A., Marras, W.S., 1993. A stochastic-model of trunk muscle coactivation during trunk bending. Spine 18, 1396–1409.

Sommerich, C.M., Joines, S.M.B., Hermans, V., Moon, S.D., 2000. Use of surface electromyography to estimate neck muscle activity. Journal of Electromyography and Kinesiology 10, 377–398.

Stålhammara, H.R., Leskinena, T.P.J., Kuorinkaa, I.A.A., Gautreaua, M.H.J., Troupb, J.D.G., 1986. Postural, epidemiological and biomechanical analysis of luggage handling in an aircraft luggage compartment. Applied Ergonomics 17, 177–183.

Straker, L., 1997. Box pushing and pulling maximum acceptable forces. In: Proceedings of the Productivity Ergonomics and Safety Conference 1997, Gold Coast, Queensland.

Waters, T.R., Putzanderson, V., Garg, A., Fine, L.J., 1993. Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics 36, 749–776.