In-Depth Survey Report

Bag handling assist controls for airport screening processes

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Abstract

Through an inter-agency agreement, researchers from the National Institute for Occupational Safety and Health (NIOSH) were requested by the Transportation Security Administration (TSA) to conduct ergonomic assessments of a vacuum lifting assist device at the Oklahoma City International Airport (OKC) and of an automatic baggage moving system at the Chicago Midway International Airport (MDW). We assessed the effectiveness of the two engineering controls in reducing the risk of low back disorders (LBDs) associated with baggage screening operations. Data were collected on June 11, 2008 at OKC in the T7 checked baggage screening area and on February 8, 2011 at MDW in the L3 baggage screening area. The two systems were used to lift/move bags from several Explosion Testing Device (ETD) tables and one clear conveyor belt (conveyor for screened baggage). Operational hand force and posture data for the engineering controls were collected from on-site mock-up operations using a force gauge and a digital video camcorder. LBD risk data (i.e., back compressive force in the lumbar-sacral region) associated with the engineering controls were analyzed by a video analysis employing the University of Michigan's three dimensional biomechanical model. Using a 50 lb. baggage weight for risk calculations, the average back compressive forces for using the vacuum lift system and the baggage moving system were 262 and 401 lbs., respectively. Compared with complete manual baggage lifting, the reductions in the back compression forces were about 63% and 44% for the vacuum lift and the automatic baggage moving system, respectively. Findings of the risk assessments suggest that the two engineering controls have a great potential for reducing LBDs associated with manual baggage lifting and handling.

Introduction

Background for Control Technology Studies

The National Institute for Occupational Safety and Health (NIOSH) is the primary federal agency engaged in occupational safety and health research. Located in the Department of Health and Human Services, it was established by the Occupational Safety and Health Act of 1970. This legislation mandated NIOSH to conduct a number of research and education programs separate from the standard setting and enforcement functions carried out by the Occupational Safety and Health Administration (OSHA) in the Department of Labor. An important area of NIOSH research deals with methods for controlling occupational exposure to potential chemical and physical hazards. The Division of Applied Research and Technology (DART) has been given the lead within NIOSH to study the engineering aspects of health hazard prevention and control.

Since 1976, DART has conducted a number of assessments of health hazard control technology on the basis of industry, common industrial process, or specific control techniques. Examples of these completed studies include the foundry industry; various chemical manufacturing or processing operations; spray painting; and the recirculation of exhaust air. The objective of each of these studies has been to document and evaluate effective control techniques for potential health hazards in the industry or process of interest, and to create a more general awareness of the need for or availability of an effective system of hazard control measures.

These studies involve a number of steps or phases. Initially, a series of walk-through surveys is conducted to select plants or processes with effective and potentially transferable control concept techniques. Next, in-depth surveys are conducted to determine both the control parameters and the effectiveness of these controls. The reports from these in-depth surveys are then used as a basis for preparing technical reports and journal articles on effective hazard control measures. Ultimately, the information from these research activities builds the data base of publicly available information on hazard control techniques for use by health professionals who are responsible for preventing occupational illness and injury.

Background for this Study

Through an inter-agency agreement, researchers from NIOSH were requested by the Transportation Security Administration (TSA) to conduct a variety of engineering controls or ergonomic interventions for baggage screening and handling operations at airports. Compared with complete manual baggage handling, automatic inline checked baggage screening systems provide substantial reductions in the risk exposure to repetitive manual baggage lifting, pushing, and pulling associated with low back disorders (LBDs). Designs of the inline systems, however, cannot entirely eliminate manual lifting/handling due to a variety of reasons such as effectiveness of screening machines, restrictions of the airport layout, egress/ingress requirements, and TSA's changing security levels. TSA officers (TSOs) working in the checked baggage screening area at the end of these inline systems typically need to manually lift incompletely screened bags from the alarm conveyor belt to Explosion Testing Device (ETD) tables for manual screening. For security clearance reasons, the screening tables are not physically connected to the outbound conveyor or clear conveyor, which transports bags to the baggage make-up area where airline baggage handlers transport the baggage to airplanes in the tarmac area. Therefore, when TSOs complete manual screening, they are also required to manually transfer the screened bags from the ETD tables to the clear conveyor. Once the bags are transferred onto the clear conveyor belt, TSOs do not have to handle the bags anymore.

Because inline checked baggage screening/moving systems cannot entirely eliminate manual baggage handling in the checked baggage screening area, a lifting assist device can be of a great assistance in reducing heavy manual lifting. There are several lifting assist devices commercially available for reducing manual lifting. Among these devices, the Vaculex® system (model TP, Vaculex® Company) and the Bagwell Oversize Baggage (BOB) moving system have been implemented in the checked baggage screening areas at the Oklahoma City International Airport (OKC) and the Chicago Midway International Airport (MDW) at the time of request from TSA. Therefore, we evaluated the effectiveness of only the two implemented engineering controls for reducing the risk of low back disorders (LBDs). These two control technologies are described below.

Control Technologies

The Vaculex® TP system

The Vaculex® TP system (see Figure 1) is a vacuum lifting assist device specifically designed for a variety of manual material handling tasks including manual baggage handling. It can handle bags in different shapes, sizes, and soft and hard fabrics. Once the bag is picked up by the vacuum power provided by the Vaculex® system, the operator can use the controller of the system to rotate the bag in a 360º direction to fit where needed. The Vaculex® TP system only works with an overhead railing system, which is typically installed on the ceiling over the working space. A controller is attached to one end of the vacuum hose that provides suction to pick up a bag. The other end of the hose is connected to an electric pump mounted in a silencing box measuring 21× 32 × 20 inches (0.53 X 0.81 X 0.5 M) size. If the pump is turned on, a constant air flow is provided while no bag is attached to the controller. Once the controller is in contact with the large surface of a bag, the vacuum power will automatically pick up the bag without using any control button and the bag will stay at approximately the operator's eye level; however, the height of the bag can be controlled by operating the Vaculex® handle. Once the bag is attached to the system, the operator can move the bag with the controller along the overhead railing to the coverage areas, typically onto an ETD table or a conveyor belt. When the bag is moved to the destination, the operator disengages the bag from the controller by depressing a thumb trigger located above the handle. The Vaculex® system model we evaluated can handle up to a 100 lb. bag.

The BOB moving system

The BOB moving system is an automatic baggage moving system (see Figure 2) equipped with a short conveyor that helps move bags from the screening area (i.e., ETD tables) to the clear conveyor. Unlike typical conveyor systems, this system does not connect the two ends of the working station. It connects to one end at a time, and then moves itself automatically to the other end as it senses the bag that is loaded to the moving system. This system may be shared between two work stations connected by a roller bed. This engineering control eliminates lifting entirely, but requires manual pushing forces to move the bag from the screening table through the roller bed to the baggage moving system.

Occupational exposure limits of lifting hazards

As a guide to the evaluation of lifting hazards posed by workplace exposures, NIOSH investigators use the recommended limits in the NIOSH publication "Applications Manual for the Revised NIOSH Lifting Equation" [Water et al., 1993]. In this manual, the back compressive force in the lumbar-sacral region for a single lifting task is limited to 770 lbs. and used as the guide for safe lifting. In addition, the revised NIOSH Lifting Equation (RNLE) is also used to identify the overall risk of LBDs based on the outcome measure of the RNLE—the Lifting Index (LI). The LI provides an estimate of the level of physical stress associated with single (Single LI) or multiple manual lifting tasks (Composite LI). The index is calculated with several task variables in the RNLE, including weight lifted, horizontal reach distance, vertical heights of the lift at the origin and destination of the lift, asymmetry, frequency and hand coupling of the lift. The work-rest pattern is factored into the calculations of the LI. The LI has been evaluated in many studies since 1993 as a reliable and good measure for estimating the risk for LBDs [Waters, 1993, 1998, 1999, 2011; Marras, 1999]. Waters et al. [1999, 2011] reported that a LI below 1 is recommended because it poses a low risk for LBDs. A LI between 1 and 2 poses a moderate risk, between 2 and 3 poses a high risk and above 3 poses a very high risk for LBDs.

To determine the back compressive force in the lumbar-sacral region, the Three Dimensional Static Strength Prediction Program (3DSSPP) is used [University of Michigan, 2001]. The biomechanical model used in the 3DSSPP requires anthropometric data input including a person's gender, height and weight, postural data and hand load information for the lifting task. The software program calculates the back compressive and shear forces on the L4/L5 intervertebral disc as well as the percentage of the healthy working population that is capable of performing the task. The 3DSSPP has been extensively used in many studies as job design criteria for safe manual material handling [Waters, 1998].

It is important to note that not all workers will be protected from adverse health effects of lifting hazards (i.e., lifting-related task variables), even though their exposures to the overall measure of the physical hazards are maintained below the recommended limit of LI of 1.0 or back compressive force of 770 lbs. A small percentage of workers may experience adverse health effects because of individual susceptibility, or pre-existing medical conditions. In addition, the physical lifting hazards may act in combination with other workplace exposures, the general environment, or with medications or personal habits of the worker to produce health effects even if the occupational exposures are controlled at the level set by the exposure limit. Combined effects are often not considered in our risk assessments. Finally, the recommended limits to the physical lifting hazards may change over the years as new information on the effects of the hazards on the development of LBDs becomes available.

NIOSH investigators encourage employers to consider other exposure limits in making risk assessment and risk management decisions to best protect the health of their employees. NIOSH investigators also encourage the use of the traditional hierarchy of controls approach to eliminating or minimizing identified workplace lifting hazards. This includes, in preferential order, the use of: (1) substitution or elimination of lifting activities, (2) engineering controls (e.g., automation of manual material handling or use of lifting assist devices) and (3) administrative controls (e.g., limiting time of exposure to manual lifting, employee training, work practice changes, and medical surveillance).

Methodology

The risk for LBDs associated with a single baggage lifting or handling task was determined based on the LI and the back compressive force calculated with the 3DSSPP. The LI was primarily used for benchmarking the risk exposure to manual lifting without engineering controls. The back compressive force was used to estimate the risk reduction attributed to the engineering controls by determining the difference in the back compressive force with and without the controls. The data collection methods for the risk assessments are described in detail in the following sub-sections.

Procedure of measuring hand and thumb forces for using the Vaculex® system

Because only one Vaculex® system was installed at OKC in the T7 baggage screening area, the workstations for using the Vaculex® system in this area were chosen for the assessment. Mock-up baggage lifting tasks from one ETD table to the clear conveyor belt in this area were performed for the assessment (Figure 3). Hand and thumb forces required to operate the Vaculex® system for the mock up lifting tasks were measured by a force gauge (Chatillon Model MSC-200, AMETEK Inc., 2006).

The upper and lower pictures in Figure 3 respectively show the origin and destination of the mock-up baggage lifting tasks. The heights of the ETD table and the conveyor belt were 30 and 44 inches, respectively. Three lifting conditions were tested based on three levels of hypothetical baggage weights (25, 40 and 50 lbs.). One small test bag measuring 15 × 23 × 8 inches in size (Kennith Cole Inc.) was used to mock up lifting a 25 lb. bag, while one large test bag measuring 27 ×18 × 9.5 inches (Kennith Cole Inc.) was used to mock up lifting a 40 or 50 lb. bag. Clothes and books were stuffed in the bags to mock up lifting conditions as realistically as possible. Prior to testing, each bag was measured using the force gauge to match its targeted weight. During each lifting condition, the bag was picked up by the Vaculex® controller at the origin of the lift. Once the bag was picked up, the tester started pushing the bag horizontally using the force gauge to the destination of the lift. Force data were recorded during the testing period from the origin to the destination of each lift. Each lifting condition was repeated five times to increase the precision of the measurements. In addition, the posture used for operating the Vaculex® system during each trial was recorded by a digital camcorder (Model DSR –SR 300, Sony Inc). Video and force data were recorded in synchronization by custom software developed in the Labview software program (Version 6.1, National Instruments, Austin, Texas) on a laptop computer. This data synchronization allowed the investigators to precisely identify the starting and ending points of each lifting trial.

Thumb trigger forces required for operating the Vaculex® system were measured using the same force gauge in a separate testing condition. In the separate testing condition, a small round adapter, attached to the force gauge, was used to measure the thumb forces. The adapter was perpendicularly positioned against the trigger during the measurements. The data were recorded from the start of pushing the force gauge against the trigger until the trigger was depressed completely. Five measurements of the thumb forces were collected in the same manner.

Procedure of measuring hand forces for using the BOB moving system

Similar to the testing for the Vaculex® system, mock-up baggage handling tasks were used for assessing the BOB moving system. A randomly chosen BOB unit among the six units installed in the L3 checked baggage area at MDW was used for the mock-up baggage handling tasks. Hand forces for pushing bags through the roller bed to the BOB moving system were measured with a force gauge (Chatillon Model MSC-200, AMETEK Inc., 2006). Two baggage weights (25 and 50 lbs.) were used for estimating hand forces required for pushing the two baggage weights in three baggage contact orientations (wheel side, non-wheel side and lateral side). Each test condition was repeated five times. The force gauge was positioned to simulate the posture used by most TSOs observed during the survey (Figure 4). This posture involved an approximately 30° angle between the tester’s forearms and the table surface. The maximal push force during the test period was recorded and used for data analysis.

Data collection for estimating postures used for the two controls

Postures used for the two bag control technologies were estimated from on-site video recording on several TSOs. At OKC, four TSOs' work postures while lifting baggage with the Vaculex® system in the T7 working area were recorded using a digital camcorder (Model DSR –SR 300, Sony Inc.). At MDW, five TSOs' work postures while pushing baggage to the roller bed attached to the BOB moving system were recorded using the same digital camcorder. The video recording was used to estimate 15 body angles (trunk flexion, trunk lateral bending, trunk axial rotation, and arm and leg angles) of work posture required for using the 3DSSPP. For the Vaculex® system, the recorded posture data were used with the mean of the force measurements across five trials for each mock-up testing condition (i.e., each baggage weight) to estimate the risk of LBDs associated with each baggage weight. For the BOB moving system, the mean of the 15 trials for the 3 different baggage contact orientations (wheel side, non-wheel side and lateral side) for each baggage weight was used to estimate the risk of LBDs associated with each baggage weight.

Benchmark risk of LBDs with manual handling process

Seven manual lifting tasks performed by four different TSOs at the OKC T7 workstations were analyzed by the LI and the spinal loads at the L4/L5 intervertebral disc (i.e., back compressive and shear forces) without any engineering controls. On the basis of observations and communications with the participating TSOs, we estimated the mean lifting frequency to be approximately one lift per five minutes (i.e., 0.2 per min). Additionally, a hypothetical lifting frequency of one per min was also used for calculating the LI for estimating intensive lifting during rush times. The actual lifting frequency may change depending on the number of TSOs assigned in the T7 area and number of bags to be hand searched, which could not be determined accurately in the present study. The work postures were simulated from the video recording in a NIOSH laboratory in Cincinnati, OH, to determine the task variables for using the NLE and the body angles for the 3DSSPP [Waters et al., 2011; Lu et al., 2011]. The same three baggage weights for measuring the hand force for using the Vaculex® system were used for both LI and spinal load calculations. To calculate the spinal load for the typical lifting condition, one half of each recorded hand force was used for each hand. This division applied to two-handed baggage lifting at OKC in this biomechanical analysis. The anthropometric data (height=69 inches and weight=190 lbs.) for the average male in the US were used for determining the average back compressive force in the 3DSSPP. All TSOs at MDW did not perform manual lifting without using the BOB moving system, therefore, their risk of LBDs without using the BOB moving system was not evaluated.

Comparisons of lifting with and without the two engineering controls

Operating the two bag control systems for baggage lifting/handling is not a manual lifting task. The NLE does not apply to such a non-lifting task. Operations of both bag handling systems involve some manual push/pull forces to move the bag from an ETD table to the clear conveyor belt. Therefore, the 3DSSPP, which is capable of analyzing push/pull tasks, was used for comparing the risk of LBDs with or without using the systems. In this analysis, 3 typical TSO work postures at each study site were estimated from video recording. To compare the spinal loads (i.e., back compressive and shear forces) calculated by the 3DSSPP with and without the bag handling systems, a 50 lb. baggage weight and the estimated postures were used. For manual lifting without using the bag control systems, one half of the baggage weight was used for each hand for a lifting analysis in the 3DSSPP. The directions of the hand forces were marked upwards to indicate vertical lifting. For operating the Vaculex® system (i.e., pushing the controller to move the bag), the maximal recorded manual push force (see results section for reference) for moving a 50 lb. bag was used. The hand force of the operating hand was used for the 3DSSPP analysis. The direction of the hand force was set in parallel to the ground. For using the BOB moving system, one half of the mean of the recorded hand forces for pushing a 50 lb. bag during the mock-up testing was used (see results section for reference). The directions of the hand forces were estimated from the 3 recorded postures. Anthropometric data (height=69 inches and weight=190 lbs) for the average male in the US were used for determining the spinal loads.

Results

Hand force measurements for using the Vaculex® system

Hand force data from a sample trial of handing a 50lb. bag using the Vaculex® system are presented in Figure 5. The mean and maximum of the recorded hand forces were calculated during the test period from the beginning of pushing the Vaculex® controller to a complete stop at the end of each trial, indicated by the video data collected in synchronization with the force data. Table 1 presents the results of the force measurements for each trial as well as the mean and maximum of the hand forces by baggage size. Force data for pushing a 50 lb bag from one trial were missing due to a technical problem in the Labview program. As shown in Table 1, the average hand force for each trial of using the Vaculex® system was relatively low, ranging from 2.3 to 4.5 lbs., as compared to the forces of 25-50 lbs. required to manually lift the same size of bags. The mean and maximum of the hand forces required for operating the Vaculex® system across a variety of the lifting conditions were 3.6 and 6.8 lbs, respectively. Table 2 presents each trial's mean and maximum thumb forces required for operating the Vaculex® thumb trigger to disengage baggage from the Vaculex® controller. The mean and maximum thumb forces across the trials were 1.5 and 1.9 lbs., respectively.

Hand force measurements for using the BOB moving system

Table 3 presents the mean of the force measurements across five trials for each baggage contact orientation for each baggage weight load. The mean values of the hand forces for pushing a 25 and a 50 lb. baggage weights in the various baggage contact orientations were 19.5 and 40.2 lbs., respectively.

Risk estimates of LBDs for manual baggage lifting

Table 4 shows the LI values for 7 sampled manual lifts. Results of the NLE analysis indicate that lifting the 3 baggage weights (25, 40 and 50 lbs.) posed a risk ranging from low (LI < 1) to very high (LI >3). On average, lifting greater than 40 lbs. caused an increased LI that is greater than the recommended value of 1.0. The increases in the average LI indicate an increased potential for developing LBDs. Table 5 presents the back compressive and anterior-posterior (AP) shear forces for the sampled manual lifts. The lateral shear forces are not presented because of their insignificant values for all trials (<5 lbs). The back compressive forces were calculated for the origin of each sampled lift. Based on our observations, at the destination of each lift, baggage was typically dropped onto the conveyor belt by the TSOs. This means that significant control of baggage at the destination of a lift typically was not required. Therefore, the most significant back loading would have occurred at the origin of the lift where they had to exert significant hand forces to manually lift baggage off the ETD tables. According to the average back compressive forces for lifting the three different baggage weights, it appears that the average back compressive forces were within the NIOSH recommended limit of 770 lbs. However, approximately 14% of the sampled lifts exceeded the NIOSH recommended limit for lifting a baggage weight of 40 lbs. and about 43% of the sampled lifts exceeded the limit for lifting a baggage weight of 50 lbs. The findings indicate an increased potential for developing LBDs from lifting a baggage weight greater than 40 lbs.

Risk estimates of LBDs for using the Vaculex® system

Results of the biomechanical analysis for 3 typical Vaculex® operations indicate a low maximal back compressive force of 262 lbs. and a low AP shear force of 50 lbs. Figures 6 (a) and (b) show the work postures used for the typical Vaculex® operation, while Figures 6 (c) and (d) show the work postures for a complete manual lifting task without any bag control system. The large reduction in the back compressive force while using the Vaculex® system was the direct result of the low required hand force and upright trunk posture. The reduction in the back compressive force was approximately 63.4%, calculated by the average back compressive force (716 lbs.) for lifting a 50 lb. bag without the Vaculex® system (Table 6).

Risk estimates of LBDs for using the BOB moving system

The angle between the forearms and the table surface while pushing baggage was estimated from the video recording of 3 TSOs during actual work. These 3 angles were 23°, 30° and 30°. This finding supports the use of a 30° angle for the on-site mock-up testing. Calculated with the 3 TSOs' posture data and the average measured push force for a 50 lb. weight, the mean of the back compressive forces (20.1 lbs. in each hand) was 401 lbs, greater than the 262 lbs for the Vaculex® system. On the other hand, the mean of the AP shear force for the BOB moving system was 18 lbs., less than the 50 lbs. for the Vaculex® system. The reduction in the back compressive force for pushing a 50 lb. bag with the BOB moving system was approximately 44% using the same benchmarked data (716 lbs. for complete manual lifting) for the Vaculex® system.

Interpretations of the LBD risk data

We suggest using the back compressive force at the L4/L5 intervertebral disc as the main risk evaluation criterion because of the scientific evidence available in the literature. For the push/pull nature of using the two bag control systems, one may consider that the shear force at the L4/L5 intervertebral disc may be an important factor for risk evaluations. However, a lack of literature on the exposure levels of the shear force in relation to incidence of LBDs does not allow us to make any implications from the current study's results. Although a review study [Gallagher and Marras, 2012] on the L4/L5 shear force suggests a permissible limit of 1,000 N for infrequent tasks and 700 N for repeated tasks, this suggestion needs to be validated with more empirical data, especially from epidemiological research. Nevertheless, the small shear forces (all data <54 lbs.) for the two bag handling control systems may not pose a significant risk for LBDs.

Put in perspective, the average 262 lb. back compressive force while using the Vaculex® system is approximately equal to the back compressive force resulting from pushing a regular door open—a daily activity that is generally not considered a risk factor for LBDs. Therefore, it is estimated that the spinal loading for operating the Vaculex® system to handle baggage should be very low and safe. As to the BOB moving system, although the back compressive force was estimated to be about 50% more than that for the Vaculex® system, the value is still within the NIOSH recommended limit and 44% lower than the value for manual lifting without any controls. Therefore, the risk of LBDs using the BOB moving system is also considered to be low.

Conclusions and Recommendations

The findings of the ergonomic assessments demonstrated the effectiveness of the Vaculex® and the BOB moving systems in reducing the risk of LBDs. The reductions in the back compressive force for lifting a 50 lb. bag using the Vaculex® and the BOB moving systems were 63 and 44%, respectively. Both reduced back compressive forces were within the NIOSH recommended limit of 770 lbs. Although the Vaculex® system seems to be a more effective control technology than the BOB moving system, many limitations of the Vaculex® should be considered. These limitations include requirements for a taller ceiling height, a restricted lifting path imposed by an overhead trailing system, a potential inability to pick up bags due to uneven/unsmooth surfaces and a potential for loud noise from the pump if not enclosed properly. On the other hand, the BOB moving system has several advantages over the Vaculex® system, such as being completely effective in transferring all types of baggage, having no requirements for continuous operations once the bag is attached to the moving system, and having the capability to move very heavy baggage (>100 lbs.). To improve the effectiveness of the BOB moving system in reducing the risk of LBDs, the roller bed or the baggage transfer surface attached to the system should be carefully selected to minimize the friction between the rollers/transfer surface and baggage. Implementation of either bag handling control in order to reduce the risk of LBDs is recommended. During planning, consider the limitations of either bag handling system, space requirements for baggage screening workstations, proper work surface heights (25-30 inches), sharing capabilities of the bag handling controls, and the overall cost for implementing the controls for the entire work area.

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Table 1. The mean and maximum values of the hand forces required for operating the Vaculex® controller

Baggage size	Trial No.	Test duration (sec)	Mean (lbs.)	Maximum (lbs.)
Large (50 lbs.)	1	14.3	3.88	6.9
	2	14.69	4.29	8.2
	3	13.74	4.18	7.47
	4	11.86	4.53	8.68
		Sub mean =	**4.22**	**7.81**
Medium (40 lbs.)	1	14.12	3.46	6.97
	2	13.7	4.13	7.61
	3	12.47	4.35	8.42
	4	14.17	3.92	7.6
	5	13.72	3.99	7.38
		Sub mean =	**3.97**	**7.6**
Small (25 lbs.)	1	11.93	2.3	4.03
	2	16.91	2.66	4.91
	3	17.1	3	5.65
	4	14.14	2.89	5.37
	5	11.99	2.83	5.33
		Sub mean =	**2.74**	**5.06**
	*Mean ± SD	13.9	**3.6 ± 0.7**	**6.8 ± 1.4**

*: Mean and SD were calculated across 14 trials

Table 2. Thumb force data required for operating the Vaculex® trigger

Trial No.	Test duration (sec)	Mean (lbs.)	Maximum (lbs.)
1	3.76	1.32	1.56
2	3.85	1.62	2
3	4.2	1.51	1.96
4	4.43	1.49	1.7
5	4.78	1.7	2
Mean± SD	4.2	**1.5 ± 0.1**	**1.9 ± 0.2**

Table 3. Hand force measurements for pushing a bag to the roller bed attached to the BOB moving system (N=5 for each baggage contact orientation)

Baggage weight (lbs.)	Baggage contact orientation	Mean (lbs.)
25	Non-wheel side	23.7±4.6
	Wheel side	18.2±2.1
	Lateral side	16.7±1.5
	Sub mean=	**19.5±4.2**
50	Non-wheel side	38.6±6.1
	Wheel side	43.3±1.3
	Lateral side	38.7±2.1
	Sub mean=	**40.2±4.2**

Table 4. The LI values as a function of lifting 3 baggage weights and 2 lifting frequency rates

Lift No.	Lifting Frequency = 1 per 5 min			Lifting Frequency = 1 per min		
	25 lbs.	40 lbs.	50 lbs.	25 lbs.	40 lbs.	50 lbs.
1	0.81	1.3	1.62	0.88	1.4	1.75
2	1.41	2.26	2.82	1.52	2.44	3.05
3	1.67	2.68	3.35	1.81	2.89	3.61
4	0.87	1.4	1.75	0.94	1.51	1.89
5	1.11	1.77	2.21	1.19	1.91	2.39
6	1.55	2.48	3.09	1.67	2.87	3.34
7	1	1.6	2	1.08	1.73	2.16
Mean*	1.1	1.7	2.2	1.2	1.9	2.4
SD	0.3	0.5	0.6	0.3	0.5	0.6

*Mean value for the 7 sampled manual lifts in the OKC T7 baggage screening area

Table 5. Spinal loads for lifting 3 baggage weights (25, 40 and 50 lbs.)

	Back compressive force (lbs.)			Back AP shear force (lbs.)		
Lifting No.	25 lbs.	40 lbs.	50 lbs.	25 lbs.	40 lbs.	50 lbs.
1	644	742	802	77	87	94
2	677	788	857	62	65	68
3	420	509	572	54	55	51
4	502	637	721	35	33	31
5	348	465	539	47	43	40
6	535	435	696	56	60	62
7	657	762	826	67	74	79
Mean*	540	648	716	57	60	61
SD	126	126	124	16	18	22

*: Mean value for 7 sampled lifts from 4 TSOs in the OKC T7 baggage screening area

Table 6. Comparisons of the spinal loads (mean and SD) at L4/L5 for lifting/handling a 50 lb. bag with and without the baggage handling control systems

	N	Back compressive force (lbs.)	Back AP shear force (lbs.)
No control	7	716±124	61±22
Vaculex®*	3	262±77	50±4
BOB**	3	401±100	18±7

*: The Vaculex TP system
**: The Bagwell Oversize Baggage Moving system

Figure 1. The Vaculex® TP baggage lifting assist system was evaluated in the study

Figure 2. The Bagwell Oversize Baggage (BOB) Moving System was evaluated in the study

Figure 3. On site mock-up testing was used for measuring hand and thumb forces required for using the Vaculex® TP system

Figure 4. On site mock-up testing was used for estimating hand forces required for pushing a bag to the BOB moving system (upper and lower pictures show the start and end of the pushing task)

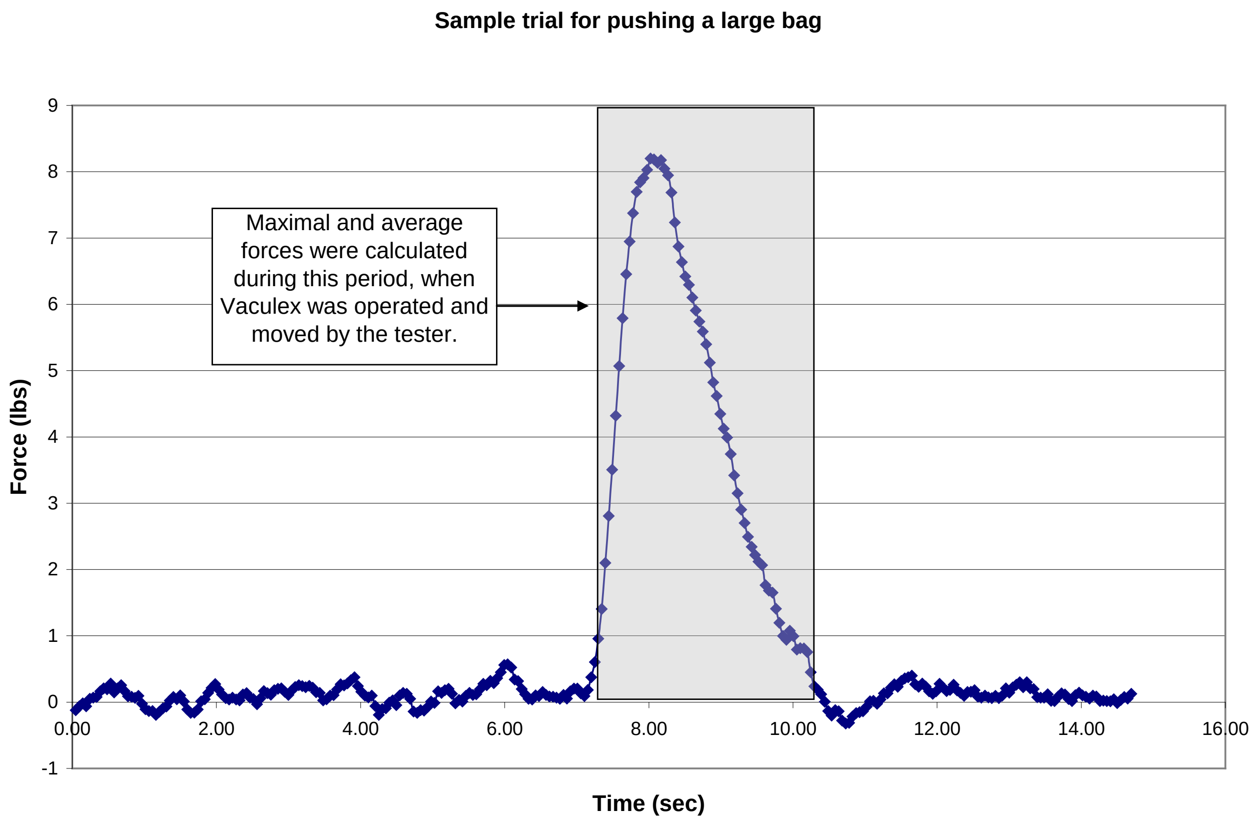

Figure 5. Hand force data of a sample trial for lifting a 50 lb bag using the Vaculex® TP system is shown

(a) (b)

(c) (d)

Figure 6. Different postures were used for lifting a bag manually (a and b) and handling a bag using the Vaculex® system (c and d) in the OKC T7 baggage screening area

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