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Coors Distributing Company
Golden, Colorado

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PREFACE

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ACKNOWLEDGMENTS AND AVAILABILITY OF REPORT

This report was prepared by James D. McGlothlin, Ph.D. of the former Engineering Control and Technology Branch, Division of Physical Sciences and Engineering (DPSE), and Steven J. Wurzelbacher, M.S. of the Division of Applied Research and Technology (DART). Dr. McGlothlin is now an Associate Professor of Industrial Hygiene and Ergonomics at Purdue University. Editorial assistance and desktop publishing was performed by Frankie J. Smith, B.S., Division of Applied Research and Technology (DART). Review and preparation for printing were performed by Penny Arthur.

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Highlights of the NIOSH Health Hazard Evaluation

Risk of Developing Musculoskeletal Disorders among Beer Keg Delivery Personnel, Coors Distribution Center (CDC), Golden, Colorado.

The National Institute for Occupational Safety and Health (NIOSH) was asked by a Coors representative to provide technical assistance to evaluate potential musculoskeletal injury risk among its delivery personnel during beer keg delivery, and to provide recommendations to decrease this injury risk through ergonomic controls. The NIOSH evaluation determined that there was a high potential for worker fatigue and musculoskeletal injury, especially to the low back, during keg handling and delivery. Ergonomic controls, such as the Friction Feed Pulley System (FPS) evaluated in this study, and good work practices while manually handling beer kegs will decrease the potential for musculoskeletal injury.

What NIOSH Did

- Carried out an ergonomic study of deliverymen lifting, carrying, and pushing 165 lb beer kegs during delivery routes.
- Videotaped deliverymen to estimate the risk for injuries such as muscle strains, sprains, and tears.
- Collected heart rate data to determine body stress.
- Compared the stresses of lifting kegs from the truck in the current way to lowering the kegs using a new friction feed pulley system (FPS) .

What NIOSH Found

- There is high risk for low back injuries among beer delivery workers. Many delivery tasks, including all unaided keg lifts and the wheeling of kegs inside using a handcart, produce back compression levels which are greater than the NIOSH Back Compression Limit of 770 lbs.
- The pulley system (FPS) cuts down the risk for back injury during delivery truck unloading.
- The tasks of unloading and arranging kegs in the coolers of the bars and wheeling kegs inside, especially when going down steps, also create high body stresses.

What Coors Distribution Center Managers Can Do

- Encourage the installation of assisted lift devices such as friction feed pulley systems (FPS) to unload kegs from delivery trucks and also inside coolers.
- Purchase and use hand-trucks with oversized wheels and tank treads on the back side of the frame to improve level ground handling and pushing/ pulling up and down stairs.
- Coordinate with delivery site management to ensure that the easiest route inside the establishment is made available to delivery personnel and that this route is properly maintained and cleared.
- Work with Coors design engineers and Coors customers to develop, design, and install lift assist devices within coolers.
- Continue an ergonomics training program to educate delivery personnel in proper lifting techniques and work practices that reduce biomechanical and physiological demand.

What Coors Distribution Center Employees Can Do

- Use the friction feed pulley system provided by Coors when installed on delivery trucks.
- Perform good work practices including: clearing coolers prior to unloading, combining billing and rest, and pacing work throughout shift by balancing heavy load stops with light.
- Report to Coors management work situations that pose high risks for injuries such as muscle strains, sprains, and tears and help devise strategies through peer focus groups to reduce these risks through a combination of engineering controls and good work practices.

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National Institute for Occupational Safety and Health
NIOSH

Health Hazard Evaluation Report 97-0076-2805
Coors Distributing Company
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SUMMARY

Researchers from the National Institute for Occupational Safety and Health (NIOSH) conducted a health hazard evaluation (HHE) of the risks for musculoskeletal disorders of the upper limbs and back to beverage delivery personnel during keg delivery from the Coors Distributing Company (CDC) and evaluated a recently introduced ergonomic intervention, a friction feed pulley system (FPS) with the trade-name Keg Boy™. The objective of the hazard evaluation was to identify job tasks in the keg delivery cycle which may increase the risk for musculoskeletal injuries and to provide recommendations to decrease and prevent such injuries. The primary purpose of the intervention evaluation was to determine if the friction feed pulley system (FPS) was effective in reducing the risk of musculoskeletal disorders during the truck unload phase of delivery.

Analysis of postural and heart rate data from the job showed that unloading kegs from the delivery truck and moving kegs in the cooler of the establishment to which the delivery was made represented the tasks with the highest biomechanical and physiologic demand. Specifically, lifts of kegs from the delivery truck and from the ground in the confined space of the cooler were both determined to produce back compressions of the lower back (L5/S1, 5cm) averaging 1065 lbs (+/- 117, +/- 118), which exceed the NIOSH Recommended Compression Limit (RCL) of 770 lbs. Another work activity that caused significant back compression forces was “wheeling kegs inside the establishment” (level ground) which averaged 996 +/- 89 lbs. The mean weight lifted per day was 18,532 +/- 3915 lbs by the deliverymen during beer delivery routes.

The FPS was determined to offer a biomechanical advantage over the traditional manual lift method by inducing significantly lower back compression levels ($p < 0.0001$) during the delivery truck unload phase. Use of the FPS to unload kegs from the truck was associated with the lowest average back compression (303 lbs +/- 128) of all keg lifting tasks. The FPS lift and traditional lift were not shown to be significantly different physiologically in terms of heart rate mean. Although the FPS was shown to produce a significantly lower heart rate increase than the traditional lift ($p \sim 0.02$), it also produced a borderline significantly greater heart rate maximum than the traditional lift ($p \sim 0.06$) and heart rate peak percent maximum ($p \sim 0.06$). The FPS averaged almost 7 times as long to use (40 seconds versus 6 seconds) than the traditional manual method. Much of the difference in time between the two systems is attributed to a lack of experience with the FPS.

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Based on this Health Hazard Evaluation it was determined that risk for musculoskeletal overexertion injury to the back and upper limbs exists for the beer keg deliverymen evaluated during this study. Risk for back and upper limb injury was greatest during keg handling in walk-in coolers. The task of manually unloading kegs from trucks produced back compressions that averaged 1.5 times higher (1065 lbs) than the NIOSH recommenced compression limit of 770 lbs. However, when the Friction Pulley System was used back compressions averaged less than 50 percent (303 lbs) of the NIOSH recommended compression limit. During this study, it was determined that the mean weight lifted per day per deliveryman averaged over 18,000 lbs, which is among the highest weight totals for all private sector delivery jobs. Recommendations to reduce musculoskeletal injuries during manual handling of beer kegs are contained in the recommendations section of this report.

Keywords: SIC 2082 (Beer), musculoskeletal disorders, manual materials handling, cumulative trauma disorders, beer delivery, keg delivery, ergonomics, product design, and engineering controls.

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INTRODUCTION

An Ergonomic Evaluation of the FPS

The purpose of this report was to evaluate the effectiveness of a friction-feed pulley system (FPS) with the trade-name, Keg Boy ™ as an ergonomic control in the beer keg delivery industry and to characterize the biomechanical and physiological demands of the current keg delivery cycle. The FPS was introduced as an alternative to traditional manual lifting methods required to unload beer kegs from the delivery truck to the handcart. It consists of a rope and tackle configuration that is attached to a bar over the door of the delivery truck (See Figures 1 and 2). The hooks at the end of the rope are attached to the keg handles and the keg is lowered by friction feeding the rope through the pulley, thus transferring the keg from the truck to the ground.

BACKGROUND

On January 20, 1997, NIOSH received a request to assist management in conducting an ergonomic evaluation of manual material handling of beer kegs during delivery for the Coors Distributing Company (CDC), Golden Colorado. Particular concern was expressed about the keg delivery cycle where approximately 40 deliverymen each day handle several full or partially full keg containers of beer weighing up to 165 lbs. Specific questions included how to protect the deliverymen from musculoskeletal injury during keg handling while they were unloading kegs from the delivery trucks, using hand trucks to transport the kegs to and from the trucks at their customers places of business, and manual handling of kegs inside the walk-in coolers.

This technical assistance request was generated because NIOSH researchers had conducted a study of soft drink beverage deliverymen which the Coors Distributing Company had found useful, but limited since it did not include the handling of kegs.[1] The current report was needed to address specific hazards associated with beer keg delivery. In particular, Coors wanted the NIOSH ergonomics evaluation to help with identifying and implementing equipment control measures, including a market-available Friction Pulley System to lower kegs from the delivery truck to the ground. No medical records evaluation was requested of NIOSH because Coors had medical staff available to evaluate their own injury records.

METHODS

Experimental Design

An ergonomic evaluation was conducted on route deliverymen working for the Coors Distribution Center in Golden, Colorado. To determine the effectiveness of the Friction Pulley System (FPS) design over traditional controls (i.e., manual lifting), a random block design was used. This design was selected to statistically evaluate the effects of the FPS on workers' physiological and biomechanical demands versus those demands for a traditional non- FPS manual lift. The time efficiency involved in using the FPS versus non-FPS lifts was also investigated using this design. The use of the FPS was randomly allocated for each stop during a "typical" day of three Coors delivery personnel. Each deliveryman (referred to as "subjects" in the remainder of this report) received a short training session on the use the FPS before trials began. The first subject was monitored on July 15, 1997, while the second and third subjects were monitored on July 17, 1997 and July 18, 1997 respectively.

All 3 subjects were male volunteers. Demographic characteristics for these men are summarized in Table 1. Heart rate (HR) data from each subject was monitored continuously during the workday at five-second intervals using Polar Vantage XL™ Heart Rate Monitors with telemetry units. The monitor stored up to two hours and forty minutes of heart rate data when programmed to collect data every five seconds. When it was convenient for the worker, the monitor was changed, approximately every two and one-half hours. Up to five receivers were used per worker, per day. Later, the data were downloaded through a transmitter-receiver coupling device connected to a portable computer. The heart rate data files were then transferred to a computer spreadsheet package (Excel ™). Subjects were videotaped performing their delivery duties at each stop during the day. The clock in the portable video camera was synchronized with the time of day on the heart rate receivers. Extraneous signals, caused by electronic noise or by poor contact with the skin, were deleted from the spreadsheet.

Biomechanical Method

The FPS and manual keg unloading lifts were first evaluated to determine their associated biomechanical demands. A videotape analysis system/software package (Vision 3000) was utilized to capture frames of each worker performing both types of lifts. Later, this same system was used to analyze the other tasks in the work cycle, including "wheeling in the kegs", "wheeling kegs up and down steps" and "unloading in the cooler" to characterize the biomechanical demand of the truck unload phase in the context of the entire delivery cycle. A software version of the University of Michigan's 3D Static Strength Prediction Model (3DSSP) was then employed for the biomechanical analysis.

The Michigan 3DSSP program uses joint position data obtained from still pictures or a single frame of film/video and the forces acting on the hands to estimate the reaction forces and moments of force at the L5-S1 level of the lumbar spine, torso, shoulder, elbow, hip, knee, and ankle joints.[2] The magnitude of the compressive force acting at a 5 cm moment arm on the L5-S1 inter-vertebral disc is also estimated for comparison to the NIOSH Recommended Compression Limit (RCL) of 770 lbs. The justification and application of the RCL is discussed in a subsequent section entitled "Evaluation Criteria". Note that the 1991 NIOSH Lifting Equation was not applied to this evaluation because the large load size of 165 lbs greatly exceeded the NIOSH recommended limit of 51 lbs and because FPS lifts were performed with one hand.

The first step of analysis was to compare and contrast FPS and Non-FPS (manual) keg unloading lifts in detail principally using this model. Each lift was defined to have three phases, consisting of a beginning, middle and end. These phases were qualitatively assigned to approximate the range of postures used during each lift. The analysis of FPS lifts was restricted to those lifts performed with one hand lowering the rope and one hand pulling the keg out from the truck by approximately 10 inches to clear the keg from the truck's frame, while lowering it to the ground. Three trials for each phase in the FPS lift cycle, including one from each subject, were analyzed. The forces on the subjects' hands were considered first and were approximated on a task basis by force meter measurements for each lift phase. The measurements for the subjects' keg-pulling hands were determined at a horizontal distance (from the pulley to the edge of the keg) of 1 inch for the beginning phase, 6 inches for the middle phase, and 10 inches for the end phase. The magnitudes of force on the subjects' rope lowering hands for each of these phases were then measured for each phase. Angles of force on the subjects' hands (both keg-pulling and lowering) were determined for each lift phase by individual frame analysis using Vision 3000 ™ software and Michigan 3DSSP conventions.

For each manual keg unloading lift phase, three trials, including one from each deliveryman, were analyzed using the Michigan 3D system. For the purpose of evaluation, the magnitude of force on the subjects' hands was considered to be the total weight of the keg (165 lbs), equally distributed, and acting at an angle of –90 degrees (straight down on the hands).

Physiological Method

Lift Task Definitions

As in the biomechanical evaluation, differences between FPS and traditional manual lifts were investigated first in the physiological analysis and then compared to other tasks within the keg delivery work cycle. However, unlike the biomechanical analysis, which included only specific FPS lifts, all instances of FPS and non-FPS keg unload lifts were considered for the physiological analysis. As well, for all physiological comparisons, a 10 second time period was added to each task interval to address the time lag in heart rate activity associated with a given work task.

The Non-FPS (manual) keg-unloading lift task was defined for all evaluations to last from the moment the keg was grasped when inside the truck to 10 seconds after the keg had been set down on the ground. For both FPS and Non-FPS keg unloading lifts, and all parameters, the average of two keg lifts was taken if two kegs were unloaded within 20 seconds of each other.

The FPS keg-unloading lift task was defined to begin just before the keg was raised off of the keg from the truck bed or keg top (if stacked on another keg) and to end 10 seconds after the keg was on the ground and the FPS had been removed. This definition attempts to reflect the physiological demand associated with the FPS lift alone as well as the demand associated with the FPS lift and set-up. These distinctions are important because the physiological demand required for the FPS set-up may be reduced with training, design modification, or experience. Thus, the true physiological demand of the FPS may be better represented by heart rate data associated the FPS lift alone. However, since heart rate data tends to be cumulative for subsequent tasks, any physiologic measure of the FPS lift will reflect the activity of set-up that immediately precedes the actual lift time. Thus, it was hypothesized that the cumulative effect of the FPS set-up would be registered in certain physiological measures, such as mean and maximum heart rate, while the more transient effect of the FPS lift would be registered in another parameter, heart rate increase. These measures are described in detail below.

Physiologic Measures

Five physiologic parameters were developed from the continuous heart rate (HR) data obtained from each of the three subjects. These included HR increase, mean HR, maximum HR, percent of maximum HR range required for the task (based on mean HR), and percent of maximum HR range required for the task (based on maximum HR).

HR increase was defined to be the difference between the lowest HR (in beats per minute) and the highest subsequent HR within the defined lift period. For same-type lifts within 20 seconds of each other (e.g. both FPS) the higher of the two HR increases for the two lifts was used. Mean HR was defined to be the average HR for the time interval (Sum/ n). For same-type lifts within 20 seconds of each other, the mean of the two individual lift-averages was taken. Maximum HR was defined to be the highest HR reading reached during the specified lift interval. For same-type lifts within 20 seconds of each other, the higher maximum for the two intervals was taken.

Percent of maximum HR range required for the task (based on mean) was defined to be [(mean task HR- resting HR)/ (maximum heart rate capacity- resting HR)], where the maximum heart rate capacity was calculated as (220 – subject's age in years). For same-type lifts within 20 seconds of each other, the mean task used in the equation was determined as described above. The "percent of maximum HR range" parameter, developed by Astrand and Rodahl,[3] approximates the percent of maximum aerobic capacity (VO_2 Maximum) required for a task. This percentage is used to determine the extent of physiological fatigue that can be expected from the performance of a particular task. In addition, the "percentage of maximum aerobic capacity required for a full work shift " was also determined to indicate the potential for fatigue over the work day. This was defined as the (mean working HR for the day, excluding lunch – resting HR) / (maximum heart rate capacity – resting HR).

A third "percent of maximum HR range" parameter was used for this study to represent the maximum physiological demand placed on a worker. The "percent of maximum HR range required for the task (based on maximum)" was defined to be [(maximum task HR- resting HR)/ (maximum heart rate capacity- resting HR)], where the maximum heart rate capacity was calculated as (220 – subject's age in years). For same-type lifts within 20 seconds of each other, the maximum task used in this equation was determined as described previously. This parameter represents maximum transient demands in terms of an individuals' aerobic capacity, and can indicate the potential for fatigue and "possible heart problems in susceptible people at high, near maximum heart rates".[3]

Time Efficiency Method

For the purpose of time efficiency evaluation, the FPS lift task was considered to begin the moment that the FPS unit was set up (including positioning the FPS over the keg and attaching the hooks to the keg) and to end 10 seconds after the keg was on the ground and the FPS had been removed. This definition was used to reflect the actual total time required to operate the FPS with little training, in comparison to the traditional manual lift. Therefore, the manual keg unloading lift was still defined for all time efficiency evaluations to last from the moment the keg was grasped when inside the truck to 10 seconds after the keg had been set down on the ground. For both FPS and manual keg unloading lifts, the average duration of two same-type keg lifts was taken if the two kegs were unloaded within 20 seconds of each other.

As in the physiological analysis, all videotaped instances of FPS and non-FPS keg unloads were considered in the time efficiency analysis. Mean, maximum, and minimum lift times were then determined for each worker for both types of lifts.

General Job Analysis Method

Overall Workload Analysis

Workload assessments for the entire keg delivery route were also conducted in the form of the continuous heart rate monitoring (discussed within the physiological results) and an estimation of the total weight lifted during the day. This weight estimation has been used in past NIOSH studies as a benchmark for biomechanical stress.[1] To perform the estimation, the bill of sale for each deliveryman was simplified into deliveries of cases and kegs. Each delivery was then assumed to be paired with the removal of a similar empty container. The average weight for each of these items was determined and a single handling weight was calculated. Finally, it was assumed that each case and keg was handled at least twice: once when loaded on the handcart and once when unloaded from the handcart. Thus, the total weight handled or lifted was determined to be twice the single handling weight.

Specific Task Analysis

As indicated, an initial ergonomic evaluation of the defined tasks within the keg delivery cycle was also conducted as other beer delivery tasks were compared to the FPS lift and Non-FPS lift tasks. This evaluation included: (1) discussion with beer delivery personnel regarding musculoskeletal hazards associated with their job, (2) the aforementioned videotaping of the keg delivery process, and (3) the aforementioned biomechanical evaluation of musculoskeletal stress during the defined tasks of the cycle.

Videotapes of the jobs were analyzed at regular speed to determine job cycle time, slow-motion to determine musculoskeletal hazards of the upper limbs during manual material handling tasks, and stop-action to sequence job steps and perform biomechanical evaluations of working postures. All video analysis procedures were used to document potential musculoskeletal hazards in performing the job.

The videotapes were then coded for activities and analyzed using the Vision 3000 ™ frame capturing system. To this end, the work cycle of a keg stop was defined to have four main tasks. These included: (1) the unloading of kegs from the truck with the FPS, (2) the unloading of kegs from the truck without the FPS, (3) the wheeling of 2 half-barrel kegs (165 lbs each) into the establishment, and (4) cooler work comprised of unloading the kegs from the handcart and re-arranging the old and new kegs in the cooler. A special subtask, the "wheeling of kegs up/down stairs," was later delineated for biomechanical analysis.

Using the Multi- Media Video task Analysis (MVTA) system from the University of Wisconsin-Madison, the work tasks defined as "cooler work" were then further investigated. Cooler work in general was hypothesized to pose an additional risk factor for low back injury due to the confined nature of the typical cooler workplace which impedes the execution of proper lifting techniques. Once more, delivery personnel were often required to rearrange and lift full kegs from the ground under such confined conditions and the MVTA was used to determine the frequency of these lifts in relation to other cooler tasks.

To perform the frequency analysis, "cooler work" was differentiated into six categories:
1) Full keg-lift from ground– typically defined as raising a keg from an initial position on the ground to a destination on top of another keg [vertical displacement = 32 inches].
2) Full keg-lift from keg top—typically defined as a lowering of a keg from an initial position on top of another keg to a destination on the ground [vertical displacement = 32 inches].
3) Empty keg-lift—typically defined as any movement of an empty keg where the keg is no longer in contact with a supporting surface.
4) Keg-shift—typically defined as any movement of a keg (full or empty) in which the keg does not leave the surface supporting it.
5) Case-lift—typically defined as any movement of a case of 24 beer or case of wine bottles where the case is no longer in contact with a supporting surface.
6) Undefined cooler tasks—typically involves wheeling kegs in cooler, connecting kegs, and ordering.

Videotapes of each worker were coded using the MVTA and time frequency data were calculated and transferred to a spreadsheet.

In summary, time and motion study techniques and work methods analysis were used for the first phase of job analysis. The second phase of job analysis was to review the job for recognized occupational risk factors for Work-Related Musculoskeletal Disorders (WRMDs). These WRMDs risk factors include repetition, force, posture, static loading, and contact stress,[4] and the determination of these criteria are described in the following section. To fully assess these factors, a biomechanical evaluation of forces exerted on the upper limbs, back, and lower limbs of the worker while performing the task was also conducted. This two-phase approach for job analysis and quantification of forces which act upon the body during materials handling, forms the basis for proposed engineering and administrative control procedures aimed at reducing the risk for musculoskeletal stress and injury.

EVALUATION CRITERIA

OSHA requires an employer to furnish employees a place of employment that is free from recognized hazards that are causing or are likely to cause death or serious physical harm [Occupational Safety and Health Act of 1970, Public Law 95–596, sec. 5.(a)(1)]. Thus, employers should understand that not all physical hazards have specific OSHA exposure limits such as PELs and short-term exposure limits (STELs). An employer is still required by OSHA to protect their employees from hazards, even in the absence of a specific OSHA PEL.

Work-Related Musculoskeletal Disorders

The criteria used to evaluate the effectiveness of the FPS as an ergonomic intervention and to evaluate the associated hazards of tasks in the keg delivery cycle have developed from epidemiologic studies and from biomechanical, psychophysical, and physiological models. This body of research suggests a strong link between musculoskeletal disorders and certain job risk factors including repetition, force, posture, and vibration.[4, 5] The reduction of these risks should result in the amelioration and prevention of these disorders.

Specific Biomechanical and Physiological Criteria Used for this Evaluation

For the purpose of this evaluation, the above risk factors have been identified qualitatively by cycle analysis and quantitatively by postural and heart rate data analysis using criteria selected by the 1991 NIOSH lifting equation committee. Although the risk factors are not defined empirically, results given as "physiological" tend to reflect factors of force and repetition while results given as "biomechanical" tend to reflect force and awkward posturing. The third result area, "time efficiency," largely reflects the time-motion variable of cycle time for defining ease of use and possible worker acceptance of the FPS intervention.

Biomechancial Criterion: The 1991 NIOSH lifting equation committee selected the "joint between the fifth lumbar and first sacral vertebral segments (L5/S1) as the site of the greatest lumbar stress during lifting" and concluded that "compressive force was the critical stress vector" that leads to injuries such as disc herniation and end-plate fracture.[5] These choices were made based on studies that suggested that the L5/S1 "vertebrae has the potential to incur the greatest moment in lifting and is also one of the most vulnerable tissues to force-induced injuries".[5] The 1991 committee then selected 770 lbs as the Recommended Compression Limit (RCL) at L5/S1 based on a number of studies. These included investigations into the compressive strength of cadaver lumbar segments and studies which linked "compressive force estimates with the incidence of low back disorders."[5]

Since in vivo measurements of back compression are not feasible, biomechanical models, such as the Michigan 3D Static Strength Prediction Model described previously, are then used to estimate these compression levels for comparison to the RCL. However, the compressions estimated by such static models must be considered cautiously since dynamic models, which include the effect of acceleration, produce greater compressive estimates.

Physiological Criterion: A number of studies have indicated that tasks can become fatiguing when the work performed requires more than 33% of a worker's aerobic capacity for an 8 hr shift.[6,7,8,9,10] Whole body fatigue is a definable bodily condition in which a person's heart rate does not reach a steady state, but rather rises continually as a task is performed. Citing a number of studies, the 1991 NIOSH lifting equation committee concluded that whole body fatigue could cause a "premature decrease in strength and increase the likelihood of injury" during lifting tasks.[5]

RESULTS

Biomechanical Results

Non-FPS Keg Lift (Manual Keg Unloading Lift)

The FPS and manual keg unloading lifts were analyzed using the Michigan 3D model software. The data inputted into these models, including worker anthropometry, load size and force measurements, are listed in Table 1, Table 2.1, and Table 2.2. Results are summarized in Figure 3.

For each manual keg unloading lift phase, three trials, including one from each subject, were analyzed. The middle phase of the Non-FPS (manual) keg unloading lift was found to be associated with the highest mean back compression at 1147 +/- 99 lbs. This was followed by the end phase (1056 +/- 82 lbs) and the beginning phase (992 +/- 141 lbs). The back compression values associated with all phases of the manual keg unloading lift exceeded the NIOSH Recommended Compression Limit (RCL) of 770 lbs. The maximum value for back compression for any Non-FPS lift was determined to be 1261 lbs during a middle Non-FPS lift phase for the 3rd deliveryman.

FPS Keg Lift

Table 2.1 lists the parameters of force magnitude and angle of force which were calculated for the Michigan 3D model and the back compression associated with each lift. Three trials for each phase in the FPS lift cycle, including one from each subject, were analyzed. The magnitude of force on the subjects' hands was approximated by force meter measurements on a task basis. The forces on the subjects' keg-pulling hand were considered first. These were determined to be 32.8 lbs at a horizontal distance of 1 inch for the beginning phase, 36.1 lbs at a horizontal distance of 6 inches for the middle phase, and 42.4 lbs at a horizontal distance of 10 inches for the end phase. The magnitudes of force on the subjects' rope lowering hands were next considered and were determined to average 15.5 lbs for the three phases. Angles of force on the hands for each lift were determined using Vision 300™ software and Michigan 3D conventions.

The mean back compressions associated with each phase of the FPS and non-FPS lifts are depicted individually for the three subjects in Figure 3. As with the non-FPS lift, the middle phase of the FPS lift was found to be associated with the highest mean back compression at 368 +/- 187 lbs. This was followed by the middle phase, with an associated back compression of 346 +/- 51 lbs, and the beginning phase, with a compression of 196 +/- 40 lbs. The maximum value for back compression for any FPS lift was determined to be 550 lbs, during a middle FPS lift phase for Subject III. However, this value was still below the NIOSH Recommended Compression Limit, RCL.

Statistical Results of FPS/ Non-FPS Keg Lifts (Manual Keg Unloading)

Table 3 lists the results of the statistical biomechanic comparison between the two lifts, based on back compression and shear forces estimated using the Michigan 3D model and software. Paired student t-tests were performed and it was determined that back compression values were significantly lower (t-value = 22.84, df = 8; $p < 0.0001$) for the overall FPS lift (all phases combined) versus the overall Non-FPS (manual) keg unloading lift.

Comparison of Lifts with other Tasks in Work Cycle and to the NIOSH Recommended Compression Limit (RCL)

Differences across tasks within the keg delivery work cycle were next investigated in the biomechanical analysis. Figure 4 depicts the back compression means associated with each task as compared to NIOSH's Recommended Compression Limit (RCL). Again, the experimental compression values were determined by videotape analysis using the Michigan 3D model. Of the tasks defined in the previous section, the FPS lift (middle phase, Subject III) had the lowest associated maximum back compression value at 550 lbs, followed by "wheeling kegs downstairs" at 607 lbs. Thus, of keg delivery tasks studied, only these tasks were found to be associated with maximum back compressions lower than the NIOSH RCL of 770 lbs.

Again, the delivery task associated with the highest maximum back compression was the Non-FPS keg unloading lift from the truck (middle phase, subject III) at 1261 lbs, followed closely by cooler work at 1169 lbs. Cooler work, principally characterized biomechanically as lifting a keg from off the ground in a confined space, also produced similar mean compression values (1065 +/- 118) to the unloading lift from the truck (1065 +/- 117). Finally, the task of "wheeling kegs in" was also found to be associated with high back compressions at a maximum of 1074 lbs and a mean of 996 +/- 89 lbs.

Physiological Results

Overall Physiological Comparison of FPS Lifts and Non- FPS Keg Lifts

The five heart rate parameters described in the above physiologic method were then analyzed for each FPS keg lift and manual keg unloading lift throughout the course of the day for each subject. This data is presented in Tables 4.1 to 6.2. Differences for the two conditions within and between subjects were then investigated.

Overall non-statistical results indicated for Subject # 1 that the FPS was associated with a higher mean and maximum HR, and thus HR percentages than the manual keg unloading lift. However, the FPS was also associated with a much lower HR increase than the standard keg lift (11 +/- 3 bpm versus 5 +/- 2 bpm). For deliveryman # 2, the HR increase and the HR maximums were almost identical for the FPS and manual keg unloading lifts. Once more, the mean HR and the % maximum HR (based on the mean) were only slightly higher for the non- FPS lift. Finally, for deliveryman # 3, the FPS appeared to be slightly less demanding than the manual keg unloading for three of the five physiological parameters, including HR increase, mean HR, and % maximum HR based on mean. However, the FPS scored higher for those parameters related to the maximum HR.

Comparison of FPS Keg Lifts and Non- FPS Keg Lifts Under Specific Conditions

The physiological results for the FPS and manual keg unloading lifts were then averaged across the three subjects and characterized to control for the potential HR confounder of time pressure. To do so, each of the five parameters was recalculated to reflect AM and PM values as well as "before lunch" and "after lunch" designations. The data was then analyzed for trends versus the values obtained for the overall day.

Generally, the physiologic demands of both the FPS and non-FPS lifts are greater during AM hours and before lunch. The notable exception to this is the extremely elevated HR increase in the non- FPS PM condition.

Statistical Results of Physiological Comparison

A series of student t-tests were performed to characterize the physiological variability between the FPS and Non-FPS keg lifts across the three subjects. The results of these are given in Tables 7.1 to 7.3. The only statistically significant physiological finding was that the FPS showed a lower HR increase across the subjects than the traditional manual keg unloading lift (t-value = 2.51,df = 22; p ~ 0.02). However, borderline significant results indicate that the FPS was associated with a higher percent of maximum HR (based on maximum heart rate) (t-value = -1.96,df

= 22; p ~ 0.06) and a higher HR maximum (t-value = -2.00, df = 22; p ~ 0.06). Finally, no significant physiological difference was found between the FPS and manual keg unloading conditions for the HR percent maximum (based on mean heart rate), (t-value = -0.68, df = 23; p ~ 0.50) and HR mean (t-value= -1.03, df = 22; p ~ 0.32).

Comparison of Delivery Truck Unload Lifts with other Tasks in Work Cycle

The lifting task of unloading full kegs with and without the FPS from the delivery truck was then compared to other tasks within the work cycle. The previously defined tasks were then evaluated using these parameters. These results and the formulas for the percent of maximum HR parameters are presented in Tables 8.1 to 8.3 and Figures 5 and 6. In addition to the above parameters, the percentage of maximum aerobic capacity required for a full work shift was also determined and found to be 24% for Subject #1, 24% for Subject #2, and 32% for Subject #3. This percentage was based on the mean work pulse throughout the day, beginning with the first keg stop, but excluding lunch. A shift profile of each deliveryman's heart rate is shown in Figures 7 a,b,c.

Overall, non-statistical results indicate that cooler work may be the most physiologically demanding task in the work cycle, as it scores highest across subjects in mean HR (133 bpm), maximum HR (137 bpm), % maximum HR range for mean (51%) and maximum (55%) rates. It is followed closely by 'wheeling the kegs inside', which scores highest in HR increase at 12 bpm and which has a HR mean of 125 bpm. Both the FPS and non- FPS lifting tasks appear to be less physiologically demanding than the other tasks in the cycle. Overall, results indicate that the Non-FPS lift may be the least demanding task, with a mean HR of 117 bpm. However, the FPS lift does show the lowest HR increase at 6 bpm, compared to 8 bpm for the lift without the FPS (See Figure 6).

Time Efficiency Results

The results of the time efficiency analysis indicate that the FPS lift requires an overall average of 40 seconds to complete compared to just 6 seconds for the traditional manual manual keg unloading lift. This difference was determined to be statistically significant (student t-value = 24.26, df = 24; p ~ 0.0001). However, a learning curve for the FPS was observed across the subjects as they became more proficient, and thus quicker, at the FPS set-up.

Subject # 1 had a mean total FPS lift time of 47 seconds, with a maximum time of 60 seconds and a minimum of 28 seconds. The total FPS lift time for Subject # 1 tended to decrease over the day (r = - .5699). Subject # 2 had a mean total FPS lift time of just 31 seconds, with a maximum of 51 seconds and a minimum FPS lift time of just 14 seconds. The total FPS lift time for Subject # 2 remained virtually constant over the day (r = 0.1021). Finally, Subject # 3 had a mean total FPS lift time of 41 seconds, with a maximum of 65 seconds and a minimum time of 20 seconds. As Subject #1, the total FPS lift time for Subject # 3 tended to decrease over the day (r = - .3229). However, non- FPS lift times differed little over the course of the day (r = - 0.0221) for all subjects, ranging from 5 to 8 seconds, for an overall average of 6 seconds.

The effect of the duration of the FPS set-up time on selected physiological parameters was also investigated. Overall, little correlation between FPS lift time and HR increase (r = - 0.1646), FPS lift time and mean HR (r = 0.0352), and FPS lift time and maximum HR (r = 0.1046) was determined across the subjects. However, correlations between FPS lift times and certain physiological parameters were determined for individual subjects. Specifically, Subject # 3 exhibited a relationship between longer FPS lift times and larger HR increases (r = .4045), while subject # 1 exhibited a relationship between a longer FPS lift time and higher mean HR (r = .4178). However, these correlations were slight.

General Job Analysis Results

Overall Workload

The total weight lifted during the beer delivery route for each subject is provided in Figure 8. The highest estimated minimum total weight handled was 21,864 lbs (Subject #3), while the average estimated minimum weight handled was 18,532 +/- 3915 lbs. These figures are comparable to the minimum weight totals determined for the soft drink beverage delivery industry which averaged 22,752 +/- 6,512 in a particular study (NIOSH Publication No. 96-109).

Cooler Workload

The average total weight lifted in coolers (as beer kegs and cases) was determined through video tape analysis to be 5853 +/- 569 lbs or 32% of the average estimated minimum weight handled. Seventy-one percent of this cooler weight was lifted in the form of either full kegs from the ground or full kegs from a keg top while 22% of this weight was lifted as cases of bottles. These results are given in Figure 9.

The average total times spent across subjects on different cooler tasks for each cooler visit during the beer delivery route are given in Figure 10. Although keg lifts account for 70% of the weight lifted in coolers, these lifts represent only 16% of the total time spent performing cooler work. Thus, the majority of the biomechanical workload appears to be handled in a short time period.

DISCUSSION

Biomechanics

The results of this evaluation suggest that the FPS offers a biomechanical advantage over the traditional lift by significantly reducing lower back compression levels ($p < 0.0001$) during the delivery truck unload phase. The traditional lift used during unload can be associated with over 1.5 times the NIOSH Recommended Compression Limit of 770 lbs. Such a back compression represents a high risk for low back injury in keg delivery personnel. On the other hand, the FPS lifts were shown to have associated back compressions below this limit and can be characterized as minimal risk activities for low back injuries.

Back compression values increased for both FPS and Non-FPS lifts as the lifts progressed, with the greatest compressions found in the middle and end phases of each type of lift. This back compression increase across phases can be explained in the Non-FPS (manual keg unloading lift) by the fact that the horizontal distance of the keg from the body increased as the subjects prepared to release the keg onto the ground during final phases. As well, increasing back compressions may also be explained by the fact that back flexion increased during the middle and end phase as the subjects lowered the keg to the ground.

The increase in back compression from beginning to end phases in the FPS lifts may also be explained by increasing back flexion as the lift progresses as well as a change in the direction of force on the subjects' hands. Typically, the beginning phase of the FPS lift was associated with a pull down of both the keg-controlling hand and the hand friction-feeding the rope. Such a resultant force direction produces minimal back compression; and thus, the beginning phase of the FPS was associated with the lowest mean compression value of 196 +/- 40 lbs (See Figure 3.2). During the middle phase, the direction of force on the keg-controlling hand changed and the reactant force became a horizontal or slightly upward pull while back flexion also increased. These factors resulted in an increased back compression mean of 368 +/- 187 lbs. However, the maximum back compression (550 lbs) reached during the observed FPS lifts was still below the Recommended Compression Limit of 770 lbs and significantly lower than the maximum back compression associated with a Non- FPS lift at 1261 lbs (See Figure 4.1).

Analysis revealed other significant risks for low back injury in tasks within the keg delivery cycle other than the traditional keg lift during truck unloading. The task “wheeling 2 kegs in” was associated with up to 1074 lbs of back compression. In addition, keg lifts from the ground in the confined space of the cooler were also associated with back compressions up to 1.5 times the RCL at 1169 lbs. Confined spaces prevented the subjects from using proper lifting technique which includes bending the knees rather than the back. Rather, the workers were forced to increase their back flexion as well as increase the horizontal distance of the load from their body. These cooler lifts were performed at virtually every stop for each subject. Such a risk for low back injury, because of its high probability and severity, should certainly be addressed with controls such as the FPS, or work practices including proper lifting techniques.

Physiology

The results of this evaluation suggest that the physiological difference between the FPS and manual keg unloading lift, although perhaps significant, is still unclear. The insignificant differences in HR mean and % maximum HR (based on mean HR) seem to indicate that the lifts may represent comparable physiologic demands. However, borderline statistically significant differences in % HR maximum (based on maximum HR), HR maximum, ($p = 0.06$) and significant differences in HR increase ($p = 0.02$) indicate that the use of the FPS is associated with slightly higher maximum heart rates and lower heart rate increases. These two findings may seem contradictory, but perhaps can be explained by the fact that the two parameters measure different physiologic aspects of the lifts.

The HR increase parameter is meant to measure transient HR effects while the other parameters tend to measure cumulative HR effects of activity. The difference between HR increase and the others parameters may be accounted for by the fact that the other HR parameters unavoidably include the activity of the FPS set–up that precedes the actual FPS lift. This set-up had to be learned and required the use of the arms above the head and stepping into and out of the delivery truck. It is possible that these activities could be responsible for the higher maximum HR and % maximum HR (based on maximum HR) associated with the use of the FPS. It is also possible that with practice in the use of the FPS that the maximum HR associated with this new device may decrease. However, the duration of the FPS lift time was found to have no significant effect on the mean HR increase, mean HR, or maximum HR across all subjects. Nonetheless, individual results suggested a slight trend between lower FPS lift time durations and lower HR increases and means. This is an area that requires further research.

The lower HR increase of the FPS may be explained by the fact that the Non-FPS (manual) keg unloading lift requires a great deal of energy over a very short time period (6 seconds). This means that this lift is more transient in nature and is associated with only a slight cumulative HR that is reflected in lower absolute HR maximums than the FPS lift, which is more cumulative and less transient. The observation that HR increase was markedly higher in the manual keg unloading during the PM hours may also be indicative of fatigue that could result from such a transient, yet high-demand, lift.

Although the physiological difference between the two lifts may be unclear, the physiologic demand each represents may be relatively small when compared to other tasks in the keg delivery work cycle. Cooler work and wheeling kegs inside the establishment (especially when going down steps, etc.) both represent substantially higher physiologic demands and should be addressed along with the truck unload phase of keg delivery. The mean percentage of aerobic capacity (based on mean heart rate) was 51 +/- 9 for cooler work and 44 +/- 8 for wheeling kegs inside. In addition, Subject # 3's percentage of aerobic capacity for the overall 8 hour day did approach fatigue levels (32 %), which are generally considered to be imminent when the work performed requires 33% or more of a worker's aerobic capacity for an 8 hr shift.[6,7,8,9,10] The fatigue of Subject # 3 can probably be accounted for by the fact that this particular person had the highest keg delivery load (44 kegs) for the day. Furthermore, Subject #3 completed the majority of his work-load in the morning hours before lunch.

Analysis of Subject # 3's HR shift profile also suggests fatigue in the morning hours as the recovery HR level rises from 80 BPM to 110 BPM from 9:45 AM to 11:00 AM (See Figure 7c). Rising recovery heart rates represent "incomplete recovery" that is indicative of fatigue.[3] There is a tendency for a higher physiologic demand during the morning hours across all three subjects. This finding is not surprising since the work schedule of each of the subjects was much heavier in the morning. It is quite possible that fatigue could be more of an issue on heavier delivery schedule days. Each subject remarked that the day being studied actually represented a somewhat lower workload than a normal workday. Thus, physiologic fatigue for the overall keg delivery day is an aspect that should also be addressed in terms of scheduling and work practices within the beer keg delivery industry. A number of fatigue-preventing practices were exhibited by the three subjects of this study. These included the clearing of the cooler first in the work cycle, combining billing and rest, and proper pacing techniques.

Time Efficiency

The results of this study reveal that the FPS averages almost seven times as long to use (40 seconds versus 6 seconds) than the traditional Non-FPS manual method (manual keg unloading lift). Since ease of use and time efficiency are important factors to any control introduced into the beer keg delivery industry, the extra time needed to use the FPS may be its most significant drawback. However, the results of a student t-test do suggest that learning may reduce this time-use disparity ($p \sim 0.15$) in subject # 3 and that the FPS was able to be used in a time (14 seconds) at least comparable to the traditional lift (6 second mean). Thus, this disadvantage could possibly be overcome if workers accepted the introduction of such a control and learned to master its use. In addition, a retrofit (described in the Conclusions section) in the way the FPS is attached above the kegs may also reduce its set up time.

General Job Analysis

The results of this study indicate that the overall biomechanical workload required during beer delivery routes, in terms of minimum total weight lifted per day (handling the same product twice), is equal to or less than other beverage delivery industries (e.g., soft drinks). This is due in part to the fact that beer keg delivery personnel typically handle heavier loads (as kegs) two to three times whereas soft drink delivery personnel tend to handle lighter loads three to four times.[1] The mean weight lifted per day during beer delivery routes (18,532 +/- 3915 lbs) may also be substantially higher, since the delivery personnel subjects indicated that the days on which the studies were conducted represented light to average delivery schedules. Nonetheless, even if beer delivery personnel do handle less weight per day than other beverage delivery workers they may be under greater biomechanical stress during individual lifts, as indicated by the high back compressions associated with keg lifts.

Detailed videotape task analysis of cooler work also indicated that the total weight lifted per day by beer delivery personnel may be minimized by proper work practices. Since the average total weight lifted in coolers (as beer kegs and cases) was determined to be 5,853 +/- 569 lbs or only 32% rather than 50% of the average estimated minimum weight handled, certain loads are actually handled only once. Such efficient handling is possible only if the cooler is cleared before kegs and cases are transported in, allowing the new products to be simply dropped off without further rearrangement. However, 71% of this cooler weight was lifted in the form of either full kegs from the ground or full kegs from a keg top, while only 22% of this weight was lifted as cases of bottles. In fact, subjects averaged 14 full keg lifts from the ground in the confined space of the cooler. Thus, it appears that current work practices minimize the total weight handled at the cost of a number of required high risk, confined keg lifts in the cooler.

CONCLUSIONS

The FPS friction feed pulley system does show potential as an effective ergonomic control in the beer delivery industry because it significantly reduces the back compression associated with keg unloading and thus reduces the risk for low back injury during the unload cycle. Although it does not represent a clear advantage or disadvantage physiologically, its potential biomechanical benefit is great enough to consider its use.

The FPS may be better utilized when unloading the kegs from the second tier of the delivery truck's storage compartment rather than from the first tier. First tier keg unloads, at a vertical height of approximately 36 inches, are actually at an optimal height for a traditional manual lift and were observed to be quite biomechanically smooth when performed manually. Manual lifts of kegs from the first tier of the delivery truck to the top of another keg already positioned on the handcart were especially effective, actually requiring very little upward force. The use of the FPS for first tier lifts, on the other hand, was somewhat awkward, requiring additional set-up time and perhaps additional physiological effort. This was because the worker was required to step up into the truck and perform overhead work while repositioning the FPS hook.

However, the FPS is especially effective in unloading the kegs from the second tier of the delivery truck's shelf, where the keg is at shoulder height, and the keg is more easily attached and lowered. Manual keg lifts from the second tier require the worker to lift the keg from a high vertical starting position 53 inches and extreme horizontal distance > 20 inches. Both of these parameters are identified in the 1991 NIOSH Lifting Equation as increasing the risk of low back injury when in excess of 30 inches and 10 inches respectively.[11] Thus, the use of the FPS to unload the kegs from the second tier of the delivery truck is recommended to reduce the risk of injury. However, because of the extra time needed for its use, it must be accepted by workers and mastered to become truly effective and should not be a required control at this time. The operation of the FPS may also be vastly improved with a minor re-design. The new design would replace the current hook-bar attachment with a permanently affixed, movable ball bearing push trolley that could be easily positioned from the ground over the necessary keg. Such a re-design would be ~$100 and would eliminate the need for much of the stepping into the truck and overhead work that is currently required when using the FPS and also save time.

In addition to the unloading cycle in keg delivery, other tasks must be addressed, especially those involving lifting and moving kegs in the confined space of coolers and the wheeling kegs in and up/down steps. These tasks also represent potentially significant risks for injury or fatigue. Many of these issues can only be addressed by cooperation with the management at individual delivery locations. In many cases, there may be easier routes into establishments that can be accessed if the site owner agrees. Contractual amendments might also be required to ensure that the individual sites take responsibility for the maintenance of coolers to reduce the time and effort that drivers have to take to rearrange coolers prior to unloading. As discussed, the confined lifts of kegs in the cooler are currently required to efficiently clear the cooler so that stock can be rotated and new products simply can be dropped off. Since these lifts are associated with a high risk for back injury, some consideration should be given to the use of a FPS type assist device within the cooler. Such a device would have to be permanent and movable as the proposed reconfiguration of the

FPS discussed above. Again, these may be able to be required per contract with delivery site management.

The biomechanical and physiological demand associated with wheeling kegs in, and up, and down stairs can be reduced by work practices and hand-cart redesign. The work practice of wheeling only one keg up/down steps significantly reduces the back compression associated with these tasks (See Table 2.2). However, such a practice would necessitate removing a keg before the steps are traversed and then going back up the steps to retrieve the second keg with the cart or by a manual carry. Such a work practice would add the biomechanical demand of an additional keg lift and the physiological demand of an additional stair climb, and may not be very beneficial. A better intervention might be the use of handcarts with tank-treads on the side of the frame towards the worker, or larger-diameter wheels, which would allow the hand-cart to move with less resistance on flat ground and up/down stairs. Such handcarts are commercially available and may offer a biomechanical and physiological advantage over the models currently employed.

FPS Evaluation Summarized Conclusions

Biomechanics

The FPS offers a biomechanical advantage over the traditional lift by inducing significantly lower back compression levels ($p<0.0001$) during the delivery truck unload phase.

- The traditional lift used during keg unloading can be associated with almost 1.5 times the NIOSH Back Compression Guideline of 770 lbs.

- The keg weight of 165 lbs significantly exceeds the NIOSH Lifting Limit of 51 lbs.

Physiology

- The FPS does not significantly differ physiologically from the traditional lift in terms of heart rate mean % maximum and heart rate mean.
- The FPS does show a significantly lower heart rate increase than the traditional lift ($p \sim 0.02$), but also a borderline significantly greater heart rate maximum than the traditional lift ($p \sim 0.06$) and heart rate peak % maximum ($p \sim 0.06$).

Time Efficiency

- Although the FPS averages almost 7 times as long to use (40 seconds versus 6 seconds) than the traditional manual method, learning does reduce the time-use disparity.

Overall Keg Delivery Cycle Conclusions

- Significant risk for the development of low back injuries exists among beer delivery workers. This is indicated by the estimation that a number of delivery tasks (including all unassisted keg lifts and the wheeling of kegs inside using a handcart) produce back compression levels which greatly exceed the NIOSH Back Compression Limit of 770 lbs.

- The mean weight lifted per day (18,532 +/- 3915 lbs) by personnel during beer delivery routes is equal to or less than other beverage delivery industries (e.g. soft drinks). However, beer delivery workers may be under greater biomechanical stress during individual lifts, as indicated by the high back compressions associated with keg lifts.

- The tasks of “cooler work” and “wheeling kegs inside” (especially when going down steps, etc.) both represent substantial physiologic and biomechanical demands and should be addressed along with the unload phase of keg delivery. The mean percentage of aerobic capacity (based on mean heart rate) was 51 +/- 9 for cooler work and 44 +/- 8 for wheeling kegs inside.

RECOMMENDATIONS

It is recommended that the Coors Distributing Company consider the following options to reduce the risk for low back injury and to minimize fatigue among beer keg delivery personnel:

- The use of assisted lift devices such as friction feed pulley systems to unload kegs from delivery trucks and also inside coolers.

- The use of hand-trucks with oversized wheels and tank treads on back side of the frame to improve level ground handling and pushing/ pulling up and down stairs.

- Cooperation with delivery site management to ensure that the easiest route inside the establishment is accessible by delivery personnel and that this route is properly maintained and cleared.

- Cooperation with delivery site management to place lift assist devices within coolers.

- Continue with an ergonomics training program to educate delivery personnel in proper lifting techniques and work practices that reduce biomechanical and physiological demand. These practices include among others: clearing coolers prior to unloading, combining billing and rest, and pacing work throughout shift by balancing heavy load stops with light.

- Establish an employee/ management committee to develop control solutions for ergonomic problems

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Figure 1: Close-up Illustration of Friction-Feed Pulley System (FPS)

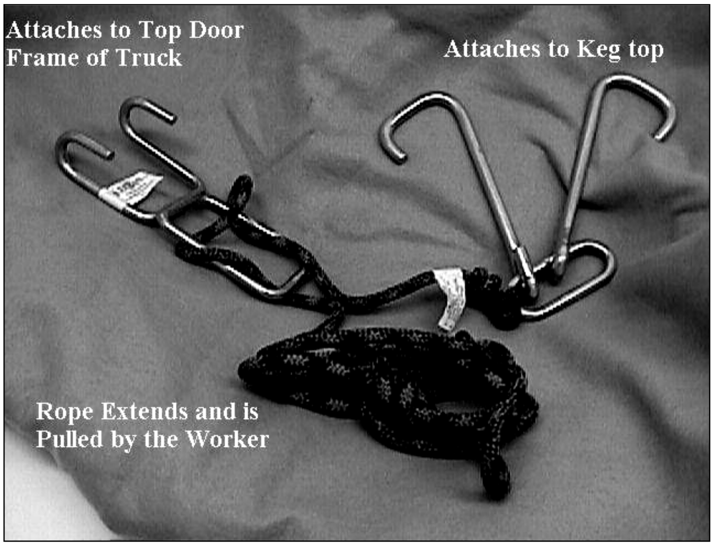


Figure 2: Illustration of Friction Feed Pulley System (FPS) During Actual Use

Figure 3: Back Compression(@L5/S1) in FPS Keg Lifts Versus Non-FPS Keg Lifts for Each Subjects and Lift Phase

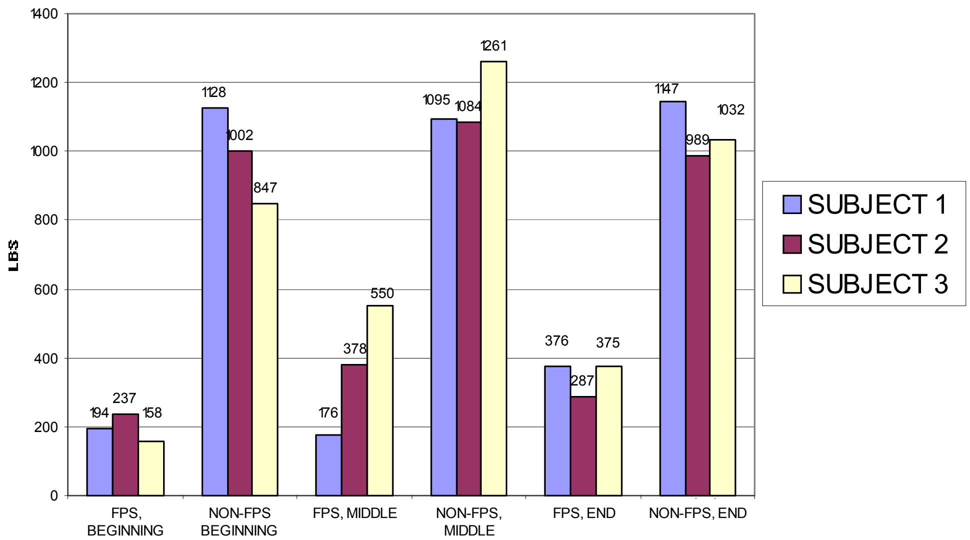


Figure 4: Back Compression Mean (@L5/S1) of Keg Delivery Tasks Across Subjects Versus the NIOSH Recommended Compression Limit (RCL)

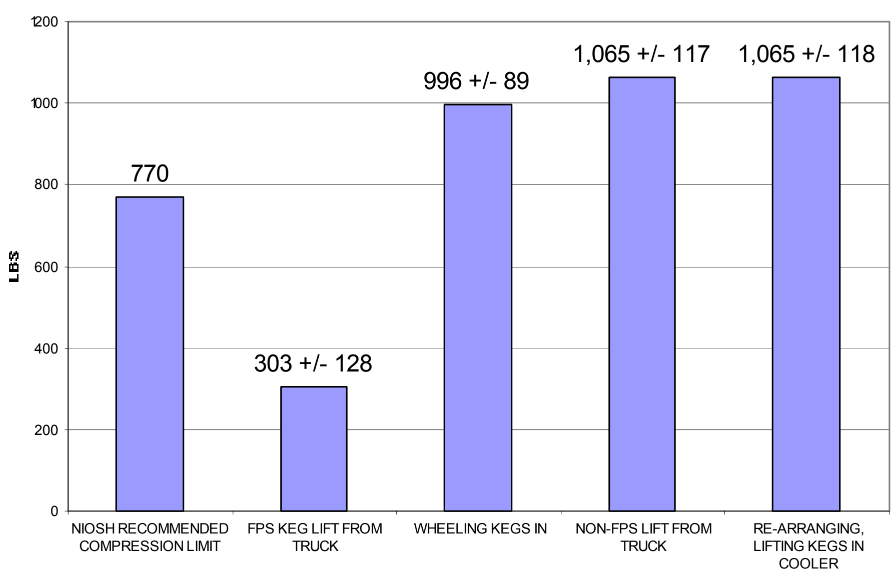


Figure 5: Mean Heart Rate for Tasks (All Subjects Combined)

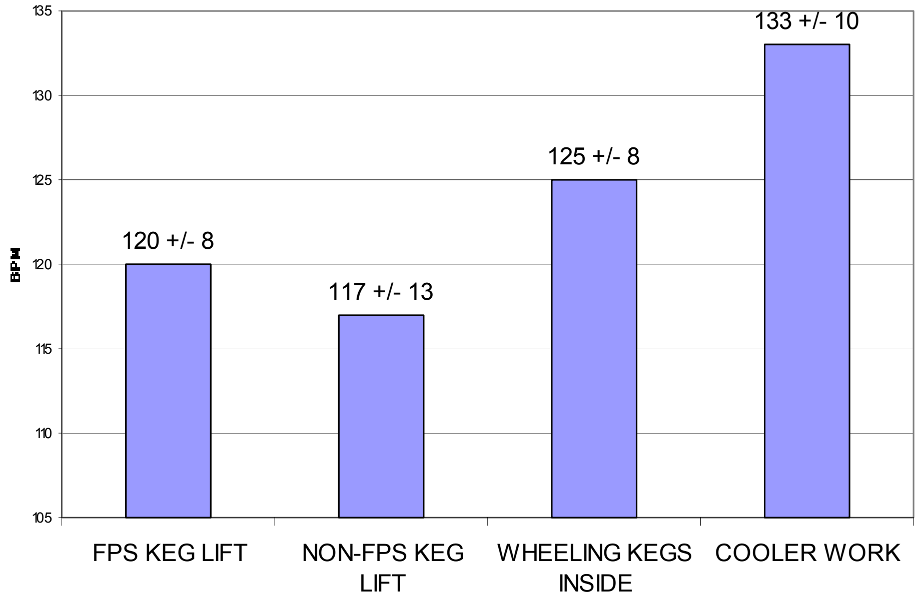
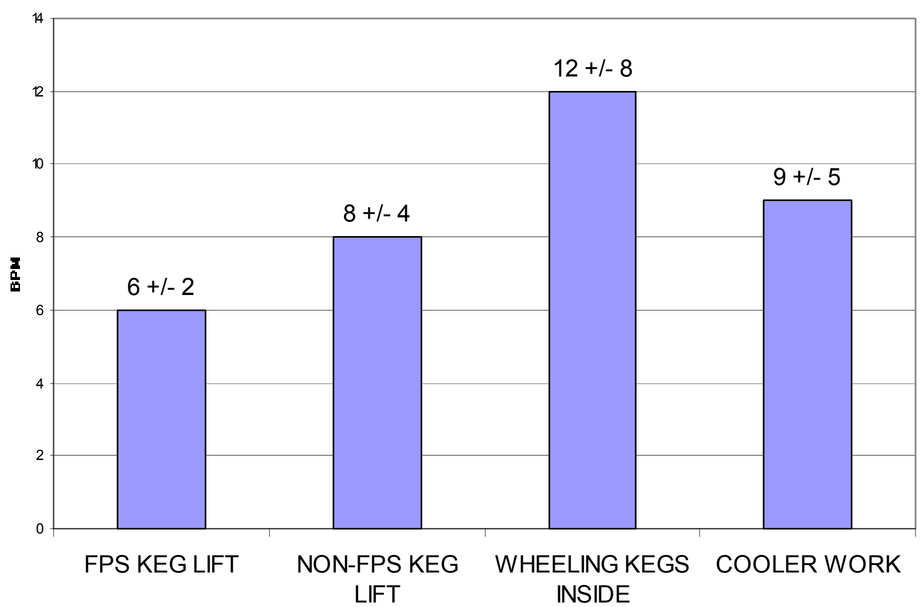


Figure 6: Mean Heart Rate Increase for Tasks (All Subjects Combined)



Figures 7 a, b, c: Heart Rate Profiles for Subjects Across Entire Shifts

a.

FIGURE 7a : HEART RATE OVER DAY (SUBJECT # 1)

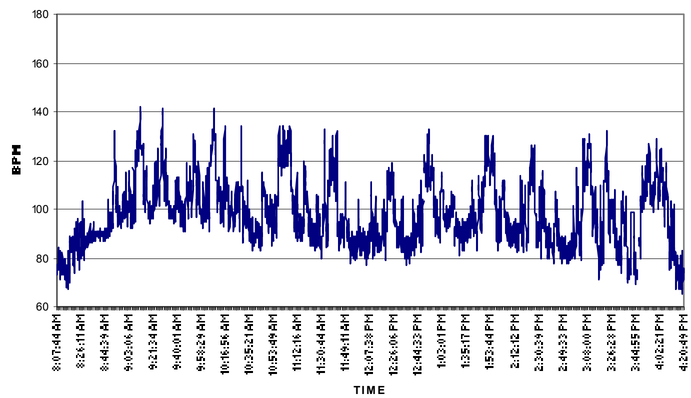


FIGURE 7b : HEART RATE OVER DAY (SUBJECT # 2)

b.

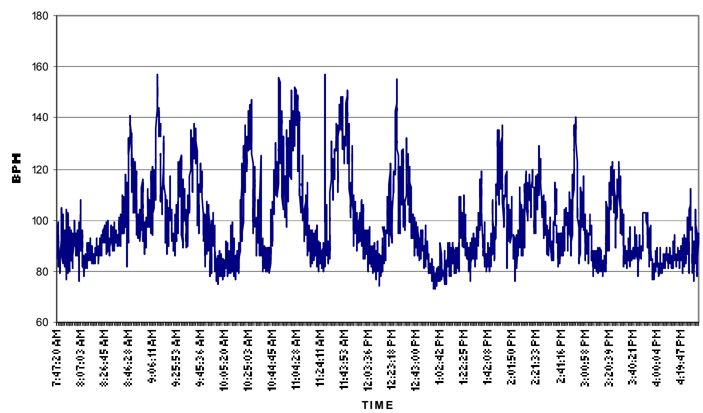


FIGURE 7c. : HEART RATE OVER DAY (SUBJECT # 3)

c.

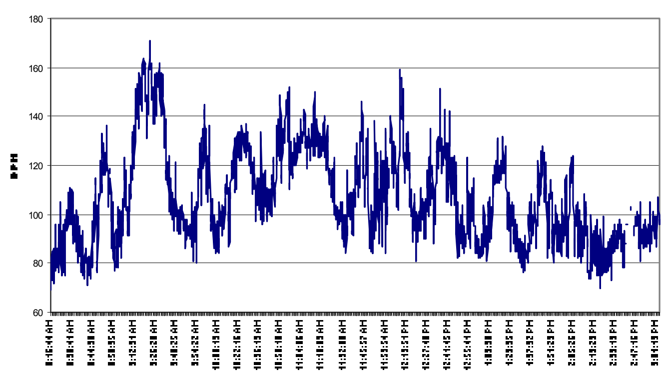
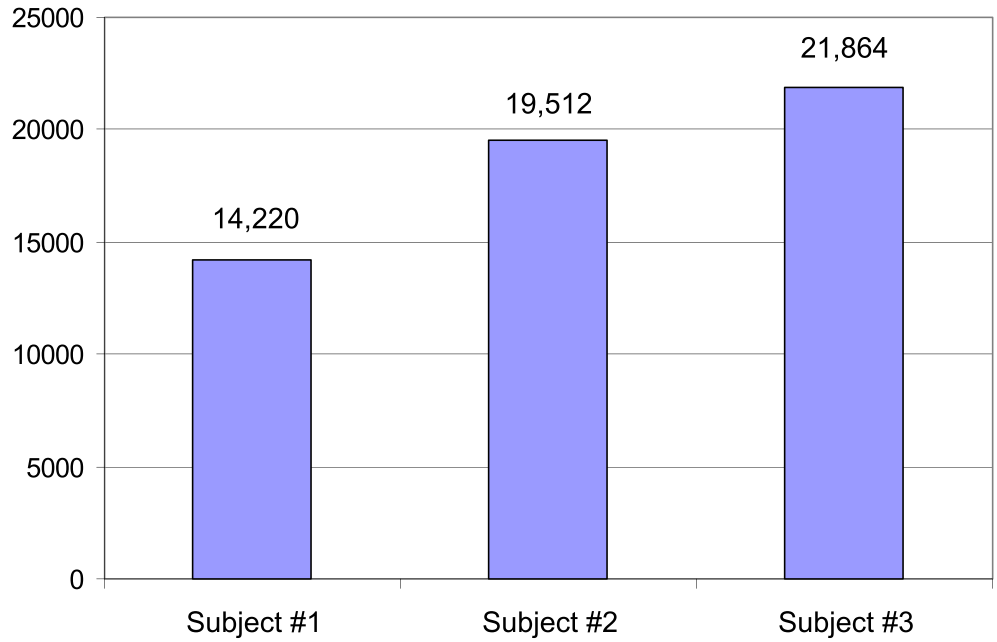


Figure 8: Total Weight (lbs) Lifted During Beer Delivery Route



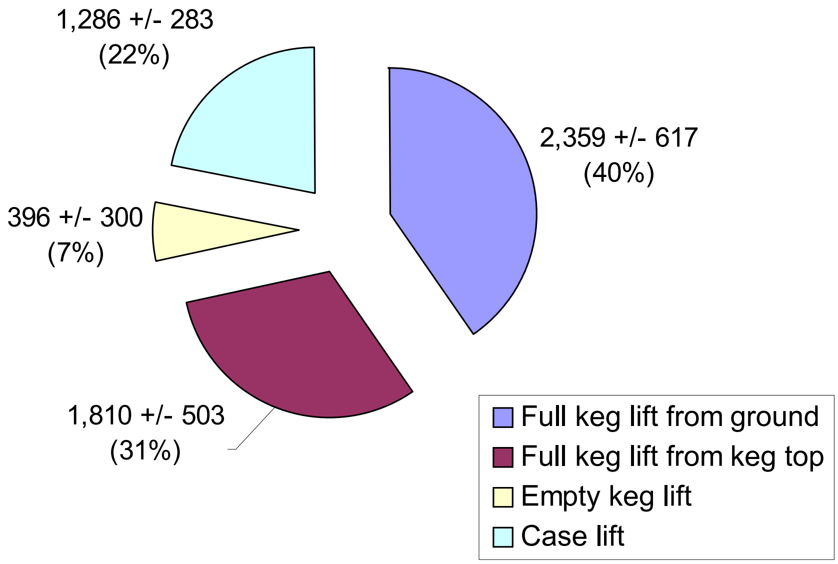
Total weight calculation:

	# Cases Delivered	#Kegs Delivered	Empty Keg Weight (lbs)	Full Case (Bottles) Weight (lbs)	Full Keg Weight (lbs)	Empty Case (Bottles) Weight (lbs)	Total Weight (lbs)
Subject #1	70	24	35	33	165	19	14,220
Subject #2	53	35	35	33	165	19	19,512
Subject #3	41	44	35	33	165	19	21,864

e.g. subject #1 : (70*33*2) + (70*19*2) + (24*165*2) + (24*35*2) = 14,220

***It is assumed each subject handled the load at least twice; once when loaded on the handcart and once when unloaded from the handcart.**

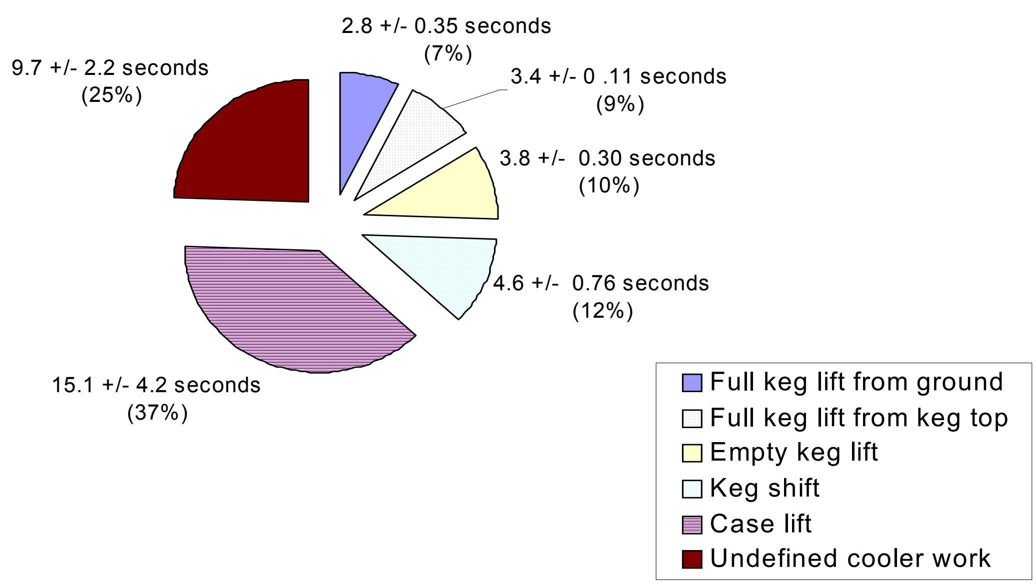
Figure 9: Mean Total Weight Lifted (lbs) of Beer Kegs and Cases in Coolers During Delivery Routes



Average Total Weight Lifted in Cooler: 5,853 +/- 569 lbs

1) Full keg lift from ground– typically defined as raising a keg from an initial position on the ground to a destination on top of another keg [vertical displacement = 32 inches (*cm).
2) Full keg lift from keg top—typically defined as a lowering of a keg from an initial position on top of another keg to a destination on the ground [vertical displacement= 32 inches (*cm).
3) Empty keg lift—typically defined as any movement of an empty keg where the keg is no longer in contact with a supporting surface.
4) Case lift—typically defined as any movement of a case of 24 beer or case of wine bottles where the case is no longer in contact with a supporting surface.

Figure 10: Mean Time Spent on Cooler Tasks for Each Cooler Visit During the Beer Delivery



Route
Average Total Time of Each Cooler Visit Across Subjects: 39.48 +/- 4.86 seconds

**** Full keg lift from ground--typically defined as raising a keg from an initial position on the ground to a destination on top of another keg [vertical displacement = 32 inches (*cm)**
**** Full keg lift from keg top--typically defined as a lowering of a keg from an initial position on top of another keg to a destination on the ground [vertical displacement= 32 inches (*cm)**
**** Empty keg lift--typically defined as any movement of an empty keg where the keg is no longer in contact with a supporting surface**
****Keg shift--typically defined as any movement of a keg (full or empty) in which the keg does not leave the surface supporting it**
****Case lift--typically defined as any movement of a case of 24 beer or case of wine bottles where the case is no longer in contact with a supporting surface**

****Undefined cooler tasks--typically involves wheeling kegs in cooler, connecting kegs, and ordering.**

Table 1: Subject Demographics

Parameter	SUBJECT # 1	SUBJECT #2	SUBJECT #3
Full-time start date	1995	1990	1991
Time off injury	No	Yes (1993)	Yes (1997)
Date of Study	7/15/97	7/17/97	7/18/97
# Kegs delivered on day of study	24	35	44
# Cases delivered on day of study	70	53	41
Resting Heart rate	71	76	77
Weight (lbs)	190	185	239
Height (in)	70	69	70.5
Age (years)	30	31	33
Functional reach	N/a	27	27
Max heart rate (220 – age in years)	190	189	187

Table 2.1: Biomechanical Evaluation of NON-FPS KEG LIFTS and FPS KEG LIFTS Using the Michigan 3D Static Strength Prediction Program Analysis

Task	Back Compression @ L5/S1, 5 cm (lbs)	Force on each hand (lbs, degrees)	Subject #
NON-FPS KEG LIFT			
Beginning	1128	82. 5@ -90	(1)
	1002	82. 5@ -90	(2)
	847	82. 5@ -90	(3)
Mean StDev	992 141		
Middle	1095	82. 5@ -90	(1)
	1084	82. 5@ -90	(2)
	1261	82. 5@ -90	(3)
Mean StDev	1147 99		
End	1147	82. 5@ -90	(1)
	989	82. 5@ -90	(2)
	1032	82. 5@ -90	(3)
Mean StDev	1056 82		
FPS KEG LIFT			
Beginning	194	R: 15.50 @ 58 L: 32.80 @ 30	(1)
	237	R: 15.50 @ 59 L: 32.80 @ 22	(2)
	158	R: 15.50 @ 59 L: 32.80 @ 20	(3)
Mean StDev	196 40		
Middle	176	R: 36.10 @ 22 L: 15.50 @ 60	(1)
	378	R: 15.50 @ 65 L: 36.10 @ -34	(2)
	550	R: 15.50 @ 53 L: 36.10 @ -27	(3)
Mean StDev	368 187		
End	376	R: 42.20 @-41 L: 15.50 @ 45	(1)
	287	R: 15.50 @ 63 L: 42.20 @ -47	(2)
	375	R: 15.50 @ 49 L: 42.20 @ -56	(3)
Mean StDev	346 51		

Table 2.2: Biomechanical Evaluation of Other Delivery Tasks Using Michigan 3D Static Strength Prediction Program Analysis

Task	Back Compression, @ L5/S1, 5 cm, in lbs,	Force on each hand (lbs, degrees)	ubject #
Wheeling in Kegs			
	899	55 @ -138	(1)
	1014	55 @ -129	(2)
	1074	55 @ -141	(3)
Mean StDev	996 89		
Wheeling Kegs up steps			
1 KEG	415	156 @ -50	(2)
2 KEGs	607	287 @ -50	(2)
Wheeling kegs downs steps			
1 KEG	380	114 @ -50	(2)
2 KEGs	438	211 @ -50	(2)
Cooler Work (lifting keg from ground)			
	936	82. 5 @ -90	(1)
	1169	82. 5 @ -90	(2)
	1090	82. 5 @ -90	(3)
Mean StDev	1065 118		

Table 3: Statistical Comparison Of FPS And Non-FPS Keg Lifts

Lift Phase	**FPS Keg Lift (Back compression @ L5/S1, 5cm, in lbs)**	**NON- FPS Keg Lift (Back compression @ L5/S1, 5cm, in lbs)**	**D**	**Subject #**	**Student's T-Test**
BEGINNING	194	1128	-934	1	
	237	1002	-765	2	
	158	847	-689	3	
MIDDLE	176	1095	-919	1	
	378	1084	-706	2	
	550	1261	-711	3	
END	376	1147	-771	1	
	287	989	-702	2	
	375	1032	-657	3	
Overall			-762		t-value = 22.84; Df= 8; P < 0.0001

Table 4.1: Subject #1 Physiologic Data for Non-FPS Lifts

TASK: NON- FPS LIFT	**% MAX HR RANGE FOR TASK** ***= Mean Task HR – Resting HR / Maximum HR Capacity - Resting HR***	**% MAX HR FOR TASK (PEAK)** ***= Maximum Task HR – Resting HR / Maximum HR Capacity - Resting HR***	**HR RATE INCREASE FOR TASK**	**HR AVERAGE**	**HR MAXIMUM**
Time AM *Of Day*	43	47	13	122	127
	39	42	7	118	121
	32	34	7	109	112
	15 (BEFORE LUNCH)	18	8	89	93
	32	38	14	109	116
	28	33	13	104	110
PM	21	29	13	96	105
AVERAGE	30 · (AM) 24 (PM) · (Before Lunch, BL) 27 (After Lunch, AL)	34 41 (AM) 30 (PM) · (BL) 33 (AL)	11 9 (AM) 12 (PM) 9 (BL) 13 (AL)	107 116 100 110 103	112 120 106 113 110
STANDARD DEVIATION	10 · (AM) 8 (PM) 12 (BL) 6 (AL)	9 7 (AM) 9 (PM) · (BL) 5 (AL)	3 3 (AM) 3 (PM) · (BL) 1 (AL)	12 7 9 15 7	11 8 10 15 6

Table 4.2 : Subject #1 Physiologic Data For FPS Lifts

TASK: **FPS LIFT**	**% MAX HR RANGE FOR TASK (MEAN)** ***= Mean Task HR – Resting HR / Maximum HR Capacity – Resting HR***	**% MAX HR FOR TASK (PEAK)** ***= Maximum Task HR – Resting HR / Maximum HR Capacity – Resting HR***	**HR RATE INCREASE FOR TASK**	**HR** **AVERAGE**	**HR** **MAXIMUM**
Time AM *Of Day*	45	48	8	124	128
	47	51	5	127	132
	39	43	5	118	122
	32	35	4	109	113
	34 (AFTER LUNCH)	35	3	112	113
	36	39	4	114	118
PM	34	36	3	111	114
	30	36	7	107	114
AVERAGE	37 44 (AM) 33 (PM) · (Before Lunch, BL) · (After Lunch, AL)	40 47 (AM) 36 (PM) · (BL) 37 (AL)	5 6 (AM) 4 (PM) · (BL) 4 (AL)	115 123 111 120 111	119 127 114 124 114
STANDARD DEVIATION	6 · (AM) 2 (PM) · (BL) 3 (AL)	6 · (AM) 2 (PM) 7 (BL) 2 (AL)	2 2 (AM) 2 (PM) · (BL) 2 (AL)	7 5 3 8 3	7 5 2 8 2

Table 5.1: Subject #2 Physiologic Data For Non-FPS Lifts

TASK: NON- FPS LIFT		% MAX HR RANGE FOR TASK (MEAN) *Mean Task HR – Resting HR / Maximum HR Capacity – Resting HR*	% MAX HR FOR TASK (PEAK) *Maximum Task HR – Resting HR / Maximum HR Capacity – Resting HR*	HR RATE INCREASE FOR TASK	HR AVERAGE	HR MAXIMUM
Time Of Day	AM	46	48	4	128	130
		36	42	6	117	123
		38	44	15	119	126
		30	39	12	119	126
		49	49	0	131	131
		55	56	2	138	139
	PM	28	33	9	108	113
		25	29	14	104	109
AVERAGE		38 · (AM) · (PM) · (Before Lunch, BL) 27 (AfterLunch, AL)	43 · (AM) · (PM) · (BL) 31 (AL)	8 · (AM) · (PM) · (BL) 12 (AL)	119 124 106 124 106	124 128 111 128 111
STANDARD DEVIATION		11 9 (AM) 2 (PM) 9 (BL) 2 (AL)	9 6 (AM) 3 (PM) 6 (BL) 3 (AL)	6 · (AM) · (PM) · (BL) 4 (AL)	11 10 3 10 3	10 7 3 7 3

Table 5.2 : Subject # 2 Physiologic Data For FPS Lifts

TASK: FPS LIFT		% MAX HR RANGE FOR TASK *Mean Task HR – Resting HR / Maximum HR Capacity – Resting HR*	% MAX HR FOR TASK (PEAK) *Maximum Task HR – Resting HR / Maximum HR Capacity – Resting HR*	HR RATE INCREASE FOR TASK	HR AVERAGE	HR MAXIMUM
Time Of Day	AM	32	42	13	112	124
		32	38	10	112	119
		35	37	5	116	118
		45	50	11	127	133
		35	42	11	115	123
		48	50	3	130	133
		32 (before lunch)	43	11	113	125
		32 (before lunch)	35	2	112	115
	PM	33	42	8	113	124
		36	39	3	117	120
		30	37	14	110	118
		33	37	8	113	118
		29	35	10	109	116
AVERAGE		35 · (AM) 32 (PM) 36 (Before Lunch, BL) · (After Lunch, AL)	41 · (AM) 38 (PM) 42 (BL) 38 (AL)	9 · (AM) 8 (PM) · (BL) · (AL)	115 120 112 117 112	122 125 119 124 119
STANDARD DEVIATION		6 · (AM) · (PM) 6 (BL) 3 (AL)	5 · (AM) 3 (PM) 6 (BL) 3 (AL)	4 · (AM) 4 (PM) 4 (BL) 4 (AL)	6 8 3 7 3	6 7 4 7 4

Table 6.1: Subject #3 Physiologic Data For Non-FPS Lifts

TASK: NON-FPS LIFT		% MAX HR RANGE FOR TASK (MEAN) *Mean Task HR – Resting HR / Maximum HR Capacity – Resting HR*	% MAX HR FOR TASK (PEAK) *Maximum Task HR – Resting HR / Maximum HR Capacity – Resting HR*	HR RATE INCREASE FOR TASK	HR AVERAGE	HR MAXIMUM
Time Of Day	AM	65	67	5	149	151
		70	72	1	154	156
		36	41	1	117	122
		44	46	5	126	128
		50	52	2	132	134
		51	52	2	133	134
		47	49	7	129	131
		47	50	4	129	132
		26	29	2	106	109
		25	31	14	105	111
	PM	38	41	8	119	122
		38	40	3	119	121
		31	36	16	111	117
AVERAGE		44 · (AM) · (PM) · (Before Lunch, BL) n/a (After Lunch,AL)	47 · (AM) · (PM) · (BL) n/a (AL)	5 · (AM) · (PM) 5 (BL) n/a (AL)	125 131 114 125 n/a	128 133 118 128 n/a
STANDARD DEVIATION		14 13 (AM) 6 (PM) 14 (BL) n/a (AL)	13 · (AM) · (PM) · (BL) n/a (AL)	5 · (AM) · (PM) · (BL) n/a (AL)	15 15 7 15 n/a	14 14 5 14 n/a

Table 6.2 : Subject # 3 Physiologic Data For FPS Lifts

TASK: **FPS LIFT**		**% MAX HR RANGE FOR TASK (MEAN)** ***Mean Task HR – Resting HR / Maximum HR Capacity – Resting HR***	**% MAX HR FOR TASK (PEAK)** ***Maximum Task HR – Resting HR / Maximum HR Capacity – Resting HR***	**HR RATE INCREASE FOR TASK**	**HR** **AVERAGE**	**HR** **MAXIMUM**
Time Of Day	AM	34	54	4	115	136
		65	75	1	149	160
		39	41	3	120	122
		39	48	5	120	130
		44	45	5	125	129
		50	56	6	132	139
		49	53	4	131	135
		49	53	3	131	135
		46	48	0	128	130
	PM	36 (before lunch)	42	5	117	123
		35	40	4	116	121
		29	36	4	109	117
AVERAGE		43 45 (AM) 32 (PM) 43 (before lunch, BL) n/a (after lunch, AL)	49 52 (AM) · (PM) 42 (BL) n/a (AL)	4 · (AM) 4 (PM) · (BL) n/a (AL)	124 127 113 124 n/a	131 134 119 131 n/a
STANDARD DEVIATION		10 · (AM) · (PM) 10 (BL) n/a (AL)	10 · (AM) · (PM) · (BL) n/a (AL)	2 · (AM) · (PM) · (BL) n/a (AL)	11 10 5 11 n/a	11 11 3 11 n/a

Table 7.1: Summary of Individual Physiological Results: FPS versus Non-FPS Lifts

Subject ID	% Maximum HR (based on Mean HR)		% Maximum HR (based on Maximum HR)		Hr Increase		HR Mean		HR Maximum	
	FPS	Non-FPS	FPS	Non-FPS	FPS	Non-FPS	FPS	Non-FPS	FPS	Non-FPS
#1	45	43	48	47	8	13	124	122	128	127
	47	39	51	42	5	7	127	118	132	121
	39	32	43	34	5	7	118	109	122	112
	32	15	35	18	4	8	109	89	113	93
	34	32	35	38	3	14	112	109	113	116
	36	28	39	33	4	13	114	104	118	110
	34	21	36	29	3	13	111	96	114	105
#2	32	46	48	42	4	6	128	117	130	123
	32	36	42	44	13	15	112	119	124	126
	35	38	38	39	10	12	112	110	119	126
	45	30	37	49	5	0	116	131	118	131
	35	49	50	56	11	2	127	138	133	139
	48	55	43	33	11	9	113	108	125	113
	33	28	42	29	8	14	113	104	124	109
	30	25								
#3	34	65	54	67	4	5	115	149	136	151
	65	70	75	72	1	1	149	154	160	156
	39	36	41	41	3	1	120	117	122	122
	44	44	45	46	5	5	125	126	129	128
	50	50	56	52	6	2	132	132	139	134
	49	51	53	52	4	2	131	133	135	134
	49	47	53	49	3	7	131	129	135	131
	46	47	48	50	0	4	128	129	130	132
	36	26	42	29	5	2	117	106	123	109
	35	25	40	31	4	14	116	105	121	111
	29	38	36	41	4	8	109	119	117	122

Table 7.2: Differences of Mean Physiological Parameters: FPS Keg Lift versus Non-FPS Keg Lift for Each Subject

Subject	Heart Rate % Maximum Based on Mean Heart Rate (FPS)	Heart Rate % Maximum Based on Mean Heart Rate (Non-FPS)	D	Heart Rate % Maximum Based on Maximum Heart Rate (FPS)	Heart Rate % Maximum Based on Maximum Heart Rate (Non-FPS)	D
#1	38.1	30.0	**-8.1**	41.0	34.4	**-6.6**
#2	36.3	38.4	**2.1**	42.9	41.7	**-1.2**
#3	43.3	45.4	**2.1**	49.4	48.2	**-1.2**

Subject	Heart Rate Increase (FPS)	Heart Rate Increase (Non- FPS)	D
#1	4.6	10.7	**6.1**
#2	8.9	8.3	**-0.6**
#3	3.5	4.6	**1.1**

Subject	Heart Rate Mean (FPS)	Heart Rate Mean (Non- FPS)	D	Heart Rate Maximum (FPS)	Heart Rate Maximum (Non-FPS)	D
#1	116.4	106.7	**-9.7**	120.0	112.0	**-8.0**
#2	117.3	118.1	**0.8**	124.7	123.9	**-0.8**
#3	124.8	127.2.	**2.4**	131.5	130.0	**-1.5**

Table 7.3 Statistical Analysis of Mean Physiological Parameters: FPS Keg Lift versus Non-FPS Keg Lift (Combined for all Subjects)

Variable	Mean Difference *	Student's t	Df	P-value
HR % Maximum (based on Mean HR)	-1.309	-0.68	23	0.50
HR % Maximum (based on Maximum HR)	-2.965	-1.96	22	0.0625
HR Increase:	2.221	2.51	22	0.02
HR Mean:	-2.165	-1.03	22	0.316
HR Maximum:	-3.468	-2.00	22	0.0581
*The mean differences given above are averages of the three means for the appropriate column of Table 7.2. For example, the mean difference of -1.3 for the HR % Maximum (based on Mean HR) in Table 7.2 is calculated as the average of the three means in Table 7.1: 1/3(-8.1 + 2.1 +2.1)=-1.3. This averaging scheme gives equal weight to each of the three employees				

Table 8.1 : Subject # 1 Physiologic Data Across Tasks

TASK	% MAXIMUM HR (BASED ON MEAN HR) = *Mean Task HR – Resting HR / Maximum HR Capacity- Resting HR*	% MAXIMUM HR (BASED ON MAXIMUM HR) = *Maximum Task HR – Resting HR / Maximum HR Capacity- Resting HR*	HR INCREASE FOR TASK	HR AVERAGE	HR MAXIMUM
NON-FPS KEG LIFT	38 (AM)	41 (AM)	9	116	120
	24 (PM)	30 (PM)	12	100	106
OVERALL	30 +/- 10	34 +/- 9	11 +/- 3	107 +/-12	112 +/- 11
FPS KEG LIFT	44 (AM)	47	6	123	127
	33 (PM)	36	4	111	114
OVERALL	38 +/- 6	41 +/- 7	5 +/- 2	116 +/- 7	120 +/- 8
WHEELING KEGS INTO BAR	49 (AM)	50	5	129	131
	50 (AM)	55	7	131	136
	34 (PM)	39	12	112	118
	37 (PM)	47	16	115	127
OVERALL	43 +/- 8	48 +/- 7	10 + - 5	122 +/- 10	128 +/- 8
COOLER WORK: (ARRANG-ING, LIFTING KEGS IN COOLER)	56 (AM)	59	9	138	141
	55 (AM)	57	5	137	139
	n/a (PM)	n/a	n/a	n/a	n/a
	29 (PM)	33	8	106	110
OVERALL	47 +/-15	50 +/-14	7 +/- 3	128 +/- 18	130 +/- 17

Table 8.2 : Subject # 2 Physiologic Data Across Tasks

TASK	% MAXIMUM HR (BASED ON MEAN HR) *= Mean Task HR – Resting HR / Maximum HR Capacity- Resting HR*	% MAXIMUM HR (BASED ON MAXIMUM HR) *= Maximum Task HR – Resting HR / Maximum HR Capacity- Resting HR*	HR INCREASE FOR TASK	HR A V E R A G E	HR M A X I M U M

NON-FPS KEG LIFT	42 (AM)	46 (AM)	7	124	128
	27 (PM)	31 (PM)	12	106	111
OVERALL	38 +/- 11	42 +/- 9	8 +/- 6	118 +/-12	124 +/- 10
FPS KEG LIFT	38 (AM)	43	9	120	125
	32 (PM)	38	8	112	119
OVERALL	36 +/- 7	43 +/- 5	9 +/- 3	117 +/-	125 +/- 5
WHEELING KEGS INTO BAR	45 (AM)	50	9	127	132
	52 (AM)	57	12	135	140
	26 (PM)	29	10	105	111
	52 (PM, before lunch)	70	37	135	135
OVERALL	44 +/- 12	52 +/- 17	17 + - 13	126 +/- 14	135 +/- 18
COOLER WORK: (ARRANG-ING, LIFTING KEGS IN COOLER)	48 (AM)	55	12	130	138
	54 (AM)	59	3	137	143
	49 (PM)	57	28	131	140
	65 (PM, before lunch)	70	3	149	155
OVERALL	54 +/-8	60 +/-7	14 +/-12	137 +/- 9	144 +/- 8

Table 8.3 : Subject #3 Physiologic Data Across Tasks

TASK	% MAXIMUM HR (BASED ON MEAN HR) *= Mean Task HR – Resting HR / Maximum HR Capacity- Resting HR*	% MAXIMUM HR (BASED ON MAXIMUM HR) *= Maximum Task HR – Resting HR / Maximum HR Capacity- Resting HR*	HR INCREASE FOR TASK	HR AVERAGE	HR MAXIMUM
NON-FPS KEG LIFT	48 (AM)	51 (AM)	3	131	133
	33 (PM)	37 (PM)	10	114	118
OVERALL	45 +/- 14	48 +/- 13	5 +/- 4	127+/-15	130 +/-14
FPS KEG LIFT	45 (AM)	52	4	127	134
	32 (PM)	38	4	113	119
OVERALL	43+/- 10	49 +/- 11	4 +/- 2	125+/-11	132 +/-12
WHEELING KEGS INTO BAR	45 (AM)	50	4	127	132
	42 (AM)	43	3	123	124
	48 (AM)	52	8	130	134
	44 (PM, before lunch)	49	19	126	131
OVERALL	45 +/- 3	49 +/- 4	9 +/- 7	127 +/-3	130 +/-4
COOLER WORK: (ARRANG-ING, LIFTING KEGS IN COOLER)	47 (AM)	51	6	129	133
	N/a (AM)	N/A	N/A	N/A	N/A
	54 (AM)	57	6	136	140
	51 (PM, before lunch)	57	5	133	140
OVERALL	51 +/- 4	55 +/- 3	6 +/- 1	133 +/-4	138 +/- 4

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