Evaluation of Musculoskeletal Disorder Risk

in

Hotel Housekeeping Jobs

Prepared by:

Steven F. Wiker, Ph.D., CPE

Ergonomic Design Institute

4 July 2013

Executive Summary

A large number of hotels were inspected by Federal and California OSHA compliance officers and their ergonomics experts. All federal and state OSHA agencies, with the exception of one, issued no citations related to occupational musculoskeletal disorder hazard. Cal/OSHA, San Francisco, CA, issued a hazardous workplace citation indicating that housekeepers were at substantial risk for development of musculoskeletal disorders (MSDs).

In response to the citation, a study was initiated to determine if housekeeper job tasks presented risk for development of MSDs. The study was performed at the Hyatt Regency, Bellevue, Washington, where the hotel rooms were of equivalent design, layout and decor to the hotel cited by Cal-OSHA. Assessment of musculoskeletal disorder and injury risk was assessed using National Institutes for Occupational Safety and Health (NIOSH) advocated assessment protocols.

Work sampling, biomechanical and metabolic burden analyses were conducted with housekeepers performing their jobs using a variety of individually preferred methods. Results showed a wide range of forces and postures were employed to complete 34 tasks involved with housekeeping assignments. Housekeepers, as all workers, are exposed to some degree of musculoskeletal disorder risk factors in the workplace. However, exposures to acute and cumulative biomechanical stressors, as well as heart rate indices of aerobic demand, fell into acceptable zones of ergonomic design. Measured MSD risk factor exposures were sufficiently low to be deemed safe by the National Institutes for Occupational Safety and Health (NIOSH) assessment protocol. Moreover, the housekeeper's job was found to be strongly compliant with NIOSH recommended administrative controls for mitigation or elimination of MSD hazards (e.g., task variety, job rotation, adequate exposure to micro-breaks, decision latitude in execution of work, etc.).

Claims that housekeepers were compelled to lift well over 100 pounds when making beds, or that housekeepers were exposed to serious musculoskeletal injury risk, proved unfounded. Such claims were rejected by direct measurement of stressors using widely accepted analytical tools and methods used by the ergonomics community and advocated by the NIOSH MSD assessment protocol. Housekeeper's jobs proved to be safe from MSD hazard following analysis of acute and cumulative musculoskeletal disorder risk. This finding was corroborated by very low musculoskeletal injury incidence reported by the U.S. Department of Labor (DOL). Housekeeper musculoskeletal injury and illness incidence was comparable to that of the safest jobs noted by the Bureau of Labor Statistics (DOL), and approached population background levels of MSD incidence that are unrelated to occupational exposures.

All jobs have opportunities for ergonomic and industrial engineering productivity and quality improvement. Housekeeping jobs are no exception. Housekeepers were provided with several proposed housekeeping aids that were claimed to provide ergonomic and health and safety benefits. Nearly all the proposed and provided aids were untested. We tested the value of long-handled scrubbing tools, bed making or tucking aids, use of kitchen rice paddle tuck tools adopted by housekeepers, and found in most cases there were no benefits or that they increased risk of development of systemic fatigue or MSDs. Room layout, furnishings, decor and fixtures materially affected cleaning times and challenges. Any changes made to housekeeping tasks, tools, or paradigms from those studied here, should be evaluated using standard industrial engineering and ergonomics methods to determine their worthiness before implementation.

Contents

Contents

Contents

List of Equations

List of Figures

List of Figures

List of Figures

List of Figures

List of Figures

List of Tables

1. Introduction

Questions arose regarding housekeeper risk of developing acute and cumulative musculoskeletal disorders (MSDs) as a result of performing their job. A large number of hotels were inspected by Federal and California OSHA compliance officers and both internal and external ergonomics experts. All federal and state OSHA agencies, except for of one, issued no citations related to poor ergonomic design of the work. Cal/OSHA, San Francisco, CA, issued a hazardous workplace citation indicating that housekeepers were at substantial risk for development of MSDs.

In response to the citation, a study was performed to determine if housekeeper job tasks presented risk for development of MSDs. Assessment protocols and criteria advocated by the National Institutes for Occupational Safety and Health (NIOSH) were used to make evaluations and assessments. If risks were found, recommendations for engineering or administrative controls were to be made that are compliant with NIOSH MSD hazard control protocols.

The study was performed at the Hyatt at Bellevue, Washington, where the hotel rooms were of equivalent design and layout from an ergonomics analysis standpoint to those of the hotel cited by Cal-OSHA. This report summarizes the methodology, results, findings, conclusions and rationale for any recommendations.

2. Background

The National Institutes of Occupational Safety and Health (NIOSH) has increased focus upon understanding and preventing worker injuries within the service sector. Concentration on this industrial sector has grown for several reasons: a) interventions have reduced incidence of musculoskeletal disorders (MSDs) in targeted industries, 2) jobs in targeted sectors have moved overseas changing incidence-driven priorities, and 3) service industry workforce growth has been substantial within the United States.

Hotel housekeepers, a segment of service workers, have been labeled by some as a population at risk of musculoskeletal disorders or injuries. Claims examined revealed that they were not based upon accepted scientific or engineering evidence, or by incidence and severity rates reported in industrial safety and health statistics. Limited studies of housekeeper activities have been performed. Studies of bed making activities showed housekeepers were exposed to biomechanical stresses that fell within exposures zones considered to be safe by NIOSH (i.e., present a small nonzero, or nominal, risk of injury).

In the following sections, previous studies of housekeeper risk for development of musculoskeletal disorder (MSD) or musculoskeletal injury (MSI) are reviewed. Gaps in knowledge, needed to determine if housekeeper jobs are safe and healthful work, are also addressed.

2.1. Schema for MSI and MSD Hazard Detection and Prevention

The NIOSH paradigm for protection from occupationally-induced musculoskeletal injuries (MSIs) and musculoskeletal disorders (MSDs) requires one to assess biomechanical stresses to tissues and control levels of stress to not exceed tissue tolerance limits. Tolerance limits are either acute or cumulative; depending upon the tissue and nature of stressor. NIOSH has relied upon multidisciplinary expert panels to recommend exposure limits. Some biomechanical stress is requisite for tissue health and resistance to injury or illness. However, excessive amounts are generally agreed to be harmful. The goal is to work with healthful levels of musculoskeletal stress.

A large number of studies had been performed before 1981 addressing biomechanical stress, epidemiological analysis of injury incidence and severity, psychophysical strain and aerobic power demands associated with physical work. NIOSH assembled a highly-experienced panel of respected biomechanists, ergonomists, epidemiologists, work physiologists and physicians to develop guidelines for limiting biomechanical stresses linked to low back injuries. The panel reviewed previous relevant research and studies, and developed expert consensus-based recommendations for prevention of lifting-related risk of MSIs for industry. Extensive review of the literature and justifications for the panel's recommendations for exposure limits were provided in the panel's report of findings and recommendations entitled "Work Practices Guide for Manual Lifting" (1981).

The panel developed a "lifting equation" referred to as the NIOSH Work Practices Guide for Manual Lifting (NIOSH WPG) to assist laypersons and others in evaluating and designing lifting tasks for various combinations of load weights, frequencies and durations of lifts, and geometries of lifts. The lifting equation provided guidance for reducing risk of injury and for improving lifting task design from a human performance perspective.

Depending upon the nature of the load, lift trajectories or geometries, and lifting frequency and duration, the equation provided recommendations for lowering loads lifted to levels deemed safe. Recommendations were driven based upon the following objectives: 1) reduction of low back injury risk, 2) control of work physiological demand, 3) reduction of perceived or psychophysiological strain, or 4) combination of all attributes. Thus, not all reductions in loads or lifting task properties were made simply for protection from low back injury as some believe.

Some exertions or postures cannot be analyzed using the lifting equation. For those exertions, the NIOSH panel recommended evaluating lumbar disc compression using static biomechanical models such as the Michigan Static Strength and Low Back Compression Prediction model (3DSSP). Such models provide estimates for lumbar disc compression as well as task-induced strength demands and population strength capabilities. Aerobic power demands and psychophysical tests could be assessed with other tools to check for acceptable lifting task design (NIOSH, 1981). The panel recommended Action and Maximum Permissible Limits for disc compression at 3,400 and 6,400 N respectively.

Some have faulted the NIOSH WPG because it does not systematically forecast low back injury rates. The expert consensus-based lifting task design guidance was based upon comprehensive first-principles analyses--not just incidence of injury. The NIOSH WPG was not constructed with the intent that it be used as epidemiological prediction tool (i.e., forecasting rates of low back injury (LBI) or disorders (LBD) with precision). Essentially, the equation is a multi-attribute utility function that at times drives lifting guidance based upon work physiological limits, psychophysical design constraints or biomechanical criteria. One would have to understand the underlying biomechanics to determine when excessive load:AL/MPL ratios presented risk of lumbar spine injury.

Unlike the NIOSH WPG lifting equation, static biomechanical model disc compression limits were set specifically for prevention of low back injury. Unfortunately, some mistakenly map biomechanical disc compression ALs and MPLs meanings onto the meaning of NIOSH WPG AL's and MPL's and vice versa. While they share the same appellation, they have never shared the same foundations or meanings from a low back injury prevention standpoint.

The ratio of a lifted load to NIOSH WPG Action Limit (AL) determines the category of lifting task design acceptability. Static biomechanical disc compressions below the AL, are considered to present nominal risk of low back injury. If lumbar disc compression fell between 3,400 N and 6,400 N, the exertion would be considered acceptable if effective administrative controls were in place. If lumbar disc compression exceeded 6,400 N the lift was considered unacceptable and could only be made acceptable through redesign. Arguments for setting exposure limits were sufficiently founded that they gained wide acceptance within the ergonomics and occupational biomechanics communities.

The NIOSH WPG lifting equation was modified in 1991 to: a) expand the range of postures and exertions that could be addressed, b) address load coupling quality, c) expand the number of lifting duration categories, and d) increased the sensitivity of the equation to physiological workload and psychophysical ratings of lifting tasks (Waters, Putz-Anderson, Garg, & Fine, 1993). The Action and Maximum Permissible Limit labels were replaced by the Recommended Weight Limit (RWL), and employed the lifting severity index which was the ratio of the load to the RWL.

2.1.1 Absence of Dynamic Biomechanical Criteria for LBI Hazard

Force results from accelerating a mass. Moments are cross products of moment arm lengths and magnitudes of forces applied to the body segment. Static biomechanical models use acceleration due to gravity of 1 Gz. Dynamic biomechanical models include accelerations below or beyond that of gravity which are caused by changes in movement rates of loads and limb segments during exertions. Whole body dynamic biomechanical models typically produce greater resultant loads and moments acting upon the lumbar spine and other articulations in the body during positive acceleration epochs.

NIOSH set Action and Maximum Permissible disc compression loads based upon static load tests of disc tissue. No such limits have been proposed for disc dynamic loads. Neither type of model predicts cumulative injury risk.

Some have argued that dynamic disc loads exceeding statically-determined tissue tolerance limits present a greater risk of tissue injury. This comparison cannot be made because tissue tolerances change as loads acting upon discs become more dynamic. When loads acting upon the disc become dynamic, differences in load acceleration onset rates, peak values, and durations at peak values, have demonstrated materially different tolerances to such forces (See Wiker & Miller, 1983 for bibliography).

Humans run, jump, collide with other running humans in sports, without material risk of disc injury--even though the dynamic forces can exceed levels of forces and moments that are deemed hazardous if applied statically. Altered tissue tolerance associated with dynamic loading is a result of nonlinear viscoelastic properties of discs. These properties allow humans to perform a wide range of dynamic activities which result in very high dynamic loads on discs without fear of traumatic injury. Lists of relevant standards and studies showing human tolerance of large dynamic loads depending upon variations in impulse characteristics are discussed elsewhere with extensive bibliographies (Jager & Luttmann, 1989; Wiker & Miller, 1983).

Many dynamic biomechanical models have been developed, but none been accepted with sufficient consensus to replace use of static biomechanical models (Freivalds, Chaffin, Garg, & Lee, 1984; Jager & Luttmann, 1989; Marras et al., 1993; Pope & Novotny, 1993). Each differs in their complexity as well as their need for and use of reductionistic assumptions. Reductions in model degrees of freedom, or other parameters, necessary to obtain a computational solution to the model's system of equations, affect each model's fidelity and veracity.

Whether or not any particular dynamic biomechanical model is an acceptable predictor of lumbar disc and related soft tissue stress is difficult to determine. Validation of models requires direct or indirect assessment of lumbar disc and other soft tissue stresses. Direct measurement of tissue stress requires insertion of sensors into an array of tissues within the body and recording forces as a human performs a wide range of work tasks. Only on a few occasions have human use committees approved such testing, with scope of approval on a very limited scale--too limited to be widely beneficial for dynamic model development, testing and validation.

When the aforementioned issues are resolved through improved instrumentation or reduced risks, and they shall be in time, we shall have an adequate knowledge base for tissue response to the range of dynamic forces and moments addressed by current whole body spinal biomechanical models. Without such information, predicted stresses, even if accurate and comprehensive, offer no insight into risk of overexertion and related injury.

Aware of the challenges facing use of current dynamic models, NIOSH has relied upon static biomechanical stress metrics to define risk of LBI and musculoskeletal injury risk when performing manual materials handling tasks or other exertions. Studies of intra-disc pressure have demonstrated good correspondence between disc compression and predicted stress using static biomechanical models. Human strength is maximized when exertions are near static. Heavy loads make highly dynamic exertions difficult to achieve and create material challenges for control of undesired load momentum. Static measurements of exertion are more easily achieved than dynamic measurements, and measurements between trials within and between analysts are more consistent and reliable than dynamic measurements (Chaffin, Andersson, & Martin, 2006).

2.2. Musculoskeletal Disorder Risk

The Centers for Disease Control (CDC) defines occupationally-induced musculoskeletal disorders (MSDs) as "*injuries or disorders of the muscles, nerves, tendons, joints, cartilage, and disorders of the nerves, tendons, muscles and supporting structures of the upper and lower limbs, neck, and lower back that are caused, precipitated or exacerbated by sudden exertion or prolonged exposure to physical factors such as repetition, force, vibration, or awkward posture*[1]." This definition excludes acute injuries such as fractures, contusions, abrasions, and lacerations resulting in acute trauma.

Musculoskeletal disorders (MSDs) are also induced by: a) disease or normal transitional physiological events (e.g., pregnancy or menopause), b) other personal clinical factors, and c) physical activities associated avocational and occupational pursuits that promote excessive use of specific musculoskeletal tissues (Putz-Anderson, 1988). Focusing upon occupational exposures, MSDs have historically presented in jobs that are highly-cyclic in nature (e.g., assembly line work) where task, tool or other design elements are poor (e.g., excessive forces in postures that require near range of motion limits for affected joints).

Analysis of jobs plagued with MSDs led to biologically-plausible etiological hypotheses, or means for correction of industrial engineering design flaws. Eliminating poor design often eliminated or materially reduced MSD incidence and severity. Improved industrial engineering design reduced tissue stress, consistent with biologically-plausible etiological theory, and improved productivity and quality of work. Such outcomes were so generally reliable that many engineers, ergonomists and others simply leaped to acceptance of biologically-plausible etiological theories as causal models. The models presented risk factors for development of MSDs, but did not offer sufficient resolution to forecast MSD incidence or severity.

NIOSH took a rational position that if an established job had no material history of work-related MSDs in the presence of some or all proposed MSD risk factors, then the job could be deemed safe and employers could focus their efforts in workplace safety and health elsewhere. However, if incidence was material, then employers should determine if the incidence was work-related and, if so, use of the

1. http://www.cdc.gov/niosh/programs/msd/

models and good industrial engineering design to guide efforts to reduce provocative exertions and injuries and illnesses.

All jobs possess some degree of exposure to MSD risk factors. NIOSH and other entities funded thousands of epidemiological research efforts to: a) gain resolution in etiological models of MSDs, b) improve treatment and care, and c) improve return to work decisions. In spite of these efforts, no continuous dose:response relationship between MSDs and work-related factors has been achieved (NIOSH, 1997). Some have argued that any exposure to any MSD risk factor, at any level, was hazardous and that epidemiological studies simply had not studied enough workers to obtain a statistically significant relationship. Others argued that without a dose:response model, there was no relationship between exposure to MSD risk factors and incidence or severity of such disorders. The truth lies somewhere between those arguments.

While epidemiological research has yet to produce a continuous dose:response curve, it has consistently demonstrated that exposures to MSD risk factors that fall below exposure thresholds used to define epidemiological control groups are not associated with occupationally-induced MSDs. This binary dose:response relationship has proved that exposure to some or all MSD risk factors, if kept below a threshold, do not present MSD hazard.

Workforces exposed to jobs that exceed control group exposure boundaries are not necessarily hazardous. However, if such exposures are coupled with MSD incidence, those jobs or tasks are deemed hazardous and require intervention. Cardinal MSD risk factors are: 1) sufficient duration and frequency of exposure to adequate combinations of MSD risk factors, and 2) forceful exertions that exceed 20 percent of one's maximum voluntary exertion while in postures that approach the range of motion limits of the joint.

NIOSH has advocated a systematic protocol for identification and control of occupationally-induced MSD hazards (Putz-Anderson, 1988). The protocol requires that one determine if MSD risk factors are present, their magnitudes, and exposure characteristics (e.g., frequencies and durations), and compare those metrics against those of epidemiological control groups or MSD incidence. It is important to determine phase relationships among the MSD risk factors (i.e., whether they occur together such as use of very high force in an awkward posture near the joint's range of motion limit), as well their exposures (e.g., daily exposures greater than 4 hours or where exposures have high cyclic rates such as thousands of repetitions per shift).

If task exposure is consistent with those of epidemiological control groups, then one can rule out occupational risk for MSD and search for nonoccupational bases for observed MSD incidence. If MSD risk factor exposures rule out membership in a control group and no incidence of MSD exists in an established job, then no action is required for prevention of MSDs (though improved job design may be warranted for productivity and profitability reasons). If MSD risk factor exposures are beyond control group exposure boundaries and MSD incidence is present beyond population baselines, then MSD hazard exists. The hazard is eliminated or controlled by adoption of administrative or engineering controls. The goal with interventions is to bring task exposures within control group exposure boundaries.

Ergonomists have been very effective in eliminating or mitigating MSD hazard through engineering or administrative control of MSD risk factor exposure. One does not have to eliminate all MSD risk factor exposures, just break up critical combinations of concurrent exposures to MSD risk factors. A metaphor for this process is the fire-triangle. Fires develop only when sufficient fuel sources, oxygen and heat are concomitantly present. One only has to remove or sufficiently reduce availability of oxygen, fuel or heat to prevent a fire or to eliminate it. Thus, one does not have to eliminate or reduce exposure to every MSD risk factor present, one just has to bring the collective exposure or phase relationships into alignment with those found in epidemiological control groups.

The NIOSH assessment protocol aims to not only help determine if MSDs are job-related, but provides information for strategic and cost effective suppression and prevention of MSDs. For these reasons, we have followed the NIOSH protocol in this study to determine if housekeepers are exposed to unacceptable levels of MSD risk factors and, if so, how best to mediate such exposures to prevent future MSDs.

2.3. Studies of Housekeeper Tasks

Three groups have studied hotel housekeeper tasks. Two groups studied static biomechanical stress to the lumbar spine using three-dimensional static biomechanical models, and one used the Lumbar Motion Monitor (LMM) to predict risk of experiencing a lumbar spine injury when performing a LMM analysis of a wide range housekeeper tasks; including bed making. Investigators using biomechanical analyses found disc compression exposures fell below the NIOSH disc compression Action Limit and, thus, the tasks were deemed safe. Extremely low (<1%) incidence of low back injuries in housekeepers within BLS were corroborated predictions of nominal rates of low back injury (BLS, 2012).

A LMM study of hotel housekeeper tasks produced logistic regression-based classifications of housekeeping tasks and job into a high-incidence injury group--concluding that hotel housekeepers were at substantial risk of experiencing low back injuries. LMM-predicted severe low back injury incidence when in fact actual incidence rates were very low. Neither BLS nor California Workers Compensation low back injury incidence data were corroborative of the LMM's predictions or hazard classification (BLS, 2012). The studies are discussed in the following pages.

2.3.1 Study of Bed Size and Height Upon Lumbar Disc Compression

A study was conducted to evaluate the effect of hotel bed size (single, double and king) and heights (460 and 560 mm) upon static and dynamic predictions of L5/S1 compression and shear forces in a group of experienced hotel housekeepers (Milburn & Barrett, 1999). This study was a follow-on of a static biomechanical analysis of hotel bed making (Barrett and Milburn, 1997, cited in Milburn & Barrett, 1999). The results of the earlier study were reported to have been replicated in the 1999 study by its authors.

The investigators examined a single posture associated with lifting the edge or corner of the three mattresses. The posture selected for study would produce a maximum load moment for the lumbar spine. This worst case scenario obviated the need to examine other postures used that would produce less biomechanical stress. Thus, if it were safe under worst case conditions, it would be safe under all other posture conditions.

Figure 1: Example of bed tucking posture analyzed by Milburn and Barrett (1999). (Adapted from Milburn and Barrett (1999)

A single set of three static measurements were performed to estimate force needed when putting bedding on the bed, removing it, lifting a mattress corner, the middled edge of the mattress and when pushing or pulling the bed to and from the wall. All measurements dealing with the mattress presumed that the hand forces were strictly vertical in direction--further maximizing the load moment acting upon the lumbar spine. A standard differencing algorithm was used to obtain load and body segment movement velocities and accelerations after a low-pass digital filter of 6 Hz was applied to the body marker position data (Chaffin et al., 2006).

Averages of a single set of static hand force measurements were used for all subjects for both static and dynamic biomechanical analyses. This paradigm could be acceptable for static analyses, but produces errors and overestimation of biomechanical stress when performing dynamic biomechanical analyses. Milburn and Barrett did not account for the inertial and momentum effects and, thereby, did not measure actual hand forces. Use of static hand force measurements for a single subject propagated errors through the dynamic biomechanical model employed in the study. Depending upon the time epoch, dynamic biomechanical calculations produced under and overestimates of actual dynamic loads.

The investigators correctly advised the readers of "absence of recommended safe lifting limits for compressive force under dynamic lifting conditions." Thus, even if the dynamic biomechanical measurements were accurate, the investigators could not make any claims regarding the risk of performing such exertions for the reasons noted earlier. See section entitled, "Absence of Dynamic Biomechanical Criteria for LBI Hazard" on page 5.

Milburn and Barret (1999) static measurements of hand forces, summarized in the plot below, were consistent with comparable hand force measurements using force plates and ground reaction forces (GRFs) to gauge manual exertions during bed making (Wiker, 2011). The results demonstrated that housekeepers lift only a fraction of the weight of the mattress (about 7% for the King mattress) rather than the entire weight of the mattress as some have claimed.

Mattresses are sufficiently flaccid that when corners or edges are lifted to tuck the mattress, the vast majority of the mattress rests upon the underlying box springs. Tuck lifts produce limited displacement of the mattress producing equivalent amounts of mattress flex or "roll up" up; thus, the effective mass is the same regardless of whether the mattress size is a king or double.

Static biomechanical analyses showed that bed making tasks produced lumbar disc compression exposures that fell below the NIOSH Action Limit of 3,400 N. Thus, NIOSH would consider the lumbar disc compression exposures when making King, Double and Single beds to be safe (i.e., a small nonzero risk of lumbar spine. See following figures.

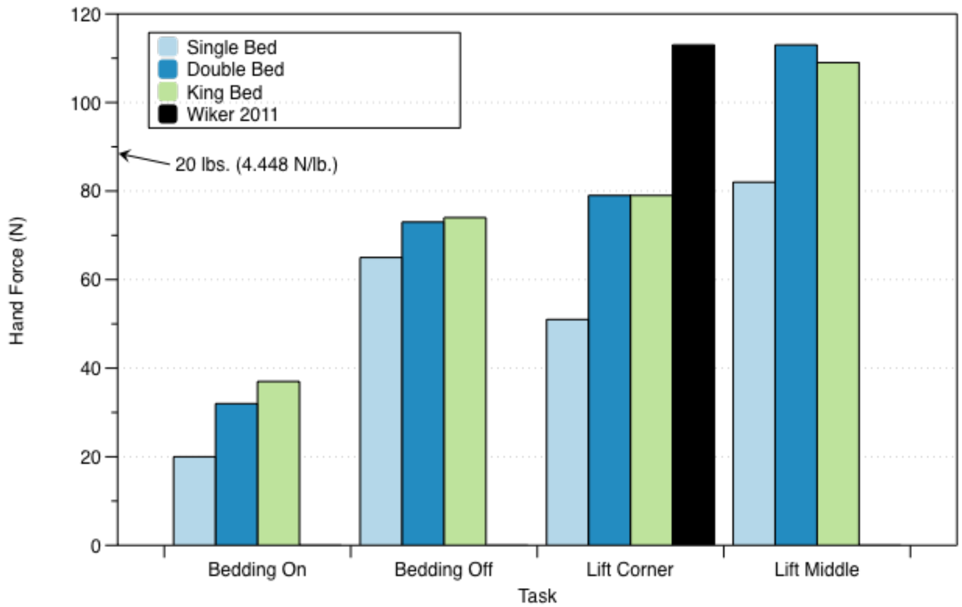


Figure 2: Milburn and Barrett (1999) static hand force magnitudes for various bed making tasks compared against peak dynamic hand forces for lifts of King bed corners as determined by ground reaction forces supplied by force plates (Wiker, 2011).

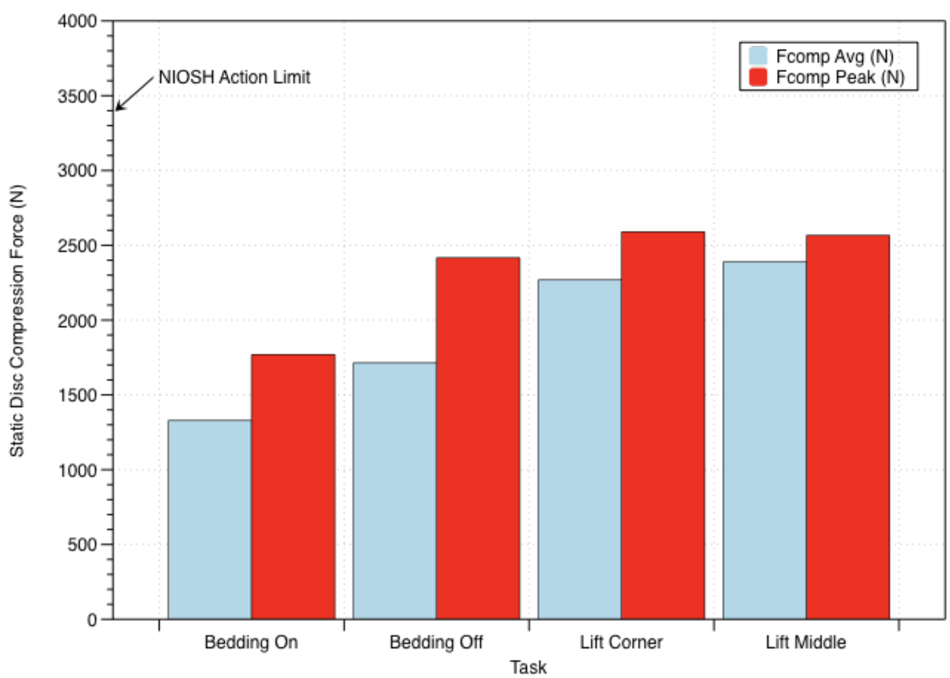


Figure 3: Predicted average and maximum or peak lumbar disc static compression forces associated with various phases of hotel bed making tasks (adapted from Milburn and Barrett, 1999).

2.4. Fitted Bottom Sheet Study

Use of fitted bottom sheets had been proposed as a means to reduce exertions and MSD injury risk when making beds, and to improve bed making efficiency. No studies could be found regarding the ergonomic benefits of using fitted rather than flat bottom sheets when making hotel beds. A study was conducted to evaluate this recommendation using a standard king-sized hotel bed with a pillow-top mattress (Wiker, 2011). The bed had a mattress cover, either a well-laundered flat or fitted bottom sheet, a flat top sheet, a linen sheet encapsulated down duvet, and two pillows and pillow cases.

While performing bed stripping and making tasks, performance times, heart rates, ground reaction forces (GRFs) and postures were recorded for subsequent examination of task performance, aerobic power demand, and biomechanical stress analysis (Astrand, 1986). GRF time histories showed that horizontal dynamic hand forces (x and y axes) when making or stripping beds were small. The majority of dynamic hand forces fell along the vertical axis (z) (i.e., lifting and lowering exertions). An exemplar of this finding is provided in Figure 4.

Housekeepers were asked to lift and hold a corner of king-sized pillow mattress to the maximum height that they had experienced in their career. The mean vertical GRF metric of static hand forces ranged between less than 23 to a max of less than 32 pounds with a mean of 27.7 ± 2.4 pounds as shown in Figure 5.

Maximum static exertion forces produced by the housekeepers did not represent typical exertions which produced lesser lifts. Yet, it served as a maximum career exposure index and showed that even with an extreme lift, housekeepers were not lifting well over 100 pounds when making beds as has been claimed on the internet.

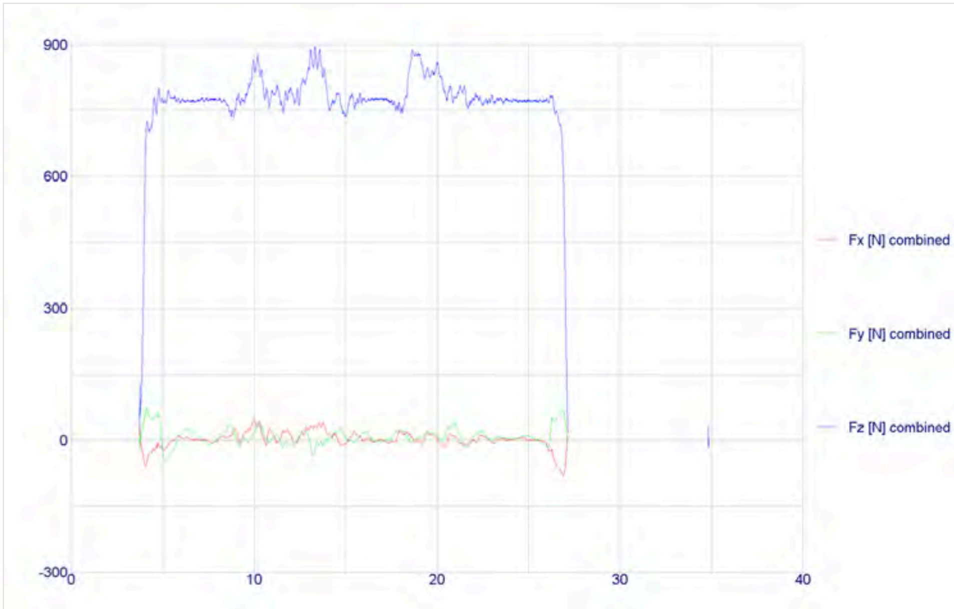


Figure 4: A typical time history (s) plot of force plate Cartesian forces (N) demonstrating that anatomical position referenced anterior-posterior and medial-lateral dynamic hand forces were negligible in comparison to vertical forces when making the corner of a king-sized bed. *(Note 4.448 N per pound of force.)*

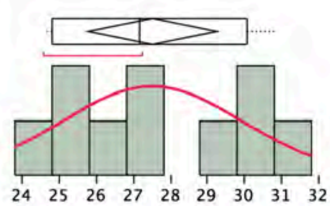
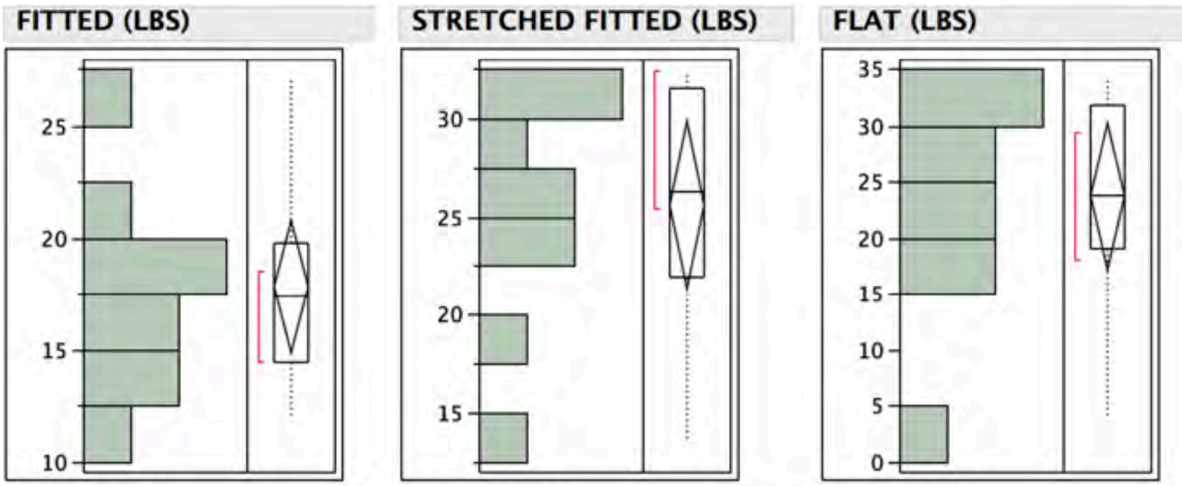
Metric	Vertical GRF (lbs.)	Distribution
Mean	27.7	
SD	2.42	
95 % UCL	29.5	
95 % LCL	26.0	
N = 10		

Figure 5: Static hand forces required to lift king-size mattress corner to maximum experienced height based upon career history.

Peak vertical dynamic hand forces were measured when applying and tucking in fitted or flat bottom sheets. Sliding the fitted bottom sheet corner over and down the mattress cover, without lifting the mattress produced a 5.9 lb reduction in hand force when compared with a flat bottom sheet ($t = 1.9$; $df = 9$; $p < 0.09$). However, if housekeepers used one hand to slightly lift the mattress corner while pulling the fitted sheet to stretch it over and under the mattress corner with the other hand, then no differences were found in measured vertical dynamic hand forces ($t = 0.57$; $df = 9$; $p < 0.58$). No differences were found in vertical hand forces between stripping fitted and flat sheets from the mattress ($t = 0.37$; $df = 9$; $p < 0.80$). See Figure 6 on page 17.

Postures recorded when performing bed making were combined with dynamic hand force vectors, and individual stature and body mass, to estimate biomechanical stresses acting upon the lumbar spine and other major articulations. The University of Michigan Three-Dimensional Static Strength Prediction Model 3DSSP (v. 6.05) was used to perform calculations. Static computational outcomes were inflated with use of peak dynamic hand forces. If the outcomes were safe with inflated values, then no further analyses would be required.



Quantiles

		FITTED (LBS)	STRETCHED FITTED (LBS)	FLAT (LBS)
100.0%	maximum	27.0089	32.3661	34.1518
99.5%		27.0089	32.3661	34.1518
97.5%		27.0089	32.3661	34.1518
90.0%		26.4063	32.3661	34.0625
75.0%	quartile	19.8103	31.529	31.7522
50.0%	median	17.4107	26.3393	23.7723
25.0%	quartile	14.5089	21.9866	19.0848
10.0%		12.2991	14.2188	5.625
2.5%		12.0536	13.6161	4.24107
0.5%		12.0536	13.6161	4.24107
0.0%	minimum	12.0536	13.6161	4.24107

Moments

	FITTED (LBS)	STRETCHED FITTED (LBS)	FLAT (LBS)
Mean	17.879464	25.647321	23.794643
Std Dev	4.1339195	5.9769304	9.057355
Std Err Mean	1.3072601	1.8900713	2.8641871
Upper 95% Mean	20.836692	29.92296	30.273884
Lower 95% Mean	14.922236	21.371683	17.315401
N	10	10	10

Figure 6: Distribution of vertical dynamic hand forces measured at GRFs on force-plates for fitted sheets, stretching a fitted-sheet over the mattress order with minimal lift, and for tucking flat-sheets with normal lift of mattress corner.

Disc compression estimates were computed for housekeepers when tucking sheets into king-sized beds using stature and body masses of representative housekeepers, their bed making postures, and GRF measurements of hand forces. A representative posture used in the analysis is provided in the following figure.

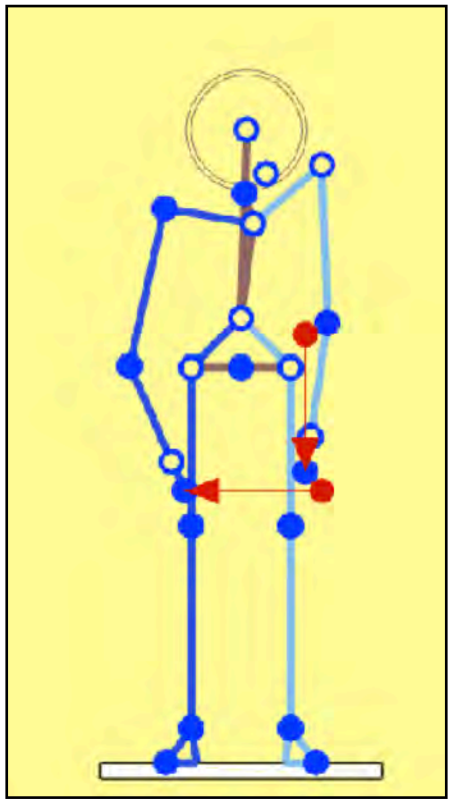


Figure 7: An exemplar posture used to perform biomechanical analysis of a housekeeper lifting the mattress corner and tucking the sheet underneath the mattress. Note that the direction of the red arrows represent the direction of hand forces.

The mean and upper 95th percentile confidence intervals for disc compressions when using fitted and flat bottom sheet applications, fell below the NIOSH Action Limit (AL). Thus, all dynamic hand force conditions recorded produced disc compression exposures that would be deemed safe by NIOSH and OSHA.

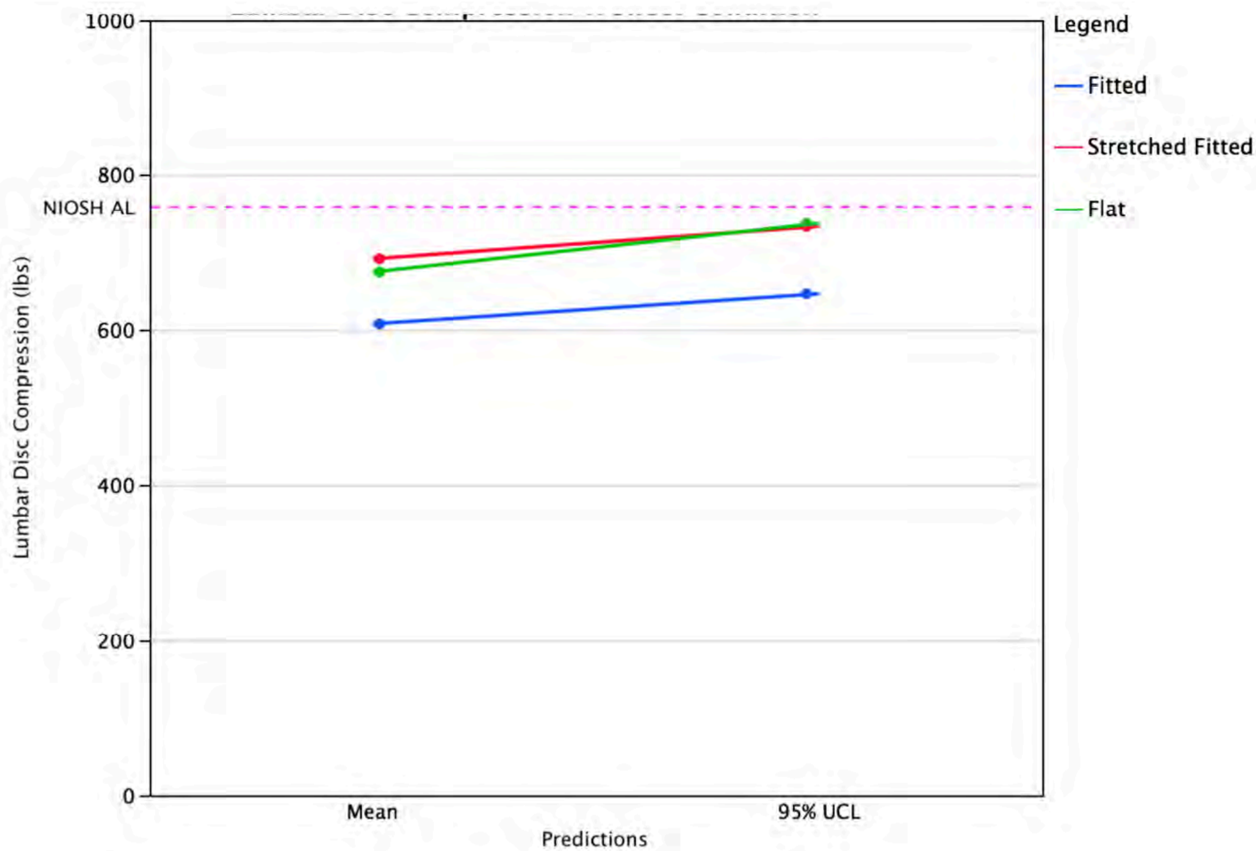


Figure 8: Plot of lumbar disc compressions based upon recorded postures and dynamic hand forces when making a bed corner wit a fitted sheet, fitted sheet stretched over the corner of the bed, and a flat sheet folded and tucked under the mattress corner.

Regardless of the type of sheet used, lumbar disc compressions, based upon either normal tucking exertions, or maximum career mattress lifting effort, were below the NIOSH Action Limits. The spinal compression forces produced nominal risk of back injury from NIOSH's and OSHA's perspective. NIOSH refers to a "norminal risk" as a small nonzero risk of injury that is considered safe.

Although, the tucking postures observed in this study differed from those examined by Milburn and Barrett (1999), the disc compressive forces from both studies were comparable and safe. See Figure 3.

2.4.1 Physical Workload With Fitted and Flat Sheet Use

Normalized heart rates recorded during bed making showed fitted sheets increased physical demands and metabolic energy consumption slightly when compared with making (6.9%; $t=2.1$; $df=6$; $p<0.04$) and stripping beds with flat sheets (+5.6%; $t=2.6$; $df = 6$; $p<0.02$). See Figure 9.

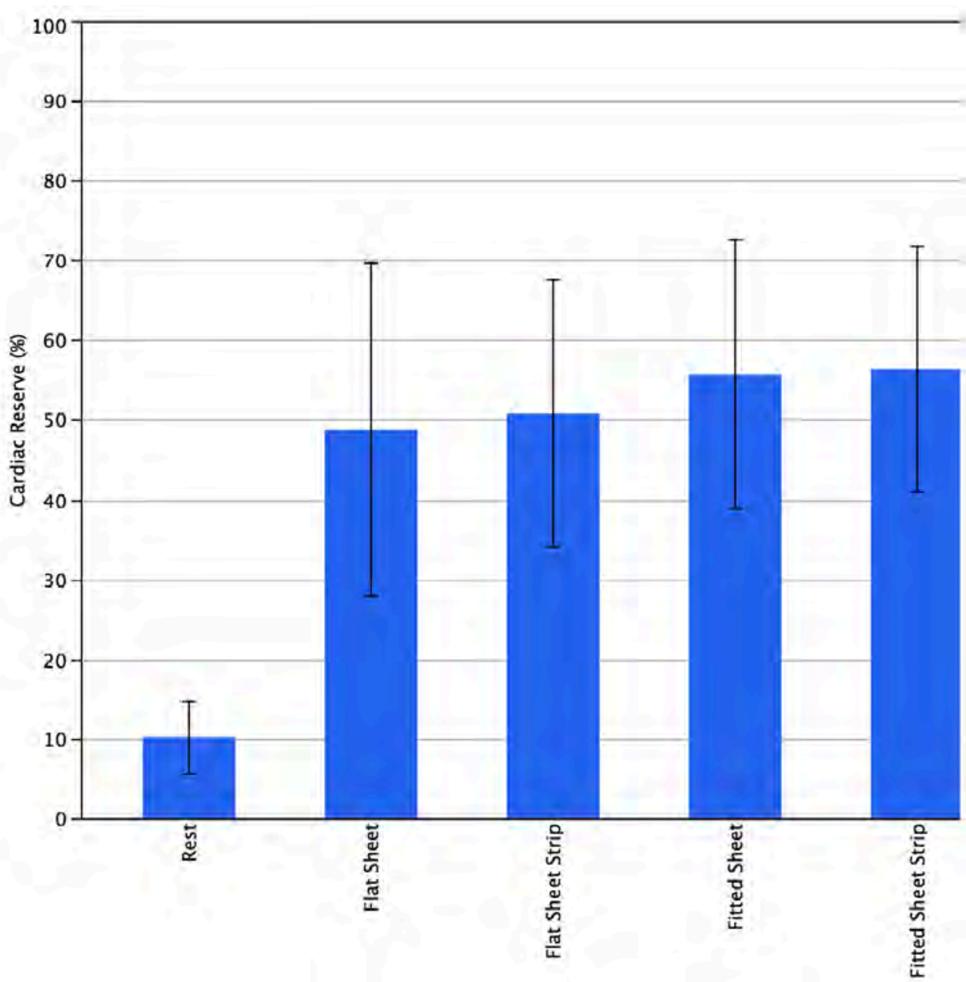


Figure 9: Mean and standard deviations for cardiac reserve requirements for making and stripping beds with flat and fitted bottom sheets. *Error bars = 1 SD.*

With flat sheets, the housekeeper had the option of postponing the fold and tuck of the flat sheet at the foot of the bed until the upper bedding was in place. With fitted bottom sheets housekeepers had to walk around the bed to strip the bottom sheet. With flat bottom sheets that walk was unnecessary; the housekeepers could simply pull the sheet off at one corner and the remaining corners unfolded and slid out.

2.4.2 Bed Making and Stripping Times With Fitted and Flat Sheets

Use of the fitted sheet reduced bed making times by approximately 5% ($t = 2.5$; $df = 6$; $p < 0.03$). No differences were found in bed strip times between sheet types ($t=1.02$; $df = 6$; $p < 0.17$). The variability in individual performance times appears to be more influenced by individual variations in their bed making methods than the sheet design. Some housekeepers showed time savings with flat sheets, some showed reduced times, while others showed no differences. A methods analysis resulting in a standard bed making method and subsequent time study should be performed before one uses this preliminary metric of time savings with fitted sheets.

2.4.3 Recommendations Regarding Use of Fitted Sheets

Results of comparative analysis of fitted bottom and flat sheets were essentially a draw. To obtain a smooth bottom sheet surface, some tension is required with the fitted sheets. Fitted sheets required some degree of corner tension to achieve a smooth sheet surface, and that tension is achieved by tight-fitting corners and mattress-induced stretching of the sheet. Also, well-laundered fitted bottom sheets had shrunk sufficiently to require housekeepers to lift mattress corners to achieve a good coupling with the underside of the mattress.

Rather than struggling with pulling the sheet over and underneath the mattress corners, housekeepers were observed lifting mattress corners to hook the fitted bottom sheet and then releasing the mattress to allow the mattress to fall back onto the box springs surface and, thereby, induce stretch in the sheet. At least three of the four mattress corners required lifting of mattress corners to acheive effective fitted-sheet coupling. This act nullified any biomechanical advantage for use of fitted bottom sheets in comparison with flat sheets.

Some housekeepers tucked only the corners at the head of the mattress and then completed the tucks at the foot of the mattress when tucking the upper bedding in as a group. This eliminated two bottom sheet tucks at the foot of the mattress that could not be saved using a fitted bottom sheet.

The absence of biomechanical benefits with laundered and shrunken fitted bottom sheets, and the slightly greater metabolic burden associated with use of fitted sheets lead to the recommendation of use of flat bottom sheets in lieu of currently-designed fitted style bottom sheets. Application of engineering methods analyses should be able to reduce the number of tucks and time required to apply flat bottom sheets; if that is the case, then less time would be required to make the bed with flat sheets.

2.4.4 Lumbar Motion Monitor Assessment of Housekeeping Job

Marras and coworkers pursued a clever analytical approach to overarch current challenges to assessing risk of low back injury using dynamic biomechanical modeling in the workplace (Marras et al., 1993). They argued that a minimal set of torso movement behaviors, with static measures of load weight and moment arm, and combined with frequency of lifting, could be used to predict risk of developing a low back injury whether tasks were static, quasi-static or dynamic in nature.

A unique torso goniometer was developed that recorded torso angular position, velocity and acceleration information concerning the torso. The goniometry information was continuously captured by workers wearing a torso goniometer (Lumbar Motion Monitor (LMM)) as they performed their repetitive lifting tasks (e.g., loading a conveyor, palleting, etc.). That information was combined with analyst's measurements of the maximum static external load moment of all lifts performed during a work shift, measurement of the total number of lifts performed during a shift.

Workers wore the torso goniometer or LMM in 403 repetitive industrial lifting jobs across 48 different industries. Investigators measured the static weights of loads lifted and the maximum distances from a spinal reference point during load handling, as well as lifting frequencies. The lifting tasks were freestanding and did not vary materially throughout the shift. Thus, collecting a single load weight, and measuring the maximum moment arm for handling that load, provided a reasonable characterization of the external biomechanical burdens because the lifts were comparable from lift to lift.

The expectation was that by using a large number of industries which exposed workers to a variety of repetitive manual materials handing (MMH) jobs, a wide variety of lifting behaviors would be captured along with historical incidence of low back injury. This information would permit the team to use multiple linear logistic regression to predict membership within discrete categories of low back injury incidence.

This approach followed a standard systems engineering approach in which a "black box" takes known inputs and attempts to predict outputs by shaping a transfer function for the process. Torso goniometry and lifting task characteristics were the inputs and low back disorder incidence was the output. The LMM LBD's single attribute transfer function was shaped only by low back injury incidence. The NIOSH WPG's multi-attribute transfer attempted to predict multiple outputs: 1) risk of low back injury, 2) task aerobic power demand, and 3) worker perceptions of lifting task tolerance (e.g., psychophysical ratings).

OSHA incidence and severity log information, as well as medical records, when available, were used to classify jobs as possessing either zero- or high-incidence LBD outcomes. The analysis classified LBD incidence without regard to severity of the incident. Zero incidence jobs were defined as jobs with at least three years of no recorded injuries or turnovers. Jobs classified as high risk possessed 12 or more low back injuries per 100 worker-years (i.e., the 75th percentile for observed or classified injury incidence for the 403 jobs studied). This classification schema produced 124 no incidence jobs and 111 jobs with 12 or more recorded LBD incidents per 100 worker-years. Unclassified jobs were not included in their analysis.

Workplace and individual characteristics measured included:

a) Maximum horizontal distance of the load from the spine,
b) Weight of the object lifted,
c) Height of the load at the origin of the lift,
d) Height of the load at the destination of the lift,
e) Frequency of lifting,
f) NIOSH's angle of load transfer or asymmetry,
g) Metrics or worker anthropometry,
h) Worker injury history, and
i) Worker satisfaction with their job.

The above metrics were combined with mean, maximum, minimum and range of angular position, velocity and acceleration of the trunk in each of the cardinal planes, were captured workers wearing the LMM while the worker performed their repetitive lifting job. Analyses performed included: 1) examination of task cyclic variability in measured parameters from lift to lift within a given job, 2) individual logistic regression modeling for each prediction variable to determine individual predictive value of each proposed predictor, and 3) multiple weighted logistic regression (using job frequency as a weighting parameter) to predict membership within zero or high incidence (12 or more injuries per 100 workers per year).

Substantial variations in kinematic measures were reported from lift to lift that were unrelated to lifting task characteristics. Interclass correlations found spanned 0.49 to 0.78. Thus, between 39 and 76 percent of the variation in task metrics among task cycles could not be accounted for.

Comparison of high and zero incidence LBD jobs showed equivalent job satisfaction. Greater loads, load moments and lifting rates were found in high incidence jobs when compared against jobs with no LBD incidence. This finding was consistent with past arguments that low back injury risk increases with external mechanical loads handled during lifting tasks. This finding did not support claims that job satisfaction is a provocateur or correlate with low back injury claims or incidence. See following figure.

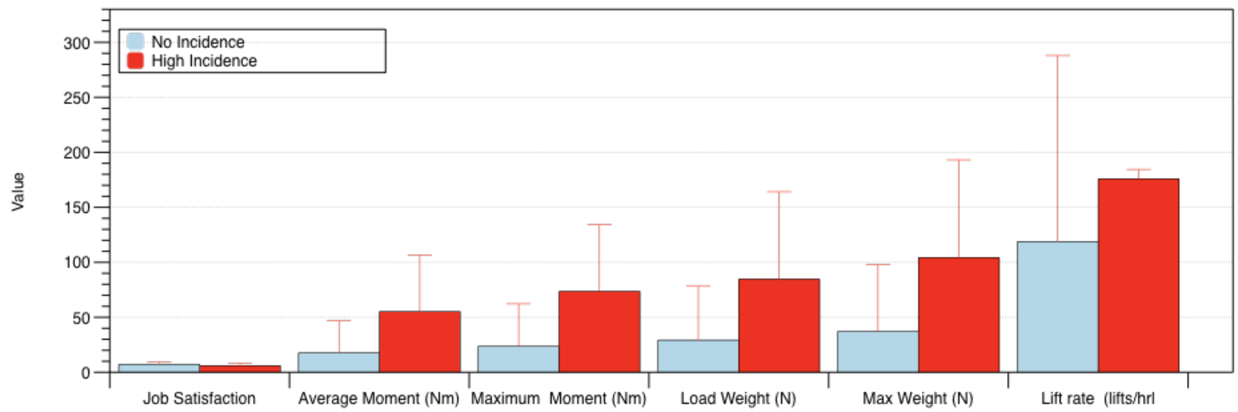


Figure 10: Means of job satisfaction, load handled, load moment and lifting frequency metrics compared between jobs with no incidence and high incidence of LBD. Note error bars = 1 SD (Adapted from Marras et al., 1993).

While load, load moment, frequency of lift demonstrated clear differences between zero and high incidence lifting jobs, metrics of lift geometry did not. The origins of loads and their distances of travel were equivalent in magnitude. Thus, elevations in estimated load moments (moment arm x weight) in high incidence jobs were because of heavier loads in lifting jobs--not changes in lifting geometries or postures.

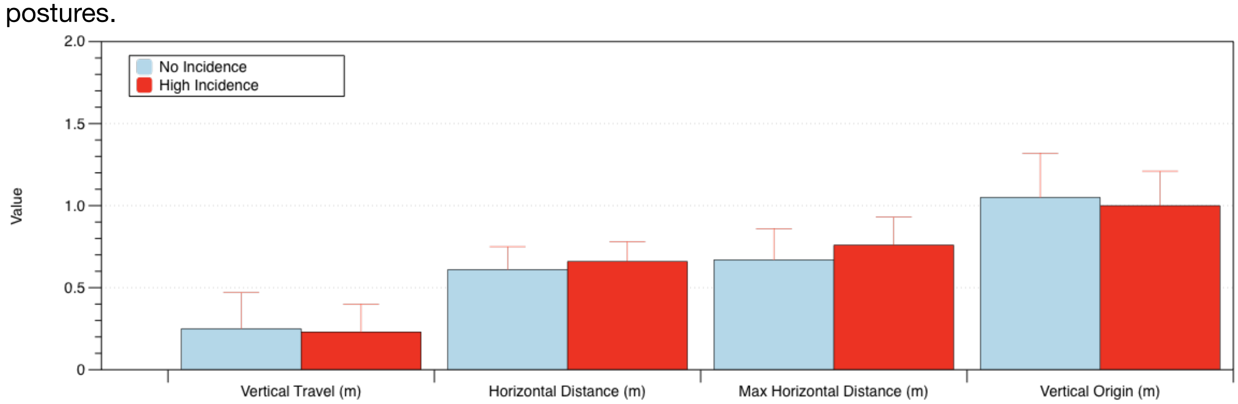


Figure 11: Means of job vertical travel horizontal distance of load, and vertical origin of lifting metrics compared between jobs with no incidence and high incidence of LBD. Note error bars = 1 SD (From Marras et al., 1993).

When trunk kinematics were evaluated within the sagittal plane, only small differences were found between LBD incidence categories. As shown in the following figures both means and variances were similar regardless of the risk of LBD.

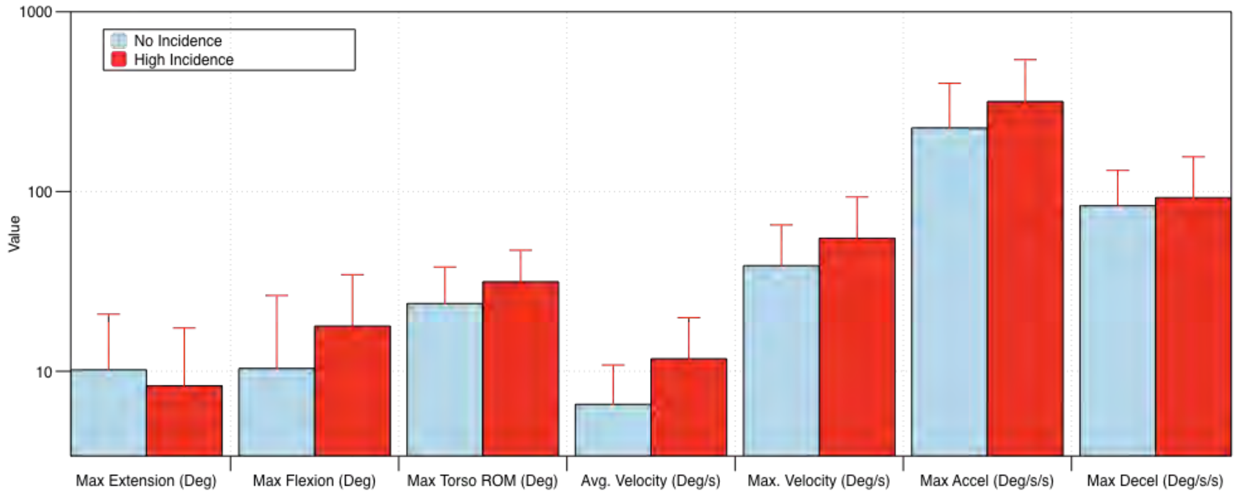


Figure 12: Means of sagittal plane torso kinematic measures compared between jobs with no incidence and high incidence of LBD. Note error bars = 1 SD (From Marras et al., 1993).

A similar pattern was found when maximum values were plotted. See Figure 13.

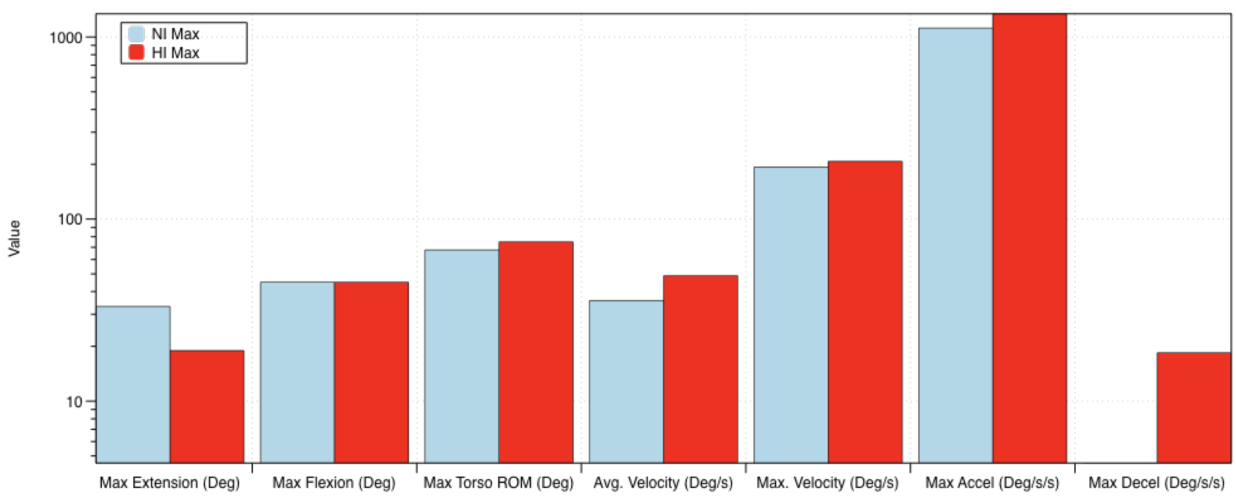


Figure 13: Maximum values of sagittal plane torso kinematic measures compared between jobs with no incidence (NI) and high incidence (HI) of LBD (From Marras et al., 1993).

Kinematic patterns found in the sagittal plane were reported to be essentially the same for the coronal and transverse cutting planes. Large sample sizes allowed detection of small differences existed for some but not all predictors of LBD between zero and high incidence groups.

A multiple logistic regression model was developed using stepwise variable selection and inclusion methods. No description of the modeling development (variances accounted for in stepwise regression process, correlations among predictor variables, etc.) was presented beyond a table of predictor coefficients and odds ratios, and a general discussion of the predictor variable importance in the final multiple logistics regression model. The model's prediction factors were:

1. Lifting frequency,
2. Maximum load moment,
3. Trunk sagittal plane flexion angle,
4. Trunk twisting velocity, and
5. Trunk lateral bending velocity.

2.4.4.1. Multicolinearity Problem

Not surprisingly, Marras et al. (1993) found that kinematic metrics of torso or trunk position, velocity and acceleration were highly correlated. This situation, referred to as multicolinearity, occurs when predictor variables are so interrelated (correlated) they cannot be jointly entered into a multivariate statistical model. Predictor variables that are potentially causal are highly correlated with predictors that are not. Thus, one must guess which predictors are causal and which are not.

Multicolinearity creates both an interpretative and mathematical challenge for development of statistical regression models. To resolve this problem, one must select a representative predictor variable from among the groups of highly-correlated predictors and eliminate the remaining predictors from the modeling process. Selection should be based upon hypothetical predictor causality rather than the predictor within the correlated group which has the highest correlation with the outcome metric.

Marras et al. explored their data to find representative predictors that offered the best correlations with LBD incidence. They argued that because of the colinearity in their data, the predictors they selected represented causality of the colinear predictors. This is not likely to be the case. If it were true the predictors selected would have to always be highly correlated with the other metrics that were dropped from the model. If they are not consistently related to predictors that are dropped from the model, the implication is that they are more causal than those that have been dropped. That certainly is not the case because there is no evidence regarding causality provided in the study. Thus, when one examines jobs that have different kinematic behaviors from those which were used to create the prediction model, predictions could be highly erroneous.

Statistical theory advocates an *a priori* selection of predictors that have rational basis for causal association with outcomes. LBD injuries are presumed to result from excessive mechanical stress to the spine. Representative predictors selected from a cluster of correlated predictors should be selected based upon their ability to forecast spinal tissue stress rather than hunting for the strongest correlations with LBD incidence within their dataset. In all studies correlations found have some degree of risk that they occurred simply due to chance.

If the study were repeated with different jobs or worker populations, correlations among the clustered predictors could be different, lower or absent. This presents a problem because selection of noncausal predictors could produce erroneous predictions when used in other lifting studies where kinematic patterns of movement differ from those used to develop the model. Correlations with the noncausal predictor would change and, thereby, reduce their association with causal predictors that had been dropped from the model.

For example, assume that head-on collisions are provoked by drivers who are temporarily "blinded" by disabling glare produced by direct sunlight entering the driver's eyes. Outside temperatures tend to be correlated with sun position in the sky. Mechanistically, the position of the sun in the sky should produce disability glare and would be correlated with daytime outside temperature. If outside temperatures, by chance, or methodological bias (e.g., collecting data only during summers) produced stronger correlations with head-on collision incidence than metrics of sun position relative to the driver's eyes, stepwise regression modeling methods used by Marras et al. (1993) would pull the outside temperature (chance) into the model and eliminate the sun's elevation and bearing as causal predictors. Outside temperature has no relationship with disabling glare, only time of day as a function of the sun's warming the atmosphere.

Statistical theory argues that predictor selection should be based upon knowledge of the structural basis for the true relationship. Selecting the bearing and elevation of sun as predictors, even though for the data set being analyzed they may produce weaker correlations and predictive performance for that particular data set, would reduce future prediction errors when temperature behavior is decoupled from sun position.

The model based upon chance correlation with temperature would over-predict head on collision risk on dark warm summer nights, or under-predict collision risk when driving during cold winter days where the sun glare could be substantial. Selection of predictors based upon arguments of causality increases both prediction equation sensitivity (increased prediction of true positives) and specificity (reduced prediction of false positives). Selection of predictors based upon correlation alone reduces the predictive sensitivity and specificity of models (Kutner et al., 2004).

Load moments are mathematical cross products of posture-mediated moment arms and magnitudes of forces acting upon the hands and body segments. Force is a product of mass and acceleration—not of velocity. Load moment arms increase as workers flex their torsos forward, or bend their torso within the coronal plane, when reaching for, lifting and placing lifted loads further from the body. Velocity information has some impact upon dynamic forces and load moments and upon load and body segment momentum (mass x velocity). However, there is a far stronger argument for using angular accelerations if dynamic biomechanical stress is believed to drive low back injury (See Chaffin et al., 2006 for dynamic moment equations).

If dynamic impulse loads on lumbar discs produce some degree of prophylaxis by eliciting protective viscoelastic properties of intervertebral discs, then substitution of velocity for acceleration metrics could better address such properties. Marras et al. (1993) reported that velocities, which contain no acceleration information, produced greater odds ratios for LBD when looking at all the variables as single predictors (OR $\leq$ 3.33). Yet, when sagittal plane (the principle lifting plane) flexion-extension velocities were entered into the multiple logistic regression model, they failed to provide any predictive utility. It is difficult to fathom why velocity of twisting or bending of the torso would have greater impact upon lumbar spine tissue stress than torso flexion or extension velocities (the principal lifting plane where dominant load moments are created).

While torso twist and bending velocities may have produced greater correlations with LBD incidence, and support the use of the LMM goniometer, they are far less plausible as metrics of biomechanical stress when compared with angular acceleration or limb displacement or moment arms (Chaffin et al., 2006).

Multicolinearity forces selection of single predictors from clusters of correlated metrics for entry into the model and, thereby, limits the number of predictors that can be used to predict outcomes (Wasserman & Kutner Michal, 1974). If two or more predictors, which are highly correlated in the development dataset, are truly causal, then all but one of the predictors are excluded from the final model. Excluding valid causal predictors reduces model quality of its fit and its predictions.

2.4.4.2. LLM LBD Predictive Validity and Performance

Marras et al. (1993) warned that their approach to the multicolinearity problem eliminated the potential for treating the model as causal. Without descriptive causality, the model's structure cannot be relied upon to diagnose underlying bases for LBD incidence, nor can it guide development or selection of interventions. That said, if the model has poor predictive validity, then the issue of causality becomes moot.

Predictive validity of the LMM LBD prediction model is likely to be weak for the following reasons:

a) It is probable that additional predictors, as well as interactions among the predictors, are required to achieve sufficient representation of industrial lifting tasks. The degree of multicolinearity within the data set prevented examination of sufficient predictors and interactions among those predictors to account for all biomechanical stresses experienced during cyclic freestyle lifting. Absence of valid predictors will, by definition, reduce model quality of fit and predictive validity.

b) As a general rule, multiple logistic regression modeling produces poor results when the number of cases fit by the statistical model fails to exceed the number of predictor variables by a ratio of 10. Thirty-two predictor variables were used in the development of the LMM LBD model for only 111 cases. That ratio of 111:32 is only 3.4.

c) The investigators failed to sequester a subset of their data from modeling efforts to enable them to test the prediction accuracy of the of the model within the data set collected. This is standard modeling procedure, but was not followed because of the limited size of the dataset that the investigators had to work with.

d) The investigators relied simply upon odds ratios to give the reader some sense of model efficacy. Odds ratios are not sufficient information for one to judge the absolute quality of the model's predictions. A regression equation with statistically significant predictor coefficients can produce wildly inaccurate predictions (Kutner et al., 2004).

e) No information was provided regarding their model's prediction or LBD risk classification accuracy. Classification tables showing predicted and actual memberships or outcomes, are typically provided for such models to demonstrate prediction sensitivity, specificity and utility. When that information is rewarding, it is provided for the community to digest and appreciate--model classification accuracy is the penultimate objective. When the classification accuracy is dissuasive, investigators often drop back to discussing the model's structure (e.g., what variables were included in the final model and their contribution to the overall odds ratio of the model, and the model's predictive odds ratio)--the presentation provided by Marras and coworkers (1993).

f) Marras et al. (1993) used statistical distribution metrics for predictor variables with no phase information. Two different jobs could produce exactly the same means, minimum, maximum and variability in the array of kinematic measures characterized. Yet, the jobs could vary remarkably in terms of body lifting movements and postures. Jobs which present the same kinematic distribution measures could vary dramatically in terms of their biomechanical stress time histories and risk of LBD. The investigators took a rational first approach to the problem, given the tremendous complexity of assessing time-phased kinematics and external load moments, but the first approach could create significant problems with LBD prediction accuracy.

g) The investigators correctly warned users do not to use the LMM-based LBD prediction model outside of the scope of jobs that were used to construct the model, and not to consider the model to be causal. They looked at an array of repetitive and highly-structured jobs that might be referred to as assembly line-type lifting tasks where the lifts are essentially repeated one after another for nearly the entire shift. Any work that does not correspond with the LMM LBD development data set cannot be addressed by the LMM LBD prediction model. To do so violates the tenets of statistical prediction theory and is likely to produce poor model predictions.

h) The model was created using cross-sectional data. Predictive validity of their model is best tested with a prospective longitudinal analysis.

2.4.4.3. Efforts to Validate the LMM LBD Model

Marras et al. (2000), recognizing the need for a prospective longitudinal test of the LMM LBD prediction validity, performed a prospective longitudinal study of 142 employees across 36 jobs where historical injury and incidence rates (IRs) were recorded. The LMM LBD prediction model was used to gather trunk kinematic information for those jobs, and direct observations were made to record maximum load moment and lifting frequency. The data were gathered using the original methodology employed for the model (Marras et al., 1993).

The investigators reported that LBD incidence prediction performance occurred with medium incidence levels for a small subset of jobs. When analyzing that many jobs and incidence categories, one expects accurate classifications in a small subset of incidence categories to occur simply by chance. No explanation was provided to explain why the model provided better predictions for a small number of medium incidence categories, and no discrimination between zero and high incidence groups (the best discrimination opportunity).

Improved predictions for medium risk classifications based upon LMM LBD risk scores, may be due to chance, but it is also possible that their reported outcome was an artifact of the classification schema used. High LBD incidence was defined as LMM LBD risk scores equal to or greater than 70%. The low LBD incidence category was defined as LMM LBD risk scores of 30% or less. That left a broader category for medium risk than the adjacent extremes. Better classification of medium risk jobs may have resulted from: a) broadening the target zone for medium risk, and because b) all regression models predict more accurately near the midrange of the data set. A predictively valid model should provide good classification for all levels of LBD risk.

Figure 14 shows LMM LBD predictions of increasing risk before and following ergonomic interventions (plotted from Table 3 data of Marras et al. (2000)). Results showed that before ergonomic interventions, the LMM LBD predictions are incongruent with actual LBD incidence. After interventions were made, concordance between predictions and LBD incidence improved. No explanation for the conflicting results was provided. In any event, that result showed that the model failed to predict consistently or acceptably throughout its intended range of application.

Inputing job and trunk kinematic measurements into the 1993 multiple logistic regression model produced highly variable predictions that largely misclassified risk classification between jobs with large differences in LBD risk (e.g., zero incidence, and 12 or more LBDs per 100 workers per year). Misclassifications were sufficient that average model classification predictions, between zero and high incidence jobs, overlapped substantially. This outcome indicated that the model failed to discriminate between jobs with zero and high incidence. Acceptable specificity and sensitivity criteria were not met with the analyses provided. See Figure 2 in Marras et al. (2000).

Generally, a predictively valid model should account for at least 50 percent of the variance in actual LBD incidence and demonstrate a strong correlation between predicted and actual outcomes (i.e., $r \geq 0.70$). The association between job LMM LBD risk scores and actual injury incidence rates was weak ($r=0.47$, $p=0.038$), and the model could account for only 22% of the total variance in injury incidence. Other deficiencies in the model included a failure to account for principal behavior of LBDs in the population of workers addressed.

Marras and coworkers (2000) presented tables of regression functions (see their Tables 4 and 5). The tabled fits presented statistically significant slopes for LMM LBD risk scores and injury incidence rates. However, the functions were not plotted against the actual incidence rate data for the jobs. Using data provided in Table 2 in their report, the means injury incidence rates were plotted against means LMM LBD risk scores. See Figure 15 on page 35.

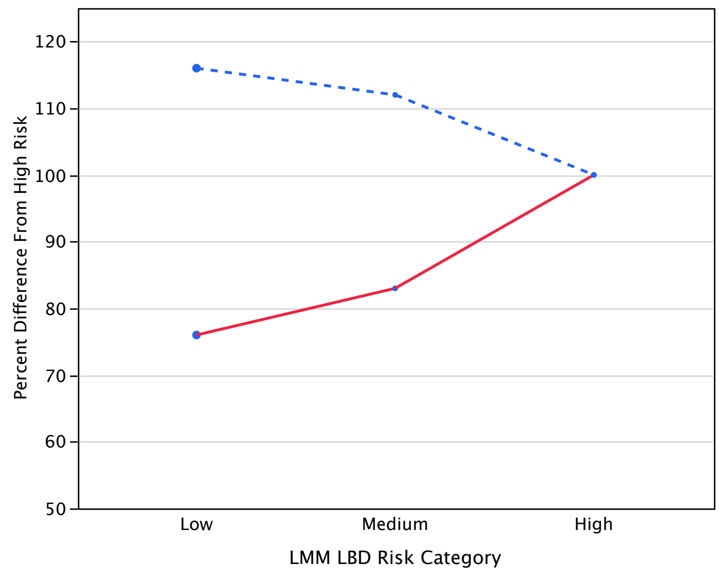
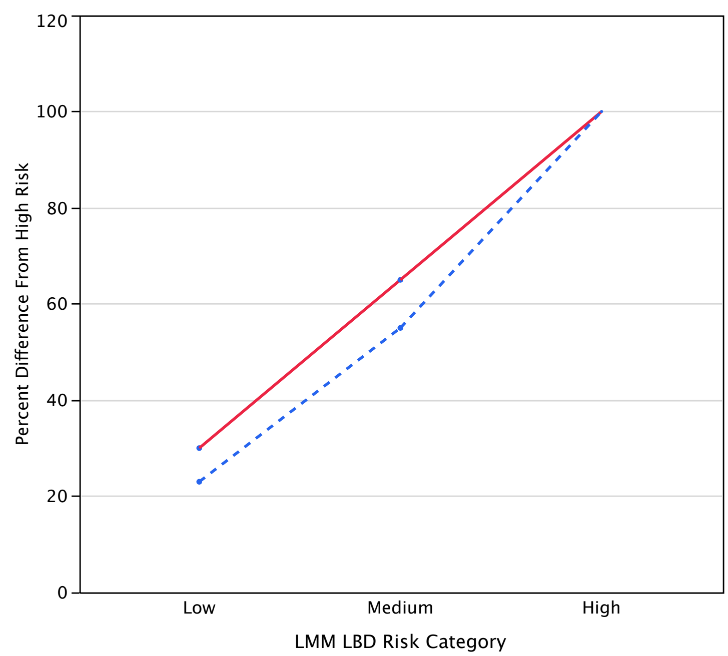
Before Ergonomic Interventions	
After Ergonomic Interventions	

Figure 14: Mean change in LBD IR (dotted Line) and LMM-based LBD for LMM-defined hazard categories (plotted from Table 3 in Marras et al., 2000).

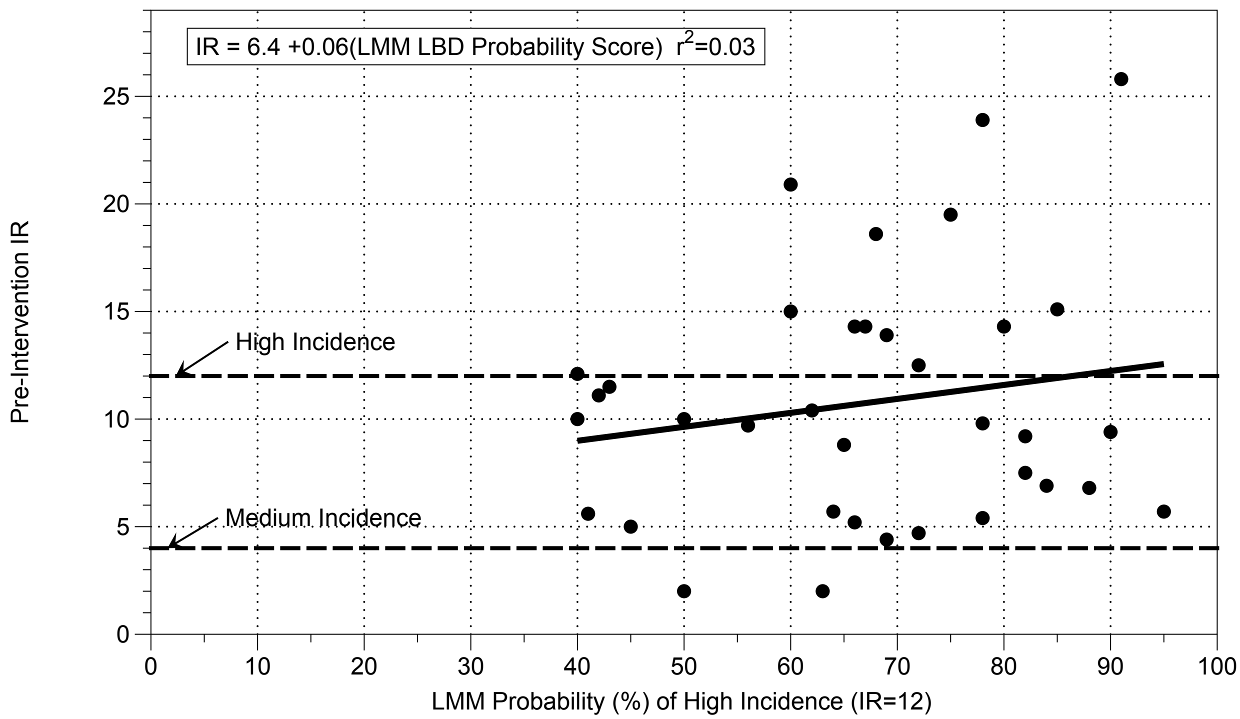


Figure 15: Relationship between LMM LBD high incidence probability score and incidence of LBDs before ergonomic interventions. Note: incidence classification thresholds reported are drawn.

Plotting of LBD incidence and LMM LBD risk score means in Figure 15, gives a better indication of the prediction performance capacity of the LMM LBD prediction model. Means are unbiased estimators of the centroids of the raw data. Thus, if the raw data were plotted, the relationships would appear worse than that shown in the plot presented.

LMM LBD risk scores before ergonomic intervention produced substantial errors in predicting associated IRs. The range effect in the LMM LBD risk scores is noteworthy. Regardless of how low the actual mean incidence was for LBDs, the model always provided mean estimates of high incidence probability of 40 percent or greater. This finding indicates that the model has a positive bias in predicting high risk of LBD.

Examination of post-intervention job LMM LBD risk scores was performed and means provided by the investigators are plotted in the figure below. LMM LBD risk scores produced greater misclassification of risk when IRs were reduced. The LMM LBD risk prediction model predicted zero-incidence jobs had between 24 and 76 percent chance of high incidence of low back injury. See Figure 16.

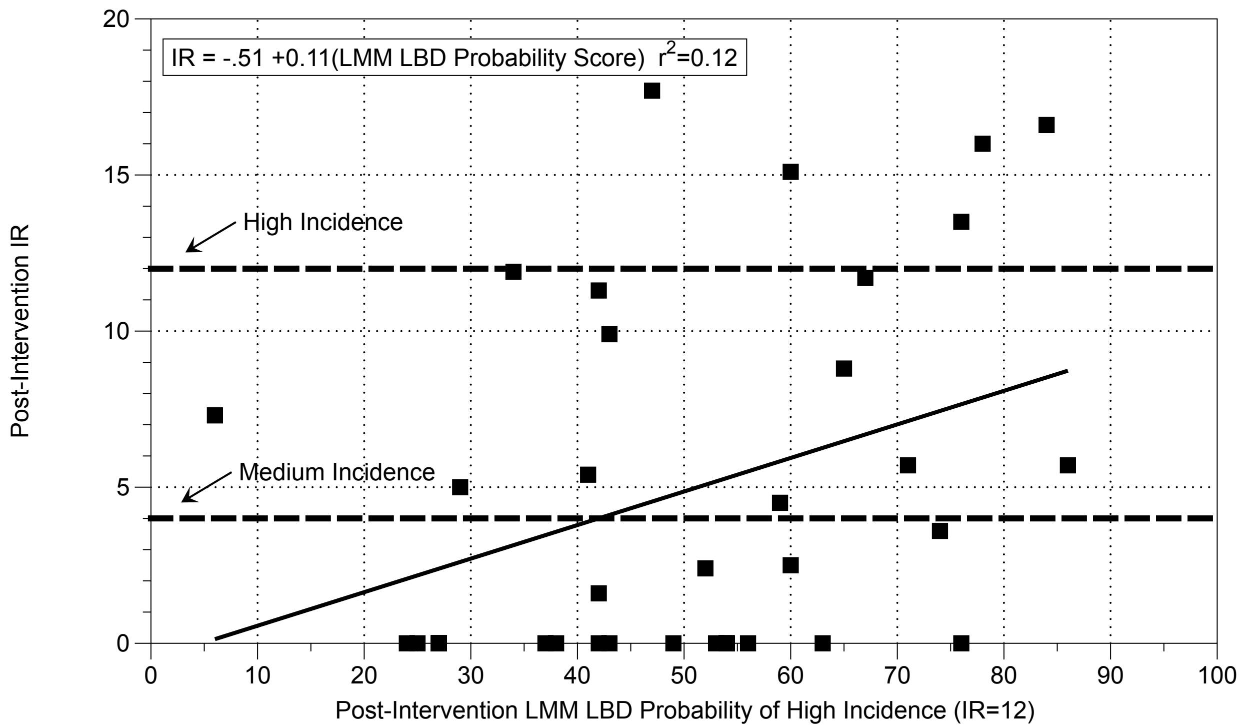


Figure 16: Relationship between LMM LBD high incidence probability score and incidence of LBDs after ergonomic interventions. Note: incidence classification thresholds reported are drawn.

Data provided in Table 2 of Marras et al. (2000) were plotted to show the relationship between mean reductions in LMM LBD risk scores and mean change in injury incidence. A reduction in LMM LBD risk score is indicated by a positive value (i.e., the difference between the pre- and post-intervention LMM LBD risk score).

A predictive causal model would show a consistent decline in LBD incidence and reductions in LMM LBD risk score. Spline functions were fit to the data and only 2 out of 6 conditions demonstrated anticipated monotonic relationships between predicted and actual LBD incidence.

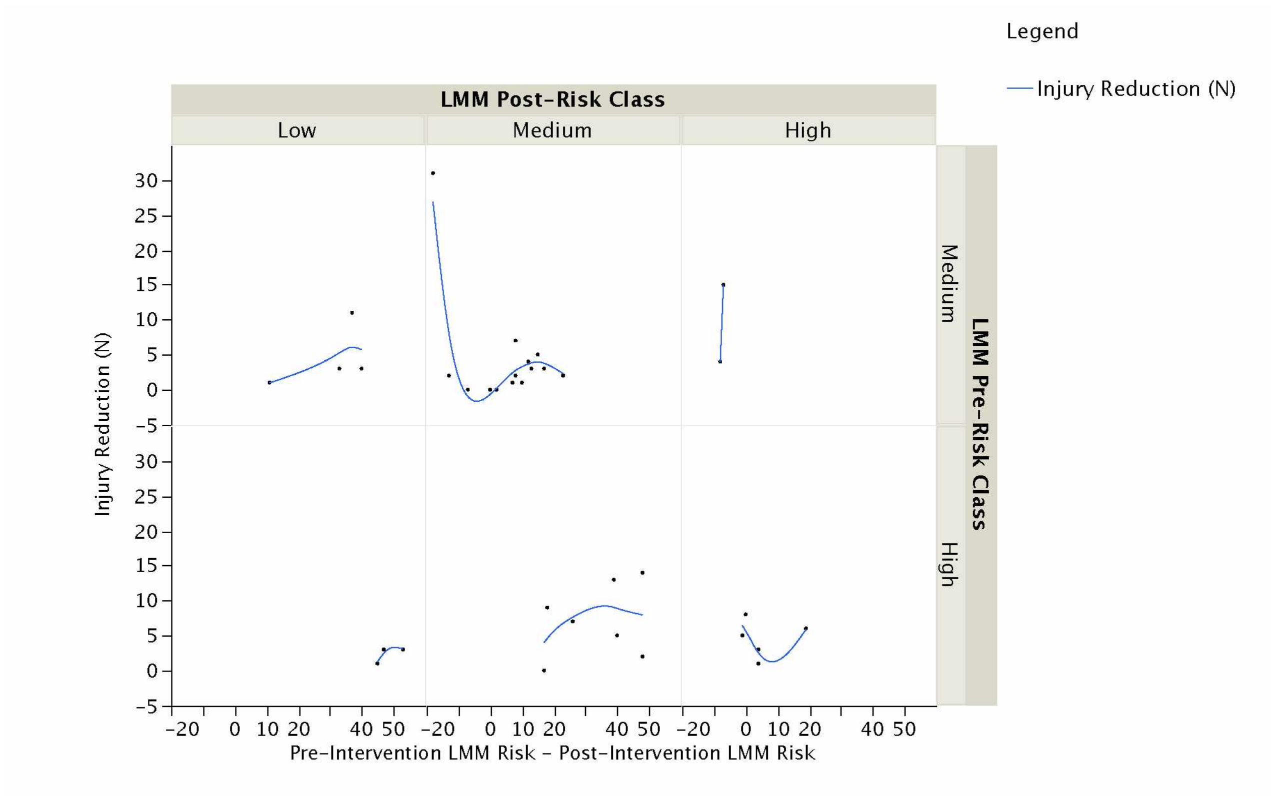


Figure 17: Relationships between mean reductions in low back injury incidence following ergonomic interventions and reductions in LMM LBD risk scores. (Taken from Table 2 of Marras et al. (2000)).

Scatter plotting the above data as an aggregate showed no expected relationships between actual LBD incidence reduction and reduction of LMM LBD risk score. The relationship between LMM LBD risk score and injury incidence is not convincing. See Figure below.

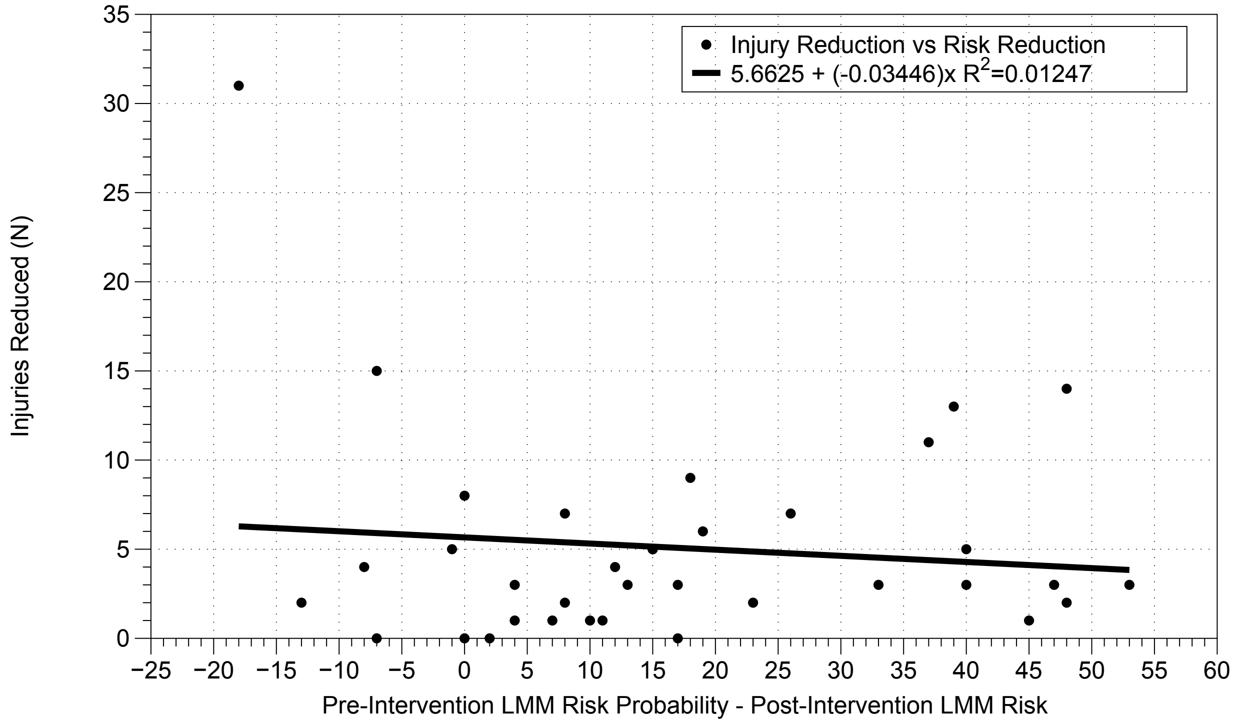


Figure 18: Relationships between mean reductions in low back injury incidence following ergonomic interventions and reductions in LMM LBD risk scores across all risk categories. (Taken from Table 2 of Marras et al. (2000)).

The LMM LBD risk prediction model's capacity to account for variation in low back injury incidence was poor--below 30 percent. Variance accountability below 50 percent is considered inadequate for claiming model predictive validity (Hennekens, Buring, & Mayrent, 1987; Hernberg, 1992; Sachs & Reynarowych, 1984). Relationship between predicted and actual low back injury incidence was poor (r=0.47) and failed to meet levels of association ($r \geq 0.70$) required for community acceptance. The LMM LBD risk model's predictions fail to satisfy any criteria for acceptance as a valid prediction model by scientific, engineering or clinical communities.

2.4.4.4. LMM LBD Risk Prediction Model Analysis of Housekeeper Tasks

The Biodynamics Laboratory at Ohio State University performed a LMM LBD prediction analysis for individual tasks performed by hotel housekeepers and for their job as a whole. The study has not been published, but a slide presentation describing the study is available on their website[2]. Approximately 19 hotel housekeeper tasks were evaluated using the LMM LBD protocol.

All housekeeper tasks (i.e., removing and returning comforters, pillow cases, top sheets, placing pillows on the bed, clean mirrors, clean toilets, tubs and vanity counter tops, pull out drawers to inspect or dust, take out trash, put iron and ironing board in closet, and push carts) were examined using the LMM LBD modeling methods and were predicted to produce at minimum a medium-risk of low back injury. Five tasks were forecasted to yield high-risk of low back injury (i.e., tucking bottom sheets, dusting furniture, cleaning shower wall tiles in the standing position, mopping the floor, and vacuuming carpet using a lightweight industrial vacuum).

Performing the housekeeper's job was predicted by the LMM LBD prediction model to have a high risk for high incidence of back injuries (i.e., a 91% probability that 12 or more LBDs would be experienced each year per 100 housekeepers). Yet, the actual incidence rate for for musculoskeletal disorders in the hotel housekeeper population, published by the Bureau of Labor and Statistics (BLS, 2012) was low. Less than 1 out of 100 housekeepers experience such injuries each year (IR=0.11).

Aside from the aforementioned predictive validity problem, tasks used to develop the LMM LBD prediction model were materially different from those performed by hotel housekeepers. The LMM LBD prediction model used a single maximum load, a single maximum load moment, and used maxima for goniometer readings as representative indicators of the biomechanical stress experienced for each lift performed during the shift because the worker was performing the same lift over and over. That type of job is not consistent with that performed by housekeepers. They do not perform the same lift over and over, perform a variety of exertions of which most were never addressed by the LMM LBD model.

---

2. http://biodynamics.osu.edu/application_pdfs/Hotel%20housekeeping.pdf

The prediction model was not based upon tasks such as carrying, pushing or pulling carts, mopping, wiping walls, mirrors and furniture surfaces, tucking sheets underneath mattresses, vacuuming, and other tasks performed by hotel housekeepers. Essentially the LMM LBD prediction model is attempting to predict risk of activities that were never considered in the development of the model. This is a classic violation of the tenets of statistical theory and regression modeling, and creates a serious potential for errors in forecasting LBDs in housekeeping tasks (Sachs & Reynarowych, 1984).

Beyond the predictive validity problems with the LMM LBD and the lack of correspondence of housekeeping tasks with those used to construct the model, we found material errors in task analyses performed to arrive at model inputs. The model inputs appear in error in terms of the postural recordings and in overstating the actual loads, load moments and frequencies of free standing lifting activities. Examples of errors follow:

1. The maximum sagittal plane torso flexion reported was less than a fourth of that observed during our analysis of housekeeper activities. Either the equipment was out of calibration, donned improperly, or some other source of error existed. Housekeepers routinely stoop to reach towels or other objects on the floors of the bedroom and bathrooms. Those postures produced torso flexion angles that approximated 90 degrees from vertical. That observation was well beyond that presented in the LMM LBD risk prediction model outputs presented on the website.

2. Analysts reported that housekeepers performed 211 lifts per room. That number was multiplied by 14 to address the total number of rooms assigned to a housekeeper. The resulting number of lifts (2,954 lifts) was divided by 8 hours to arrive at a lifting frequency of 396 lifts per hour or one lift every 9.8 seconds. However, the analysts assigned 396 lifts per hour as the lifting frequency for each of the 19 individual tasks performed per room. Their analysis effectively assumed that all 19 tasks were being performing simultaneously by an individual housekeeper. For 19 tasks in 14 rooms they estimated that the total number of lifts performed by a housekeeper per shift was 105,336. If the housekeepers performed 105,366 lifts in eight hours, then they would have to perform 3.7 lifts per second. Based upon study of the housekeeper's job, clearly the Ohio State analysts substantially overestimated the frequency of lifting performed for all of the tasks and for the job as a

whole. No human could perform 3.7 lifts per second for one second, let alone continuously for 8 hours. The excessive lifting frequency vastly inflated the LMM LBD risk prediction.

3. The Ohio State team allocated 26%, 29% and 20% of the 211 lifts per room to bed making, bathroom cleaning and vacuuming respectively. However, the vast majority of tasks performed by housekeepers do not involve any lifting (e.g., dusting, cleaning mirrors, wiping horizontal and vertical surfaces, vacuuming (beyond lifting the vacuuming off the cart and returning it to the cart), mopping, pushing a cart, toilet bowl cleaning with a brush, rolling desk chairs to the desk, and so forth). These estimates of lifting frequency were also erroneous and served to seriously inflate frequencies of lifting activity input into the LMM LBD prediction equation—exacerbating prediction errors and overestimation of risk.

4. Housekeepers never lifted their linen carts as indicated by the LMM LBD prediction model analysis. The team used a lifting frequency for cart pushing 396 lifts/hr and erroneously entered that information into the LMM LBD prediction model. Cart pushing was found to be a hazardous lifting task, and that error, along with the aforementioned, were passed into the global job inputs to create a collectively erroneous characterization of the lifting exposure for the global evaluation of housekeeper job hazard.

5. Following the same approach, bed making would account for 26% of 211 lifts/room. This fraction would require about 55 lifting tucks for bed making. Others studying bed making estimated about 20 tucks were required per hotel bed (Milburn & Barrett, 1999). Work sampling studies performed for this study found that Milburn and Barrett's estimates of bed tucking were reasonable. The Ohio State team's estimate of lifts associated with bed making tucks was more than twice that of Milburn and Barrett's (1999) estimate, and that of our observations of bed making.

6. It is important to understand that the LMM LBD prediction model was based upon workers performing the same lift over and over during a work shift. When one estimates the maximum moment arm, lifting frequency, and other external load parameters, those measures are rational for addressing the mechanical load imparted to the body for each lift. When the LMM LBD prediction model is applied to an unstructured job, such as housekeeping where each lift can be different from another, the LMM LBD presumes that

each lift is an exposure to the maxima for each parameter. This promotes an overestimate of the true exposure and subsequently the true LBD hazard.

7. The LMM LBD model is a first-order additive model that describes a single cyclic lifting task. The model presumes that each of the lifts is characterized by each of the inputs. With unstructured work (i.e., work that possesses a variety of tasks that differ and that are not performed in the same order, duration or frequency), a single event or set of unrelated events would produce a range of maxima that did not occur at the same time. Thus, rapid movement of the torso (e.g., twisting or bending while performing no lift) would be combined with maximum torso flexions that occur at some other point in time when the worker was not twisting or bending their torso. At another point in time, lifts are performed with limited torso flexion and a maximum load is handled, and a maximum moment could occur when a very limited weight is lifted very far from the body. Lifting frequency is not parsed among the aforementioned exertions in the LMM LBD model. Thus, the LMM LBD prediction model receives inputs that characterize a lift that was never performed but the model assumes those characteristics represent the lift studied and the frequency determines how often that nonexistent lift was performed. The model uses the lift characterized by torso twisting and bending while performing an extended reach and lift of a very heavy load for an eight hour period at the lifting frequency entered. That single characterization is used for every different lift performed; regardless of the lack of compliance with actual lifting tasks. The result will be a consistently biased estimate of the true risk of LBD incidence.

8. Finally, examination of the LMM LBD component scale behavior for each of the housekeeper tasks studied, as well as the job as a whole, showed very clear patterns. The maximum moments are small for nearly every task examined. A pattern of small sagittal plane flexion angles (e.g., < 10 Nm, or 7.4 ft-lbs) was also consistently encountered. The next level of maximum external moment was approximately 25 Nm for lifting bed mattress corners sufficiently to allow sheet tucking (25 Nm=18.4 ft-lbs; comparable to lifting a plastic grocery bag with 17 pounds of groceries from a shopping cart to a carrying position at the body's side). The maximum load moments and maximum torso flexion angles indicated that the biomechanical loads acting upon the body were small enough for NIOSH to consider the risk of low back injury to be nominal and the job to be safe. Had the LMM LBD frequencies been

correct, the risk forecasted by the LMM LBD prediction model would have been considerably lower.

In sum, the LMM LBD prediction model was never designed to address jobs like that of the hotel housekeeper. The majority of tasks performed by housekeepers are not addressed by the LMM LBD model, and were inappropriately treated as lifting tasks. Gross overestimation of lifting frequencies and use of extremely high lifting frequencies for tasks that possessed no lifts, drove up estimated LBD risk predictions for housekeepers which were over 90 times that of actual incidence. These and other aforementioned issues, combined with inherent problems with prediction validity, undermine the LMM LBD model's prediction that housekeeper's jobs present substantial risk for high LBD incidence.

2.5. Hotel Worker Injury Incidence Analysis

The Bureau of Labor Statistics (BLS) tracks injury incidence and severity in the hotel industry. Injury incidence is compared within and across industries using a standard metric of Incidence Rate (IR) and Severity Rate (SR). Incidence rates are normalized to a ratio reflective of reportable injury incidence within 100 full-time workers. The SR is normalized to number of lost workdays per 100 full-time workers. OSHA compliance officers, corporate safety personnel, union safety personnel and researchers examine logged IR and SR for preliminary indications of MSD risk.

A recent study examined OSHA log injury incidence in housekeepers, banquet servers, kitchen and the remaining crafts across five unionized hotel staffs between 2003 and 2005 (Buchanan et al., 2010). The purpose of the study was to evaluate injury rates by job, hotel and demographic differences, and to test their import as predictors of Musculoskeletal Disorder (MSD) injury risk. The data set consisted of 2,865 injuries across 55,327 worker-years of coverage. Worker ages ranged between 18 to 70 years. Young white males working in “other” jobs (i.e., not housekeeping, banquet service, or kitchen staff) were selected as the control group.

OSHA log injury reports were classified as: 1) MSDs, 2) acute trauma injuries (e.g., contusions, fractures, lacerations, heat burns, and sprain or strain injuries with evidence of an injury mechanism that involves acute contact with outside objects (e.g., hit by, struck against)), 3) other (e.g., lacerations, burns, foreign objects in eyes, etc.), and 4) unclassifiable (i.e., insufficient information to understand origin or nature of the accident). An injury was classified as an MSD if there was an injury or disorder of the muscles, nerves, tendons, joints, cartilage, or spinal discs that did not include injuries because of slips, trips, falls, or motor vehicle and similar accidents that produce an acute musculoskeletal injury. Back pain or pain at other body locations, and strain or sprain injuries, were also classified as MSDs unless the entry referenced stairs or ladders, or the employer-reported description of the injury referenced a slip or fall.

Incidence of occupational MSDs has varied among genders, age groups, races or socioeconomic groups, duration of job experience, and companies from within equivalent industrial sectors (NIOSH, 1981). Buchanan et al. (2010) included the following predictor variables for MSD incidence:

1. Age (18–27 years, 28–37 years, 48–57 years, and 58–70 years),
2. Gender,
3. Race/ethnicity (White, Black, Asian and Hispanic),
4. Job title (housekeepers, banquet workers, kitchen workers and other),
5. Job tenure (0–10 years, 11–20 years, 21–30 years, 31–40 years, and 41–52 years), and
6. Hotel company (Company 1 through 5).

A mean total injury incidence rate of 5.2 injuries per 100 worker years was reported in unionized hotels examined. That rate was comparable to that reported by BLS (2009) for the industry at large. The largest overall injury incidence was found in jobs other than housekeepers. The majority of hotel workers who experienced reportable injuries were men. No severity rate information was reported.

Most jobs with MSD hazard present high severity rates because overuse or musculoskeletal overexertion injuries result in material lost time from work. For example, the BLS (2009) showed that Nursing Care Facilities (NAICS Code 6231) experienced incidence rates of 8.9 and severity rates of 5.6. Hotel workers had incidence rates of 5.2 and a lower severity rate of 2.7 (NAICS Code 72111)[3].

3. http://www.bls.gov

Buchanan et al. (2010) reported large differences in incidence rates across unionized hotels; some below and others above the national average. The collective incidence rate for the unionized hotels studied was equivalent to the nationwide incidence rate. This outcome indicated that the hotels studied were representative of the industry at large; regardless of the size, nature, or unionization of the work force.

The odds ratios for the aforementioned MSD-linked predictors were either insignificant, or produced small risk ratios. No Relative Risk (RR) or Absolute Risk (AR) rates were presented for small but statistically significant odds ratios to help understand the operational significance of a few small odds ratios. For example, one may find that “the risk is doubled with exposure to a putative risk factor.” If the absolute risk changed from 0.01% to 0.02% associated with a MSD risk factor, the level of risk has doubled. While the odds ratio sounds materially important, the absolute change in risk was only one-tenth of one percent—nearly meaningless.

Buchanan and coworkers showed no change in MSD incidence because of increased age and duration of work exposure, or housekeeper job category. This outcome was not consistent with job-induced MSDs. The open literature argues that job exposure indicators (e.g., older workers or workers with longer job tenure in MSD risk-laden jobs) should produce higher MSD incidence (NIOSH, 1981; Bernard, 1997). This was not the case with hotel workers.

Buchanan et al. (2010) argued that housekeepers were exposed to high levels of physical effort or aerobic strain, dangerous repetitive movements of the upper extremities, dangerous high static muscular loads, and high frequencies and durations of stooping and crouching postures. They did not measure actual MSD risk factor exposures. Their claims were based upon assumption that tasks performed by housekeepers, which shared names with tasks performed by workers in other industries where MSD hazards existed, was *de facto* evidence of MSD hazard exposure. No evidence was presented to support such speculation.

3. Study Design

Pathology or accident-induced alterations of musculoskeletal architecture may provoke MSDs or signs and symptoms linked with MSDs that are unrelated to jobs (e.g., poorly healed fractures, pregnancy, menopause, and as side-effects of disease). Clinicians addressing MSD incidence and treatment typically rule out nonoccupational causation before classifying the illness or injury as occupational in origin. If MSD incidence cannot be linked to underlying medical conditions, then NIOSH recommends a specific study protocol be followed to determine if a job presents risk for development of occupationally-induced MSDs (Putz-Anderson et al., 1988).

All jobs possess some degree of MSD risk factor exposure. However, decades of epidemiological research have consistently demonstrated that if MSD risk factor exposure falls within the exposure definition of epidemiological study control groups MSD incidence is nominal and the work is deemed safe. The NIOSH MSD hazard assessment protocol follows a systematic approach for detection and quantification of MSD risk factors. Cardinal risk factors for MSDs are sufficient exposure to exertions that are forceful (e.g., exceed 20 percent of one's maximum voluntary contraction (MVC)) and concomitantly approach the range of motion limits of the joint are considered provocative. These exposures must be sustained or highly cyclic in nature (e.g., more than 4 hours per shift, or exceeding 840 cycles per shift).

If the job presents MSD hazard, the NIOSH protocol serves to identify opportunities for reduction or disruption of provocative exertions or exposure durations. Engineering or administrative controls are advocated until MSD incidence is eliminated or reduced to idiopathic levels. Often engineering modification of the job leads to greater production and quality of work because task demands are realigned to better match human performance and endurance capacities.

Ergonomists have been very effective in controlling MSD hazard through engineering or administrative control of risk factor exposure. One does not have to eliminate all putative risk factor exposures to address MSD risk; just reduce the magnitude of a cardinal factor or disrupt their phasic relationships.

A metaphor for the NIOSH intervention process is the "fire-triangle." Fires require concomitant exposure to fuel sources, adequate oxygen and adequate heat. One has only to remove or sufficiently reduce the availability of oxygen, fuel or heat to prevent or eliminate a fire. Similarly, one does not have to eliminate all provocative MSD factors, one or more factors to epidemiological control group exposure levels, or create phase shifts in their exposure so that they do not occur concomitantly.

The NIOSH assessment protocol aims to not only help determine if MSDs are job-related, but provides sufficient information for strategic and cost effective suppression and prevention of MSDs if problems are found. The NIOSH protocol was followed to determine if housekeepers are excessively exposed to MSD risk factors and, if so, how best to mediate such exposures to prevent future MSDs.

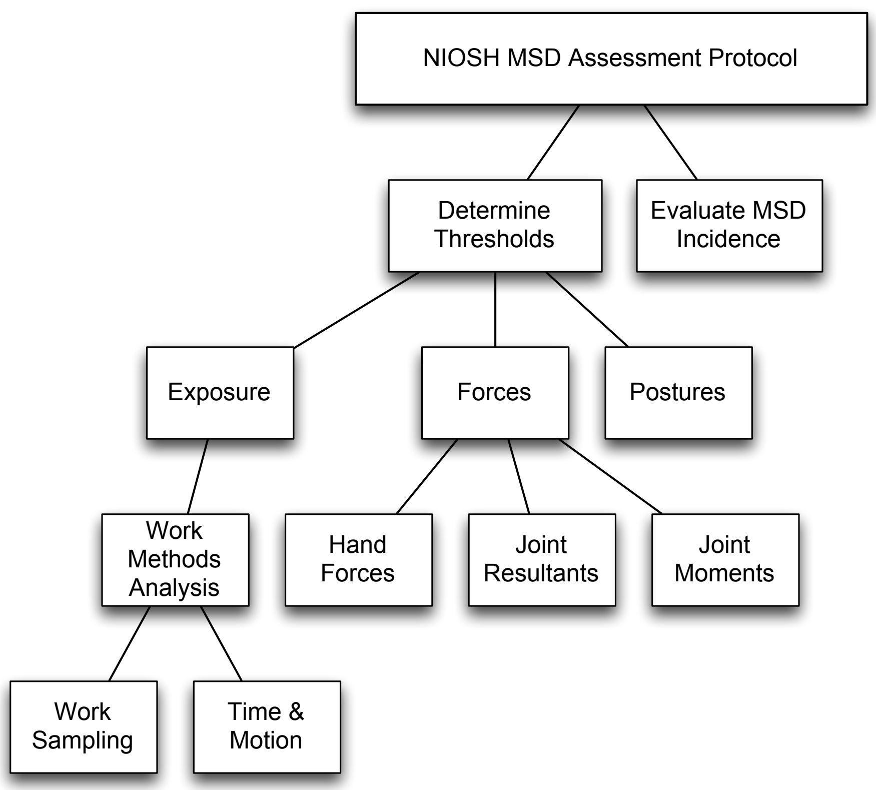


Figure 19: NIOSH recommended protocol for determining whether a job presents risk for development of occupational MSDs.

3.1. Exposure Assessment

Work, activity or occurrence sampling are used to determine the proportion of a work shift, or period, that a worker is exposed to activities, delays and MSD risk factors. The general public often confuses work sampling methods with time and motion studies; incorrectly believing that the methods and use of study results are interchangeable. Work sampling's objective is to determine the proportion of time that a worker is exposed to activities or phenomena of interest (e.g., Konz et al., 2000).

NIOSH recommends work sampling as a means to define the level of exposure to tasks that possess MSD risk factors (Putz-Anderson et al., 1988). Work sampling requires a large number of observations of job activities performed by experienced and representative workers across a representative work period. Observations may be collected randomly or uniformly as long as the sampling epochs are undetected by the workforce. Workers who know when samples are to be taken may alter behaviors just before the sample is taken and, thereby, influence exposure estimates. Use of video cameras eliminates the ability of the worker to determine when a sample will be made.

A full-factorial study design was selected to test whether differences in room tidiness, number of beds, or level of daily room cleaning produced material differences in activity exposures. For each activity, exposure was determined from video-based sampling observations collected during room cleaning. The sampling fraction was used to determine the time for performing each room cleaning activity. Fractions of room cleaning activities were matched with exposures to the activity's MSD or MSI risk factors. Both individual task and collective job exposures were determined to evaluate whether job MSD exposures were sufficient to exceed epidemiological control group boundaries. See Figure 20.

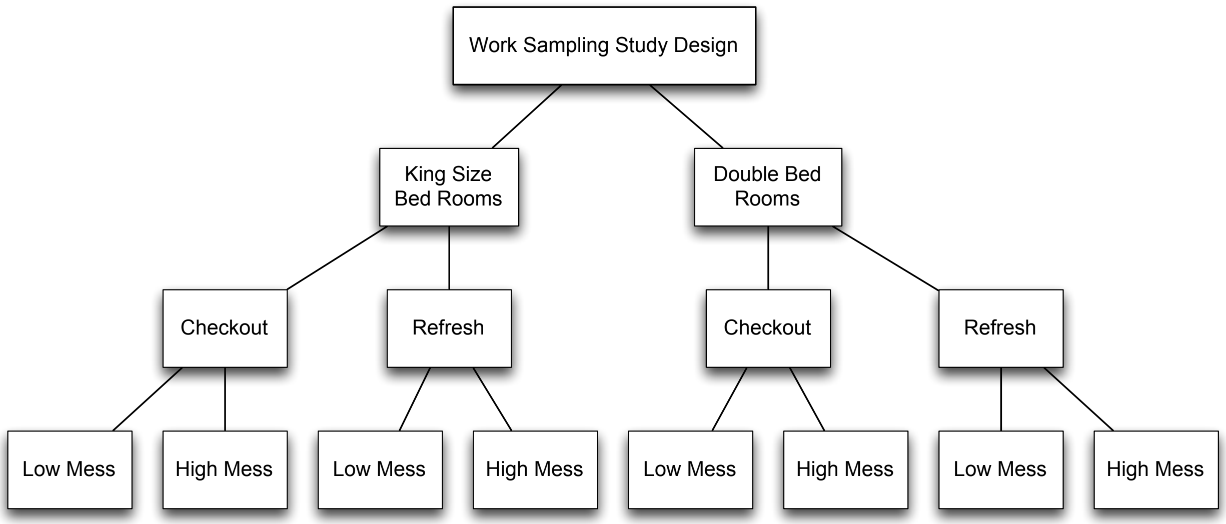


Figure 20: Work sampling full-factorial study assessing impact of room type, level of cleaning assignment and degree of room tidiness upon activity exposure.

3.2. Exertion or Force Assessment

Exertions performed by housekeepers could be defined as systemic or whole-body, or localized (i.e., confined to one or a few muscle groups). Whole-body exertions recorded, along with hand forces and representative anthropometry, were entered into the University of Michigan Biomechanical model (3DSSP). The model was used to estimate resultant forces and moments acting at major articulations, and for prediction of populations strength and lumbar disc compression (Chaffin et al., 2006).

Disc compression forces used by NIOSH used to set Action Limits and to evaluate workplace biomechanical strain in the NIOSH Work Practices Guide for Manual Lifting were based upon computations provided by this model. The model's validity is widely accepted within the ergonomics community when exertions are static or quasi-static in nature.

3.2.1 Systemic or Whole-body Exertion Demand

Heart rate measurement was performed during the work sampling study to obtain an index of aerobic power demand required with housekeeper work. Heart rates provide a direct measure of cardiac output after light work exceeds stroke volume limits. At that point, cardiac output is proportional to demand of oxygen in active muscles and corresponding heart rate. Increase in muscular activity, whether in terms of strength demand or distribution of working muscles, is associated with a linear increase in cardiac output and, thereby, heart rate. Understanding the physical demands of a job is important if job design changes are to be recommended. Heart rate measurements were made following standardized methodology described elsewhere (Astrand, 1986).

3.2.2 Hand Force Measurements

Hand forces were measured in most activities when housekeepers stood atop of Kistler portable force plates. Forces exerted by the hands are transmitted through the body and were captured at the force plate surface. Force plate surface forces are referred to as ground reaction forces (GRFs). Force due to body weight was removed from the GRF complex following the methods described by (Chaffin et al., 2006) and the resulting values used to characterize hand forces.

Use of force plates provided more accurate measures of hand forces that were applied when pushing carts, performing limited mattress side and corner lifts during bed linen tucking exertions, and when using long handled bathroom tub and shower wall scrubbing tools. Where appropriate, a calibrated Biometrics hand-held electronic force transducer was placed between the hand and cleaning cloths to obtain hand force information during vertical and horizontal surface dusting and scrubbing.

With either force sensor method, peak dynamic hand force measurements were used as inputs for static biomechanical modeling. This approach inflated values of static hand forces and subsequent computations for internal static forces, moments, lumbar disc compression magnitudes and intra-abdominal pressures. If inflated estimates of biomechanical exposures fell within safe or desired exposure zones, then the job exposures were compliant with current guidelines even if values were inflated.

Dynamic GRF estimates were used to estimate static task-based required dynamic coefficient of friction (COF). Computations used are described in detail by Chaffin et al. (2006).

3.3. Posture Measurement

Postures were recorded using high definition video cameras and a human motion analyzer recording system when ferrous or other sources of magnetic disturbance were absent. Categorical evaluations of posture were made directly from video records (e.g., presence of undesirable upper extremity postures when using long-handled scrubbing tools in the bathroom), or were matched with kinematic inputs for the Michigan 3DSSP Biomechanical Model.

3.4. Bed Making Tools

Some housekeepers have been using a kitchen utensil, referred to as a "rice paddle," to assist them in making beds. A commercially-available bed tucking set of tools[4] has also been available for use. The rice paddle, shown below, extends the reach, eliminates or reduces hand-bedding sliding friction and reduces axial compression loads on fingers when tucking bedding between the mattress and box springs. The tool was included in the study to determine if it does or does not provide a benefit to the housekeeper from a biomechanical perspective.

Figure 21: View of rice paddles used by housekeepers to assist in the tucking of sheets when bed making.

4. http://www.ckisolutions.us/bed-madeEZ

The commercially-available tucking tool comes with three mattress wedges and a short tucking blade with a spherical handle. The wedges are systematically inserted between the mattress and box springs about the bed to raise sections of the mattress and bedding is tucked underneath the mattress sections using the tuck tool. Once the bedding was tucked, the wedges are pulled from between the mattress and box springs. See Figure below.

Figure 22: View of commercially-available bed tucking system where wedges are inserted at midpoints of mattress edges and the spherical grip tucking tool is used to tuck bedding.

Neither tool had been objectively evaluated to determine if there is any material biomechanical benefit. Thus, we recorded dynamic hand force and postures when making beds with hands only, with a rice paddle and with a commercially-available tucking tool.

Long-handled scrubbing tools have been proposed for use in cleaning bathtubs and shower walls. Those tools were compared against hand wiping of the rub and shower walls to determine there were reductions in hand forces, improved postures, or a combination of both.

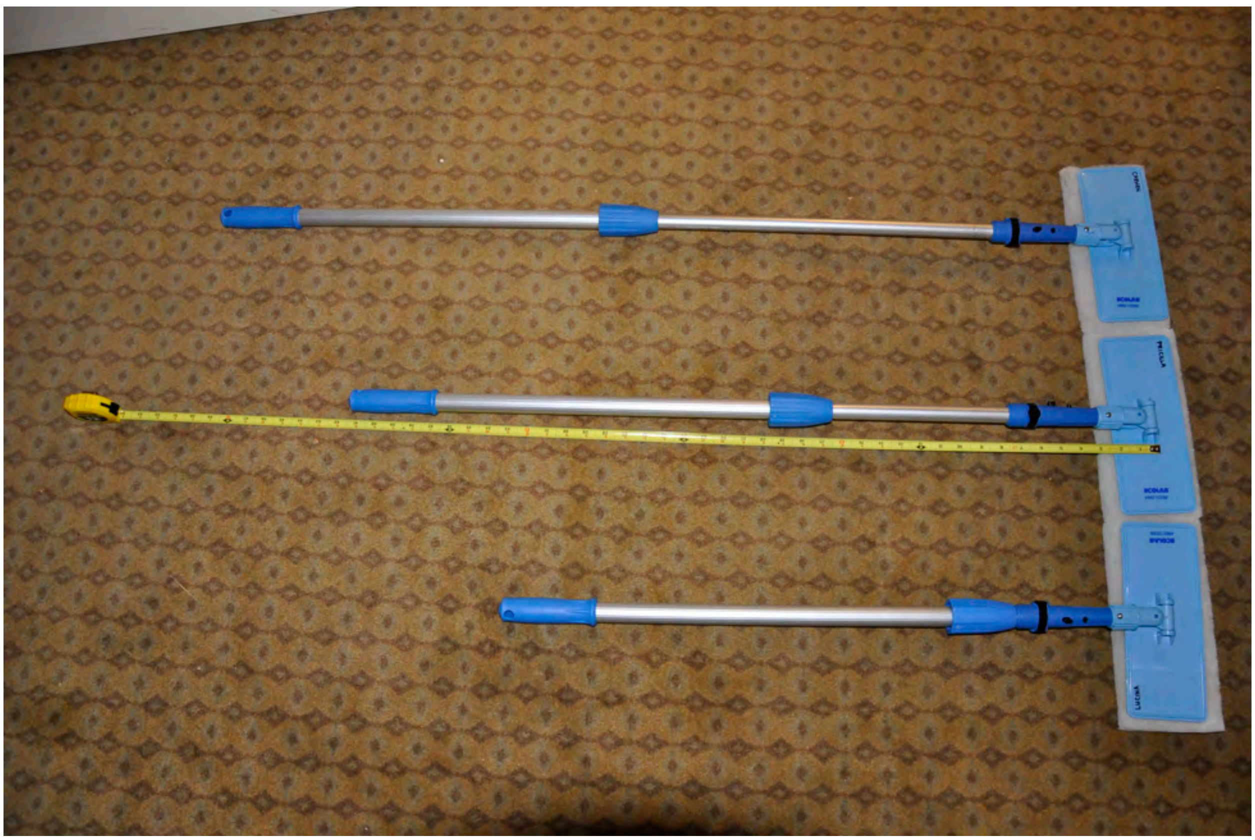


Figure 23: View of adjustable long-handled scrubbing tools that are made available to hotel housekeepers and that were used in this study.

4. Methods and Materials

4.1. Participants

Experienced hotel housekeepers were briefed regarding the purpose and methodology of the study. All briefed housekeepers volunteered to participate in the study. A random sample of ten housekeepers was selected from the volunteers. The housekeepers had completed their standard hotel housekeeper training and had been working for at least a year.

All participants appeared to be in good physical health at the time of the study and none reported a history of low back pain or other musculoskeletal disorders. Participants were paid normal daily compensation for participation in the study. Housekeepers 1 through 8 participated in the work sampling study. All housekeepers participated in the remainder of the study. Descriptive information for participating housekeepers is provided in Table 1.

Table 1: Anthropometric characteristics of housekeepers participating in work sample study.

Housekeeper	Age (Yrs.)	Stature (cm)	Body Mass (kg)
1	21	152.4	56.8
2	37	147.3	56.8
3	42	147.3	54.5
4	22	147.3	54.5
5	35	162.6	68.2
6	28	161.3	68.2
7	35	152.4	72.7
8	46	149.9	44.5
9	40	147.3	45.0
10	35	160.2	68.0
Min	21	147.3	44.5
Max	46	162.6	72.7
SD	8.2	6.2	10.0
Mean	34.1	152.8	58.9

4.2. Apparatus

Engineering drawings of the hotel were examined to rule out differences in room geometries, bathroom designs, location of windows, etc. Rooms were also directly inspected to confirm that rooms were laid out and equipped consistently. A single floor and wing of the hotel was used to conduct work sampling studies.

A suite was used to make measurements of postures, exertions, and other measurements beyond those of work sampling. The suite had a king bed bedroom, a double bed bedroom, living room and two bathrooms. Beyond the living room area, the remainder of the suite's bedrooms and bathrooms were equivalent to rooms studied in the work sampling study.

4.2.1 Guest Rooms

Cleaning of two types of guest rooms, a king size bed and double bed, were work sampled. The size of the rooms, amenities, and layouts of the rooms at the Bellevue Hyatt Regency were closely matched to Hyatt Fishermans' Wharf rooms by Fishermans' Wharf management.

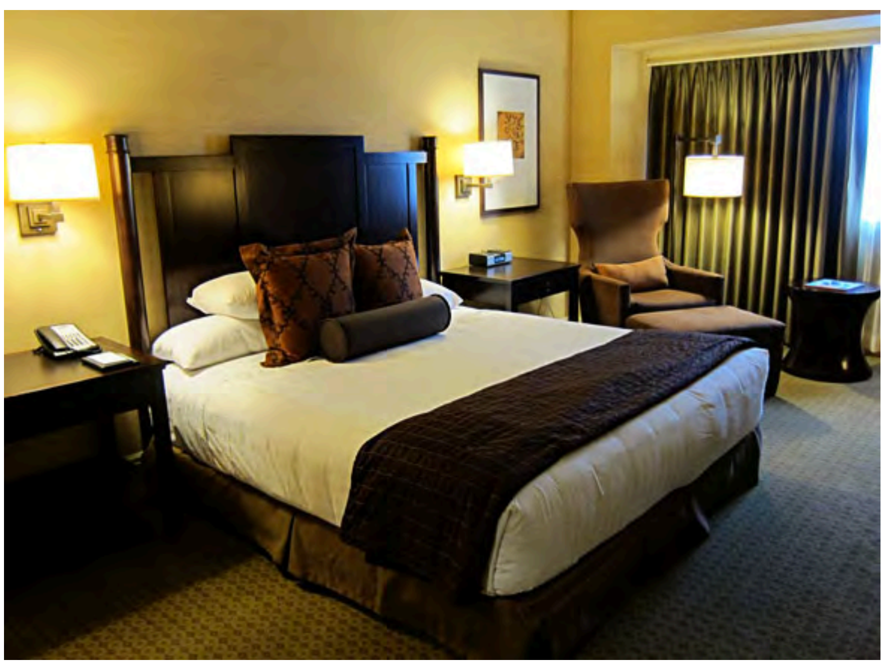


Figure 24: An exemplar photo of a king-sized bed guest room tested in this study.

Figure 25: An exemplar photo of a double-bed guest room tested in this study.

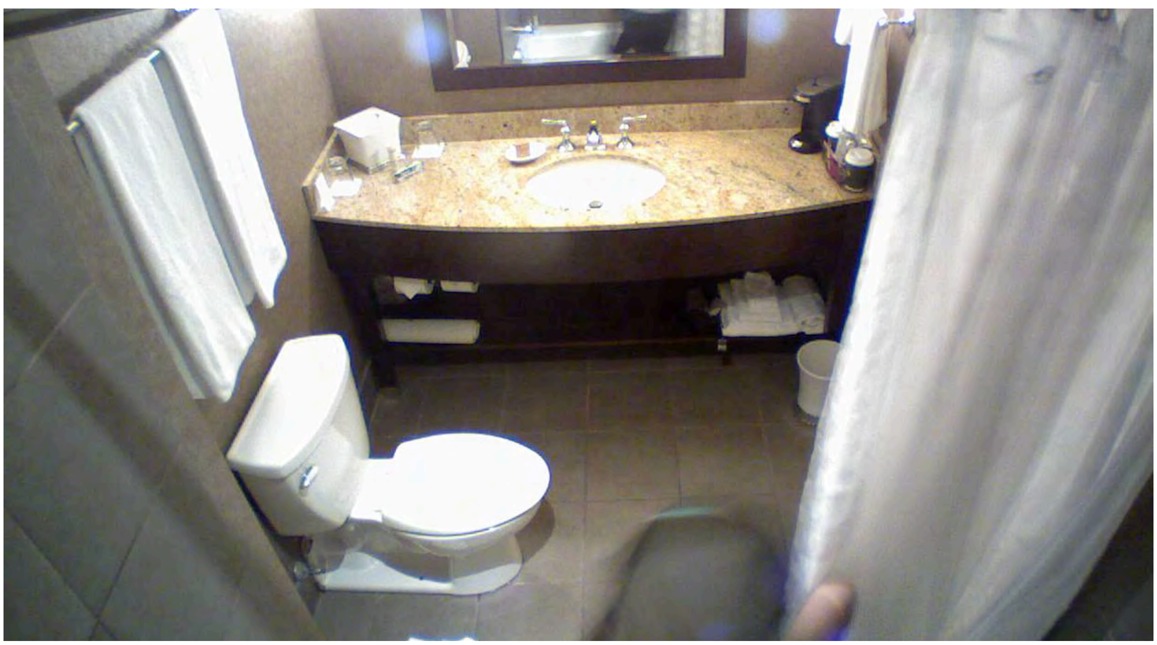


Figure 26: An exemplar view of a bathroom from the time-lapse video camera used for work sampling. Work activities in the bathtub and shower were captured in the mirror.

Figure 27: View of tub, shower stall walls and fixtures in bathrooms that were work sampled.

To vary levels of cleaning difficulty, two levels of room mess were systematically presented to housekeepers in the work sampling study. The **light mess** condition was created by half of the towels lying on the bathroom floor, one double bed remaining untouched, the king-sized bed lightly tousled, and no furniture disorganization. The **heavy mess** condition consisted of all towels on the bathroom floor, all toiletries missing and needing replacement, all beds heavily tousled, desk and reading chairs moved a couple of feet out of place, and furniture surface amenities moved out of normal position requiring repositioning.

4.2.2 Time Lapse Video Cameras

Small (64 x 46 x 106 mm) Brinno TLC200 Time Lapse cameras, with wide-angle lenses, were used to capture work activities in each hotel room and bathroom. High definition video frames (1280 x 720 pixels) were captured at one-second intervals. The cameras captured a 88 degree field of view and were mounted on vertical surfaces to allow visual coverage of tasks performed by the housekeepers. Two cameras were used to capture work activities in each room: 1) one camera mounted on the room's exterior window facing into the room, and 2) one camera mounted on the bathroom tub wall facing the bathroom and its mirror. The angle of view of the camera in the bathroom was set to enable use of the mirror's reflection of activities that could not be captured directly by the camera.

The camera clock circuits were synchronized to universal coordinated time and observations recorded on both cameras were used collectively to determine exposures to work activities. Housekeepers were in view of one of the cameras during their room cleaning activities. Clock time was used to continuously track behaviors as housekeepers moved into and out of one and into another camera's field of view.

4.2.3 Heart Rate Monitors

Each housekeeper wore a Polar RS800CX heart rate monitor. Each monitor's electrodes were moistened with water and placed upon the anterior chest wall just below the bra. Snugness of the chest bands was checked along with continuities after housekeepers fit and applied the bands themselves. Heart rate monitor accuracy was checked by taking the radial pulse. Housekeepers were asked to sit and relax for 30 minutes before the start of work sampling data collection. Heart rates were recorded and transmitted to wrist watch data capture receivers at 2 s intervals and were uploaded to a computer at the end of the study.

4.2.4 Force Plates

Two portable 500 x 600 x 50 mm Kistler 9260AA force plates with a 5 kN and 100 Hz measurement range were used to capture GFR and hand force information, and task-induced dynamic coefficients of friction (COFs). Computations of GRF orthogonal and resultant forces were performed by

Kistler Bio-Ware software and results were checked with calibrated normal and surface shear force gauges. Specific details of the hardware and software are provided at www.kistler.com.

Figure 28: View of one of the orientations of force plates with matching elevated walking and cart rolling surfaces used in this study.

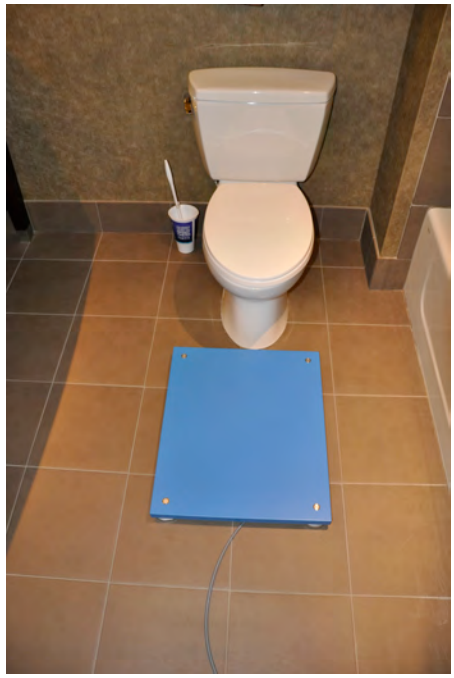


Figure 29: View of force plate in position to record GRFs when cleaning a toilet.

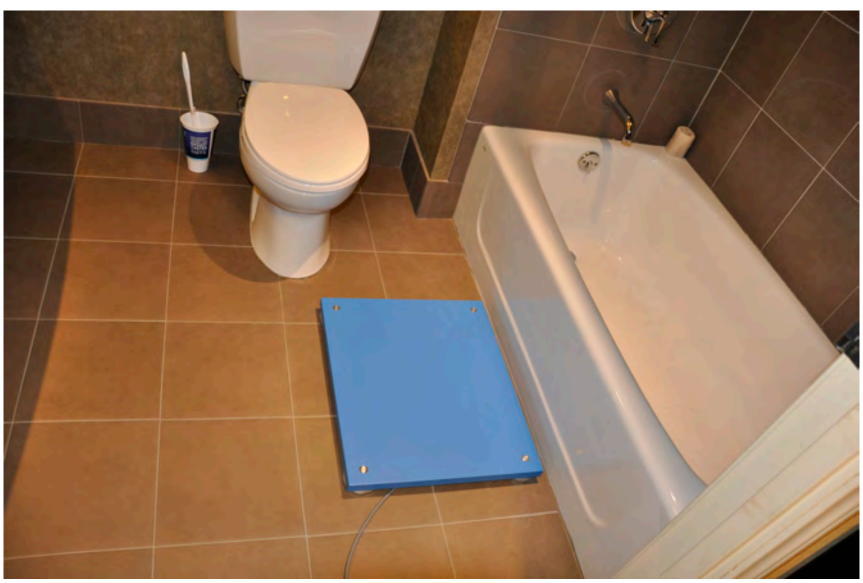


Figure 30: View of force plate placement for measuring GRFs when housekeepers stood outside and adjacent to the tub.

Force plates used in recording bathroom task GRFs raised housekeepers 50 mm above the floor. The elevation produced a small change in some postures; changes that increased biomechanical stress values. If stress metrics fell into safe zones, then the postural impact can be ignored for the purposes of this study.

4.2.5 Linen Carts Used by Housekeepers

Housekeepers load and push a four-wheeled cart that is stocked with sufficient linens, bathroom amenities (e.g., shampoo, soap, lotion, etc.), cleaning solutions, rags, vacuums, mops, Swiffers®, air fresheners and so forth. The cart tested was a Standard Three-Shelf Rolling Housekeeping cart produced by the Forbs Corporation. Unloaded the cart had a mass of 49.0 kg (108 lb.). A fully stocked cart possessed a mass of 131.7 kg (290 lb.). The front wheels were aligned with the principal axis of the cart. The rear wheels swiveled freely to allow housekeepers to steer the cart using the horizontal push handle. See the following image of a fully loaded cart below.

Figure 31: Exemplar view of the cart tested in this study in its full condition.

Figure 32: Exemplar view of cart used in this study in its empty condition. Note that the sheet was not present when testing the empty cart condition.

4.2.6 Transitions

Carts are periodically pushed over doorway sills or transitions between hard surface flooring and adjacent carpet. To measure the impact of those surface discontinuities upon cart pushing forces and other behaviors, two metal plates were stiffly coupled to the carpeted surface. Carts were pushed perpendicularly over two step-change transitions of 0.25 and 0.50 inches in height. The runway surface was matched to that of the force plates to allow housekeepers to smoothly push the cart across and walk along the force plate surfaces when the front wheels of the cart engaged and crossed over the transitions. The angle of the transitions and height of the maximum transition were designed to produce a worst case scenario in terms of pushing stress.

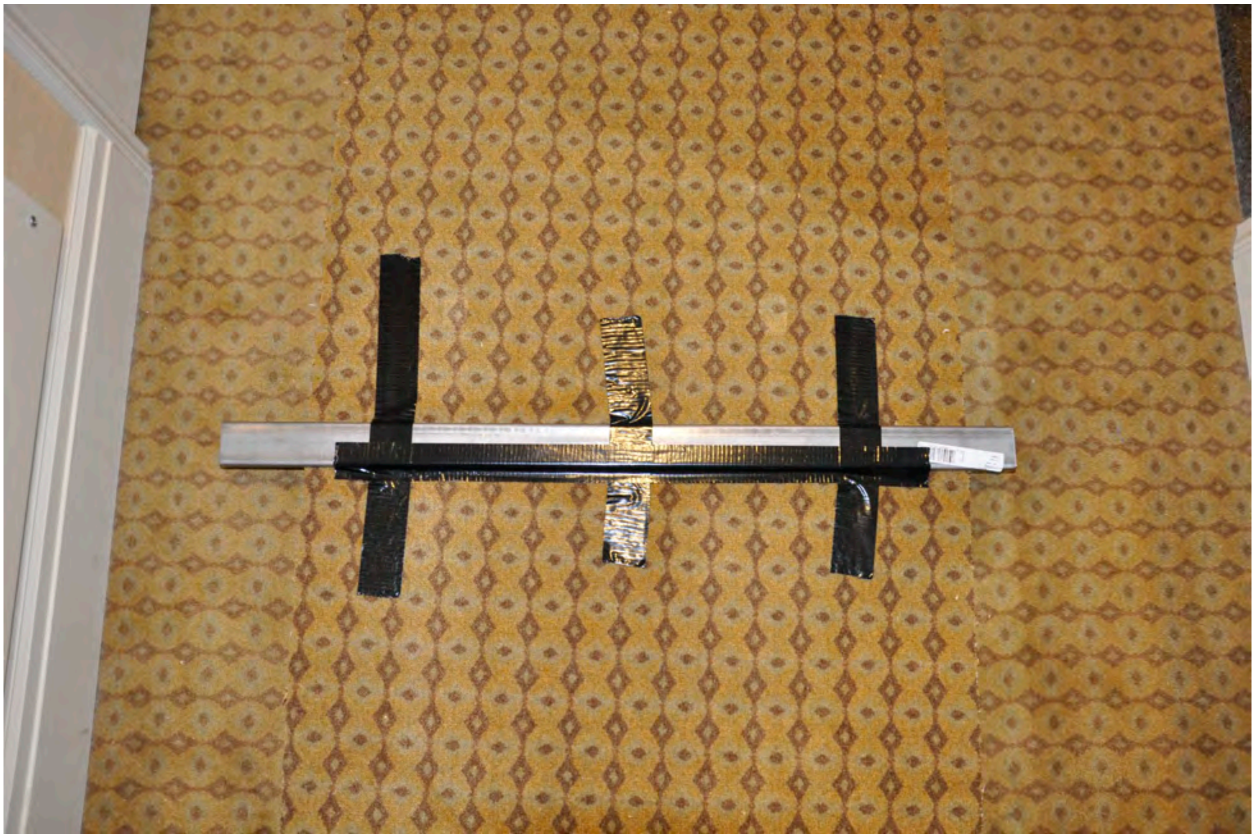


Figure 33: View of a steel alloy bar used to create a perpendicular step change in cart rolling surface.

4.3. Procedures

The study was conducted in phases. First, a work sampling study was conducted to determine activities performed, durations of activities and activity behaviors as well as aerobic power demand associated with performing room housekeeping tasks. Second, for each activity performed by housekeepers, hand forces and postures were recorded and entered into the Michigan 3DSSP static biomechanical model for computation of biomechanical stressor magnitudes. Finally, activity stressor metrics were weighted with exposure durations to determine the individual and collective stressor exposure and compliance with NIOSH job and task design guidelines for prevention of overexertion, MSDs and MSIs.

4.3.1 Work Sampling

Half of the rooms studied were king-beds rooms, the other half contained two double beds. Each room's cleaning requirements were systematically varied. Each housekeeper was positioned at the doorway for a room where they read their posted housekeeping assignment for that room (e.g., refresh, or checkout cleaning) and then began cleaning with a start signal. Thirty minutes were provided to complete room cleaning. If the room cleaning was completed early, then housekeepers were instructed to sit until signaled to move their carts to the next room. At the end of the thirty minute period, each participant pushed their cart to the next assigned room and commenced cleaning the next room following a start signal. All housekeepers wore Polar 8300CX heart rate monitors during the work sampling study. At the end of the study, heart rate data was downloaded from wrist transceivers into a laptop computer for analysis.

Each room was disarranged to either a low- or high-mess condition before the start of the next round of room cleaning. When all housekeepers cleaned all room types under all disarrangement conditions, the study was completed.

4.3.2 Housekeeping Task Measurements

Based upon results from the work sampling study, and shadowing many housekeepers in several hotels, a list of activities and tasks was developed for measurement. Postural and biomechanical analyses of tasks were performed for each housekeeper activity. The musculoskeletal and biomechanical efficacy of proposed bed making and other cleaning tools was evaluated. Carrying miniature toothpaste tubes, soaps, shampoos, lightweight trash cans, or other activities that would not produce material biomechanical stresses to the body, was captured in the work sampling study but was not evaluated biomechanically.

Housekeepers performed their tasks as they would during their work day. This protocol created the opportunity to evaluate a greater variety of methods and understand risks associated with different methods. Performance of the task created records that allowed combined analysis of body postures, forces, risk of slips and falls, upper and lower extremity disorders, and low-back injury risk. The scope of tasks examined is provided in Figure 34.

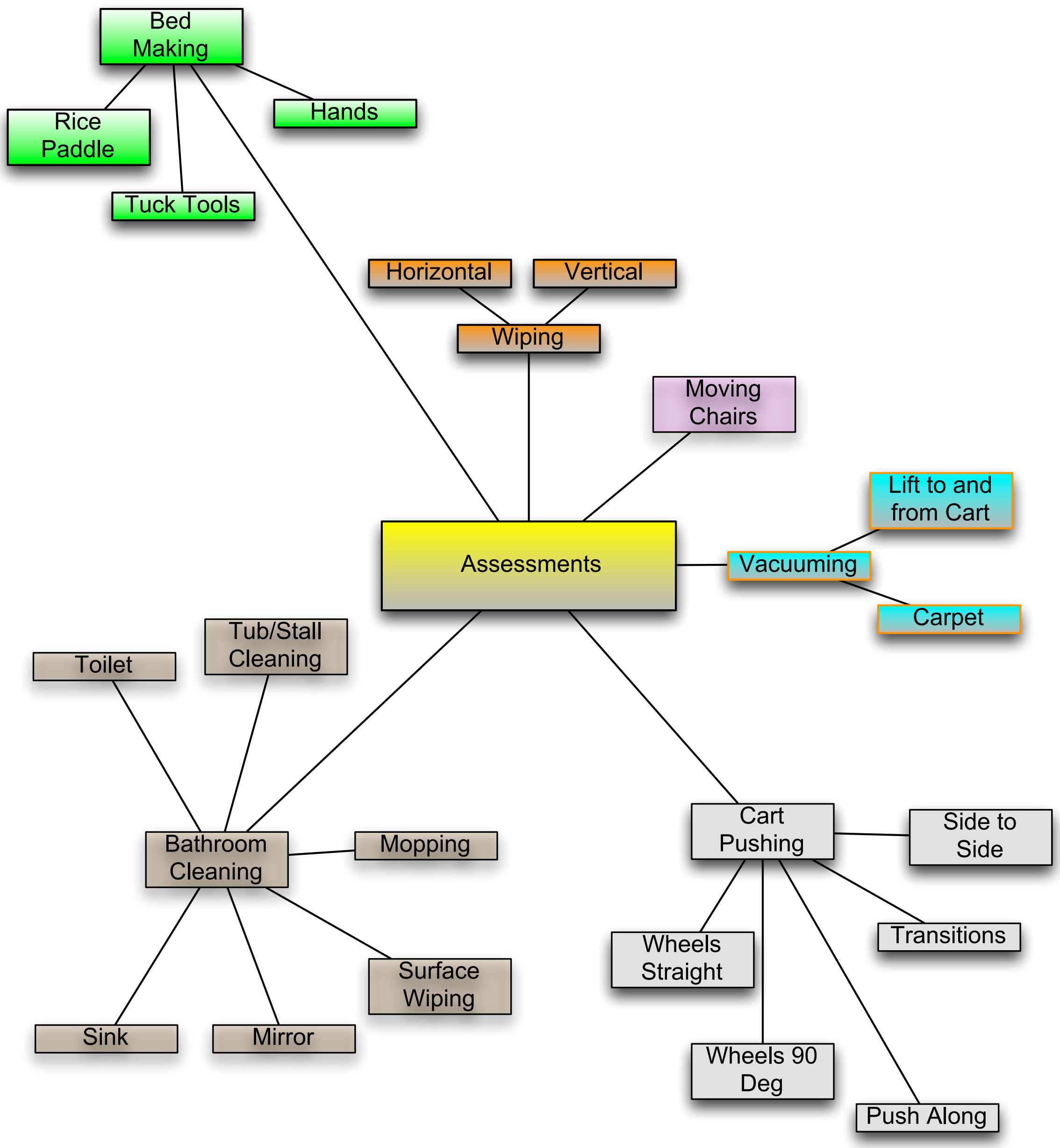


Figure 34: Scope of tasks that were examined in this study for MSD putative risk factors.

5. Results

5.1. Work Sampling Analyses

Thirty-two hours of video recording was made while eight experienced housekeepers performed their room cleaning activities for the eight test conditions addressed in the work sampling study. From a total of 230,400 single video frame captures of work activities, samples were taken every thirty frames to obtain a sequenced recording of activity occurrence. The resulting set of observations was 3,480 frames across all rooms and room tidiness conditions. The number of observations captured for each activity became the numerator for the estimated fraction of time spent performing each activity. Computations used to obtain proportions of the room cleaning task time spent on each activity followed standard work occurrence sampling methods described elsewhere (Konz and Johnson, 2000).

Durations for cleaning rooms were categorized by type of room, type of cleaning assignment and degree of mess or disarrangement of the room. Mean times required to complete either refresh or checkout level of cleaning in king and double rooms are summarized in the following figures.

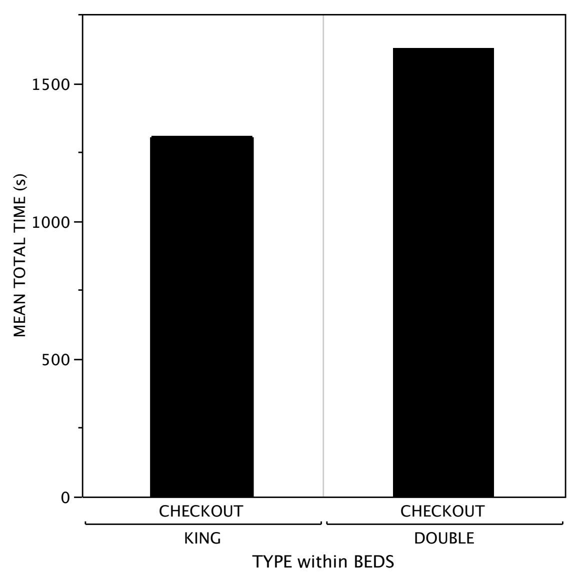


Figure 35: Mean time (s) to perform room checkout cleaning for rooms containing a single king- or two double-beds.

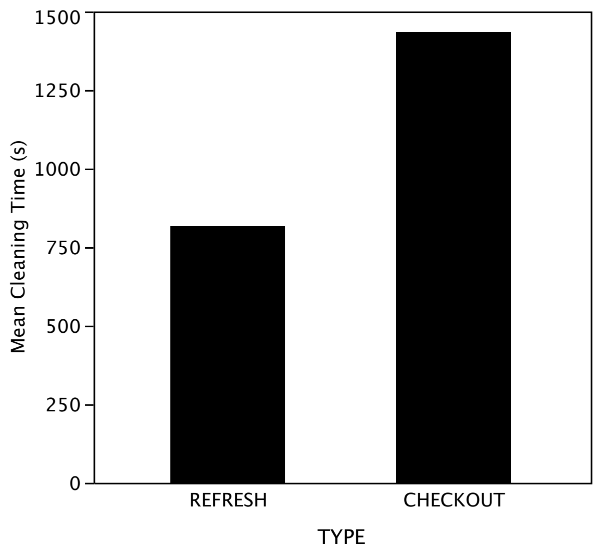


Figure 36: Mean time (s) to perform room refresh and checkout cleanings for all rooms studied.

Time to clean a room was affected by the type of cleaning (refresh versus checkout cleaning), with double rooms requiring more time to checkout clean than king rooms. No difference was found on average between king and double bed rooms when compared across types of cleaning and level of mess ($p>0.10$).

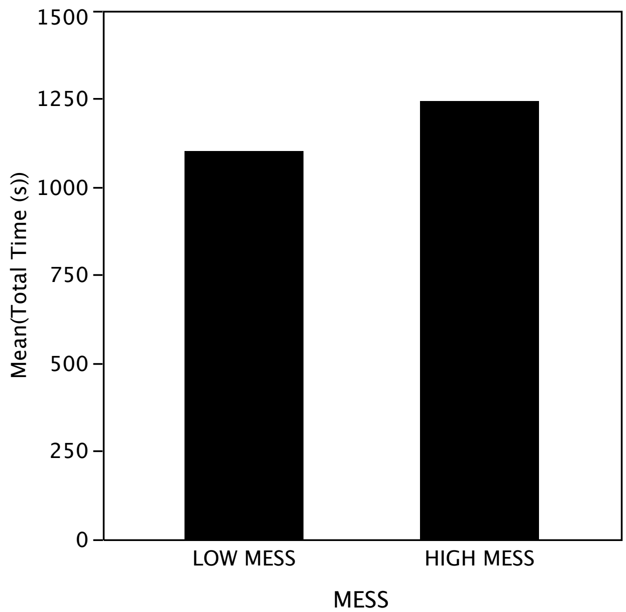


Figure 37: Mean cleaning times across all room types for low and high mess conditions.

No differences in cleaning times were found across level of mess. This finding is counterintuitive. With low mess rooms, only one of the double beds had to be made or refreshed. This condition produced equivalent bed making responsibilities between king and double bed rooms. Except for small differences in bed making, the remaining level of room mess was equivalent between room types, within type or level of cleaning required.

Checkout cleanings required more time to complete with double rooms when compared against king rooms. The effect was muted when housekeepers simply refreshed the beds without performing material bed tucking. See the following figure.

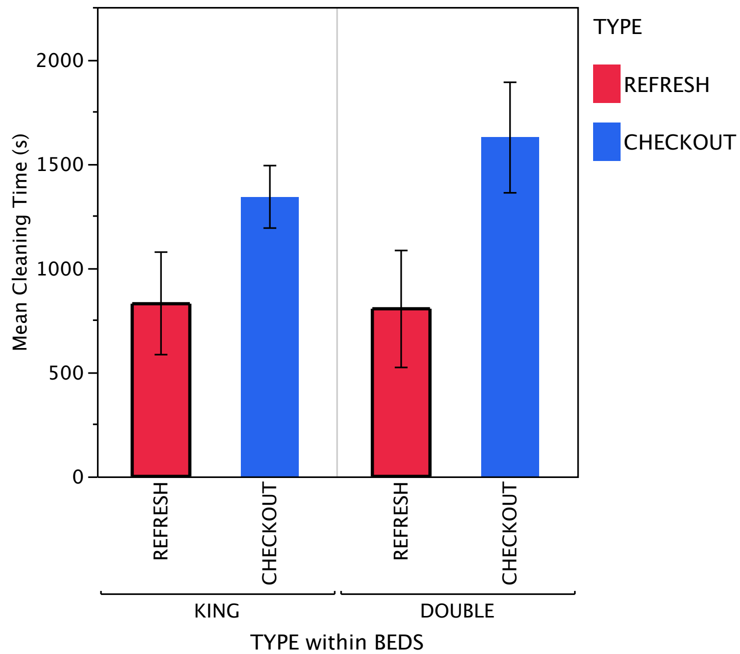


Figure 38: Differences in cleaning times between room classification and type of cleaning were found only when performing checkout cleaning in rooms with two double beds ($p \leq 0.08$).

Table 2: ANOVA Summary for Effects of Number of Beds, Level of Mess and Type of Room Cleaning (Refresh v. Checkout) Upon Cleaning Time.

Source	DF	Sum of Squares	F Ratio	Prob > F
BEDS (B)	1,28	0.00057	1.74	0.20
MESS (M)	1,28	0.00036	1.11	0.30
TYPE of CLEAN (T)	1,28	0.00836	25.38	<.01
B x T	1,28	0.00109	3.33	0.08

All observations across room type, level of disarrangement, and level of room cleaning (e.g., refresh or check-out) were used to compute a collective percentage of room cleaning time spent with each task. Results are summarized in Figure 39.

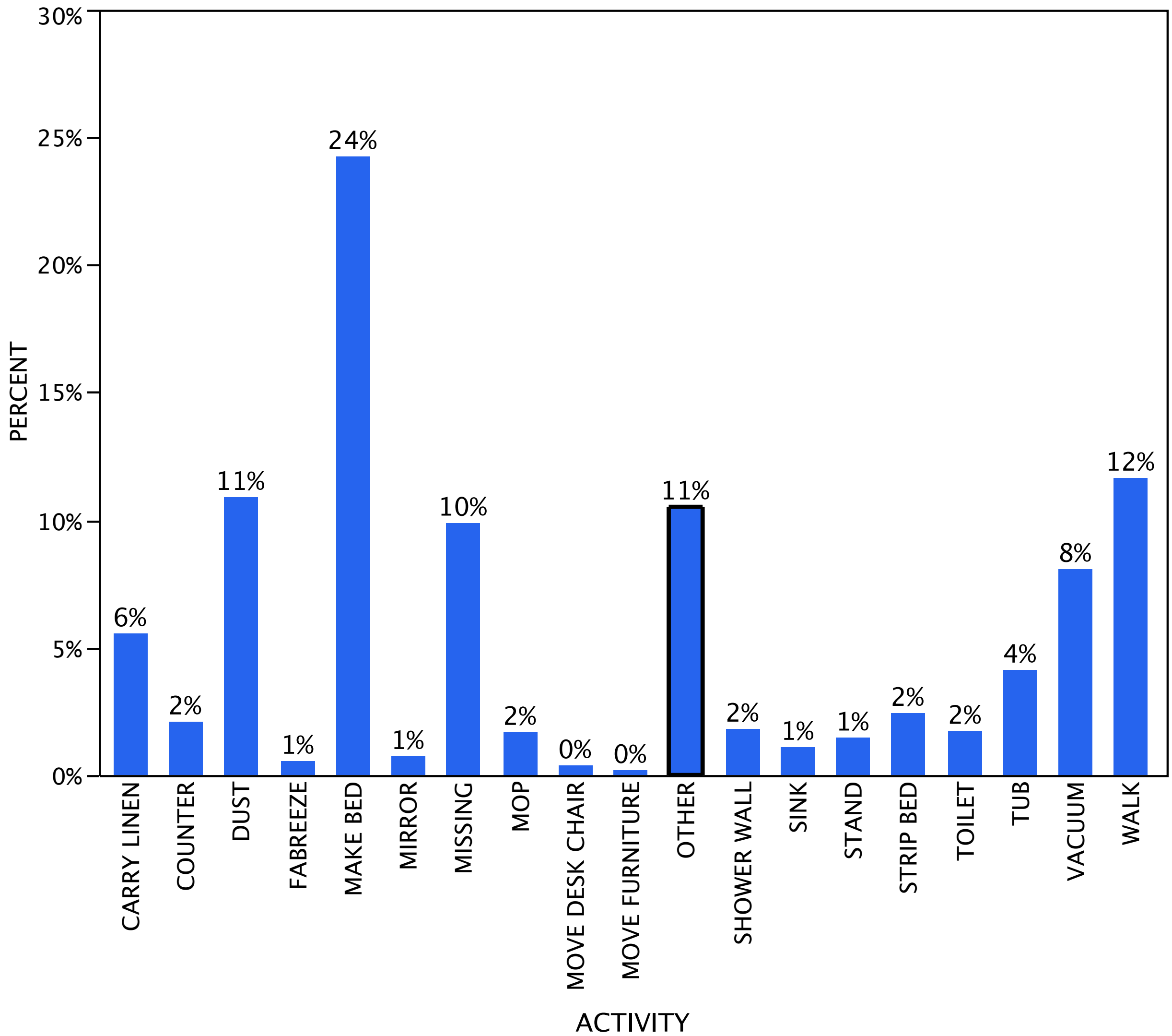


Figure 39: Aggregate work sampling results for room cleaning activities (N=1,080).

Approximately 11 percent of the observations were of activities not classified in the chart (e.g., emptying trash can, putting ironing board in closet, etc.). Those tasks were aggregated into "Other" because they were infrequent or of extremely short duration with limited force and extremity postures that did not materially deviate from "neutral" joint postures.

Approximately 10 percent of observation samples were classified as missing because the housekeeper was obscured momentarily by the bathroom door or had stepped into the hallway briefly and were out of field of view. Missing observations were not because of data loss, and the housekeeper was not performing any of the cardinal tasks classified in the chart. The observations were strictly classified as missing, but we are confident that the housekeeper was walking or standing for the vast majority of those sample times.

Work sampling was activity classified. Thus, while 24 percent of the room cleaning period was spent making the bed, the housekeeper walked about the bed and performed other activities related to bed making that did not involve tucking linens or active engagement with the bed. Work components were not broken down within activities and were not part of the activity breakdown in Figure 39 on page 71. This means that we have underrepresented the amount of walking and nonexertion times associated within each of the activities.

An ANOVA showed activities varied in terms of exposure or fraction of time spent during room cleaning ($F(18,133)=72.6$; $MSE=0.00041$; $p<0.001$). Confidence intervals for each activity exposure are provided in Table 3.

As demonstrated in Figure 40, exposure to activities amongst housekeepers was largely consistent. Paired comparisons of percent of time spent in activities revealed no statistical differences among housekeepers (all combinations of paired comparisons produced $t<0.13$, $df=18$, $P>.10$).

Table 3: Mean exposures for room cleaning activities with 95% confidence intervals.

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
CARRY LINEN	8	0.055414	0.00716	0.0412	0.06959
COUNTER	8	0.020862	0.00716	0.0067	0.03503
DUST	8	0.108864	0.00716	0.0947	0.12304
FABREEZE	8	0.005434	0.00716	-0.0087	0.01961
MAKE BED	8	0.242463	0.00716	0.2283	0.25663
MIRROR	8	0.007285	0.00716	-0.0069	0.02146
MISSING	8	0.098791	0.00716	0.0846	0.11296
MOP	8	0.016750	0.00716	0.0026	0.03092
MOVE DESK CHAIR	8	0.003701	0.00716	-0.0105	0.01787
MOVE FURNITURE	8	0.001847	0.00716	-0.0123	0.01602
OTHER	8	0.105141	0.00716	0.0910	0.11931
SHOWER WALL	8	0.018032	0.00716	0.0039	0.03220
SINK	8	0.010894	0.00716	-0.0033	0.02507
STAND	8	0.014545	0.00716	0.00037	0.02872
STRIP BED	8	0.024223	0.00716	0.0101	0.03839
TOILET	8	0.017202	0.00716	0.0030	0.03137
TUB	8	0.041184	0.00716	0.0270	0.05536
VACUUM	8	0.080732	0.00716	0.0666	0.09490
WALK	8	0.116434	0.00716	0.1023	0.13061

Std Error uses a pooled estimate of error variance

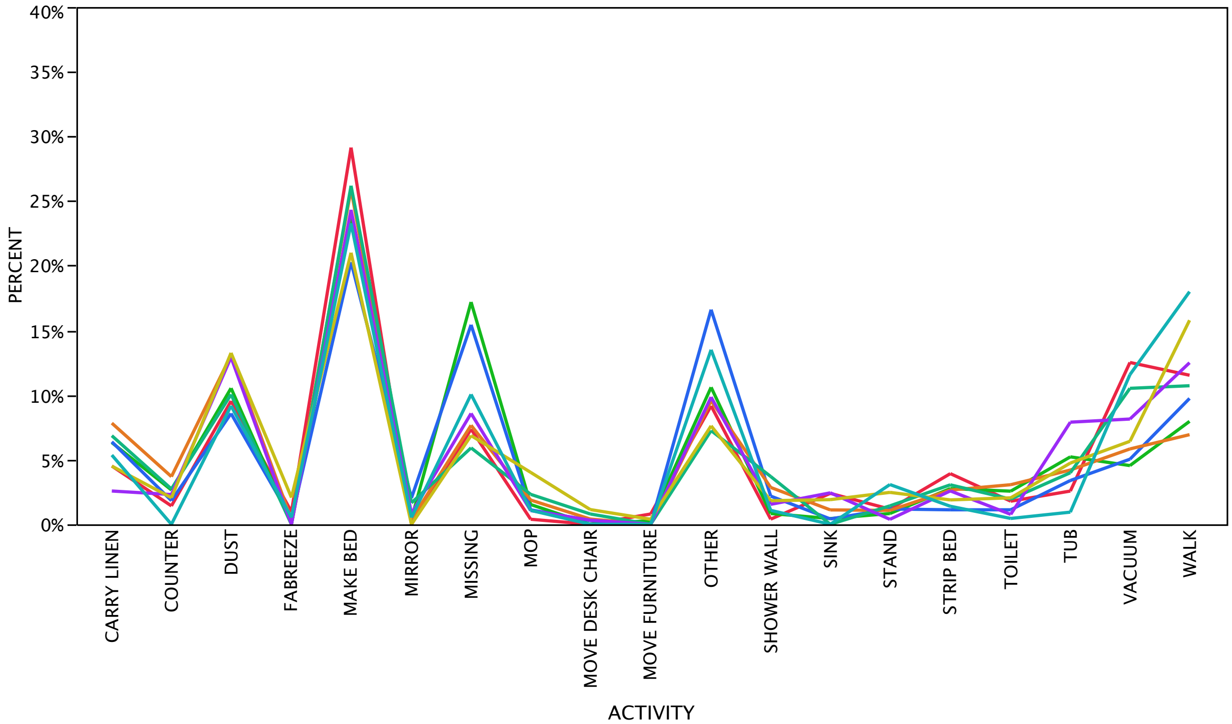


Figure 40: Activity breakdown for individual housekeepers. Each line represents an individual housekeeper.

5.2. Heart Rate

Ergonomic design guidelines for controlling whole-body or systemic physical fatigue require that one not work beyond one-third of one's maximum physical work capacity. This limit is equivalent to one-third of the worker's cardiac reserve[5]. For a 20 year old housekeeper the shift average heart rate should be limited to:

$$\text{Shift Average HR} = H_{Rresting} + ((HR_{max}-HR_{resting})/3) \qquad \text{EQ. (1)}$$

or for data plotted in the following figure:

$$\text{Shift Average HR (bpm)} = 56 + ((220-20)-56)/3 = 104 \qquad \text{EQ. (2)}$$

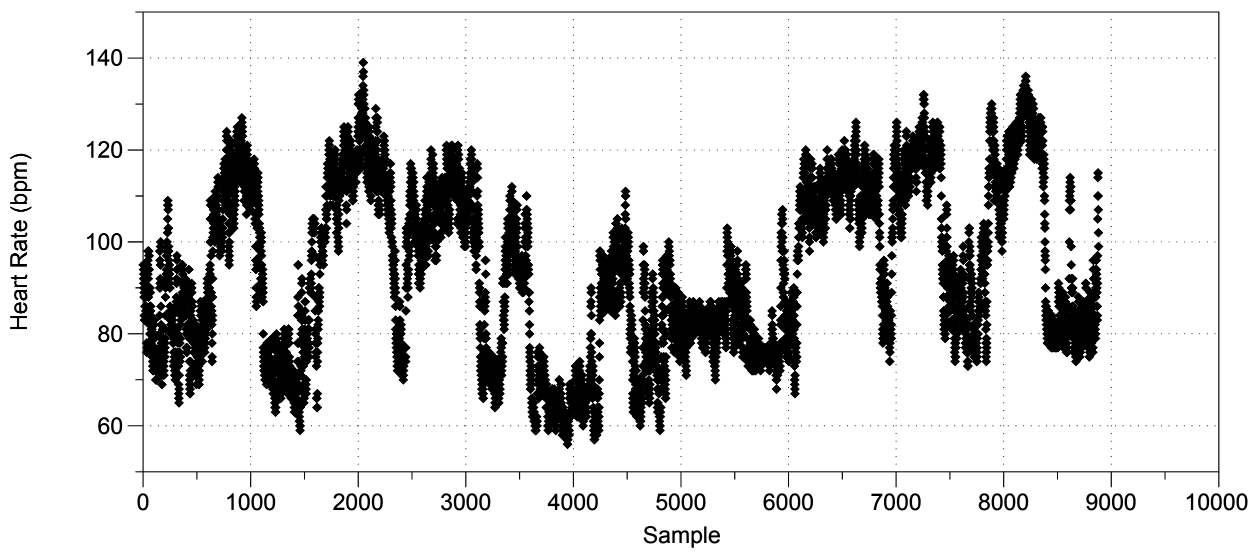


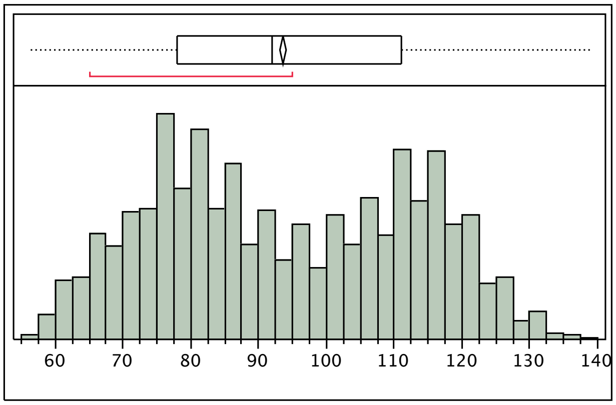
Figure 41: A representative time series of 2 s HR samples taken from a 20 year old female housekeeper.

As shown in Figure 42, the mean HR for the housekeeper during the 5 hour room cleaning and 45 minute lunch epoch was 93.6 bpm. Work activities ranged between light to moderate in aerobic

5. Cardiac reserve is the capacity of the heart to pump more blood from the heart. The maximum cardiac reserve is defined as the difference between maximum heart rate and resting heart rate. Cardiac reserve is directly proportional to taxing one's aerobic capacity. At maximum aerobic power, the heart rate is at its maximum. One-third of one's aerobic power is indicated by a heart rate at one-third of the maximum cardiac output or one-third of its maximum cardiac reserve.

demand and averaged throughout the study at levels that fell upon the margin between light and moderate physical workload.

Heart Rate (bpm)



Quantiles

100.0%	maximum	139
99.5%		131
97.5%		126
90.0%		119
75.0%	quartile	111
50.0%	median	92
25.0%	quartile	78
10.0%		69
2.5%		62
0.5%		59
0.0%	minimum	56

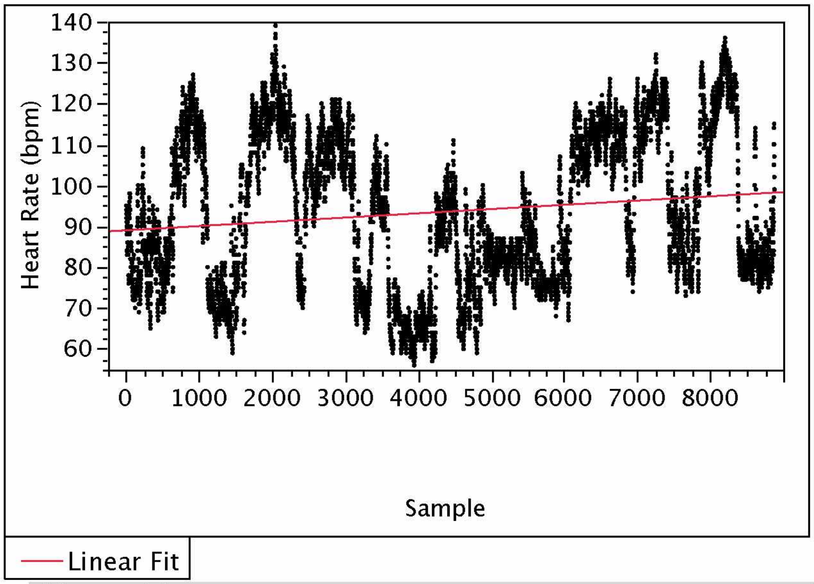
Moments

Mean	93.597726
Std Dev	18.810302
Std Err Mean	0.1995907
Upper 95% Mean	93.98897
Lower 95% Mean	93.206482
N	8882

Figure 42: Distribution analysis of heart rate for a housekeeper recorded for the 5 hour room cleaning and lunch period.

For a job that presents a relatively stable aerobic power demand, onset of systemic fatigue is indicated by creeping elevation in worker heart rate. A small creep in heart rate of approximately 1.9 bpm per hour was demonstrated for the individual housekeeper's heart rate plot. Given a mean heart rate of approximately 94 bpm after 2.5 hours of cleaning, the heart rate would be expected to creep up to an average or 104 bpm (the design limit for this worker) at the end of an eight hour shift if the housekeeper was assigned 16 rooms with a balanced distribution of room types, levels of mess and degree of cleaning comparable to that experienced during the work sampling study.

Housekeepers at the hotel studied were assigned 14 rooms per shift with a varying mixture of beds and types of cleaning assignments. If room mess is excessive, then housekeepers are instructed to advise their supervisor of the problem for a reduction in room quota, or receipt of additional housekeeper assistance to reduce workload and keep on schedule. Thus, the expected full-shift heart rate, including the total creep, would be less than the design limit of 104 bpm for the housekeeper whose heart rate recordings are shown.



Linear Fit

Heart Rate (bpm) = 88.988575 + 0.0010377*Sample

Summary of Fit

RSquare	0.020012
RSquare Adj	0.019901
Root Mean Square Error	18.62219
Mean of Response	93.59773
Observations (or Sum Wgts)	8882

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	1	62883.0	62883.0	181.3310
Error	8880	3079458.6	346.8	**Prob > F**
C. Total	8881	3142341.7		<.0001*

Parameter Estimates

Term	Estimate	Std Error	t Ratio	Prob>|t|
Intercept	88.988575	0.395223	225.16	0.0000*
Sample	0.0010377	0.000077	13.47	<.0001*

Figure 43: Regression of HR against time, or sample sequence, demonstrating evidence of a small creep in heart rate with progression of room cleaning.

From the standpoint of systemic fatigue, the housekeeper's current job quota structure is compliant with ergonomic design recommendations that total shift work not exceed one-third of the worker's physical work capacity. The job does not produce excessive aerobic power demand.

5.3. Biomechanical Analyses

Each task performed by housekeepers was analyzed using the Michigan Three-Dimensional Static Strength Prediction Model (3DSSP v. 6). Tasks analyzed were based upon cardinal cleaning activities observed and tested, as well as activities described in the housekeeper training documents that were demonstrated by housekeepers. In the following figure the minimum and maximum lumbar disc compression values are plotted. Differences between the minimum and maximum lumbar disc compression values reflect variations in postures and exertion forces produced among the housekeepers studied. See Figure 44.

For each of the tasks examined, the minimum population strength capability was determined for the variety of postures and exertions performed by the ten housekeepers. Every housekeeper clearly had sufficient strength to perform the tasks using their preferred methods. The analysis performed examined the proportion of the population of U.S. working women who could replicate the postures and hand forces. If less than 80 percent of the general working population of women could perform a particular strategy because of strength limitations in the elbow, shoulder or back, that activity was deemed to require excessive levels of exertion and exposed housekeepers to an exertion MSD risk factor. Such exposures may or may not result in increased risk of MSDs depending upon duration of exposure and other factors as discussed earlier. As shown in Figure 45 on page 80, the vast majority of tasks meet ergonomics design guidelines and different strategies could be performed by cohorts and the population at large.

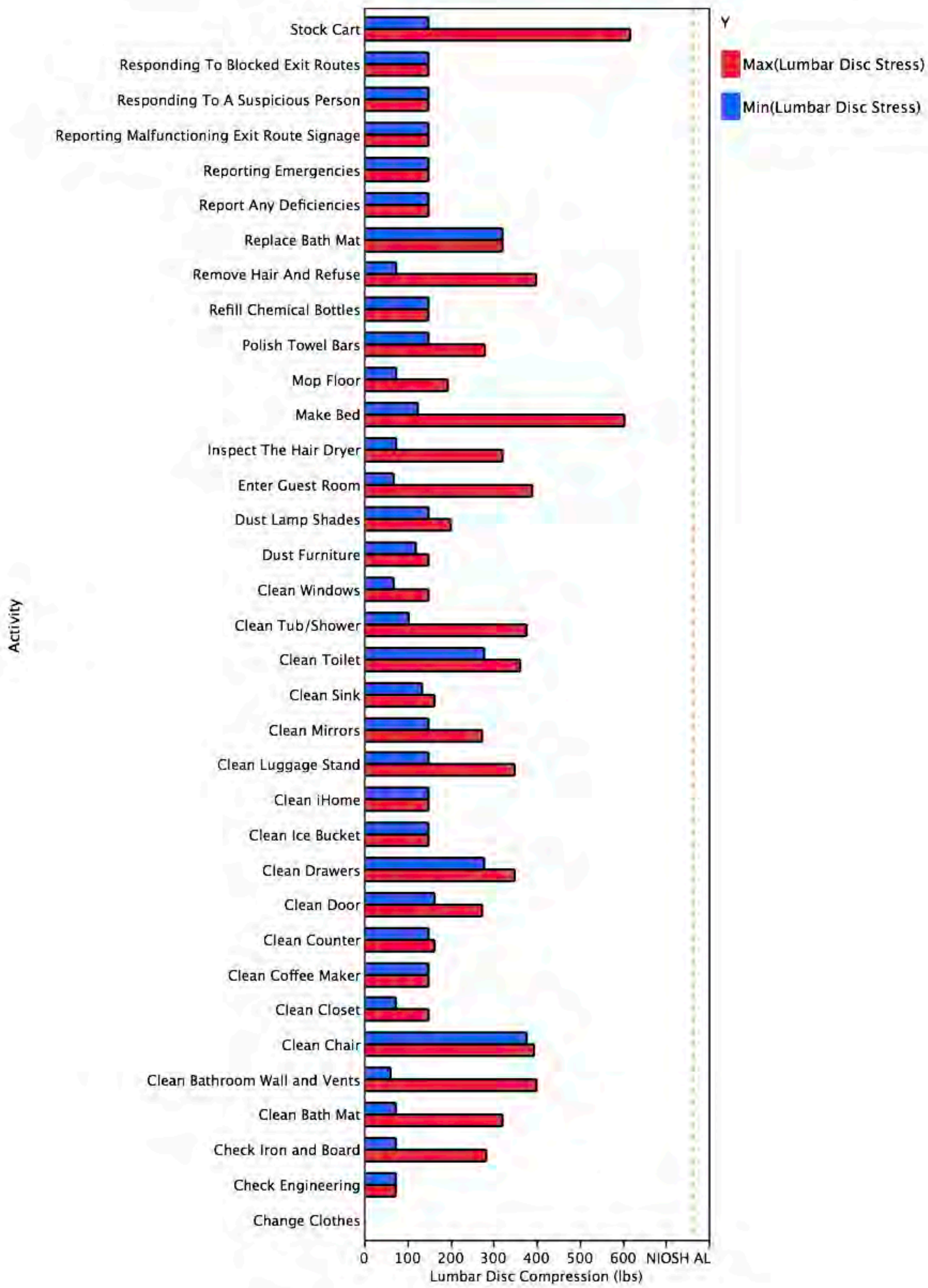


Figure 44: Plot of minimum and maximum lumbar disc compression forces for housekeeper tasks. Note: NIOSH Action Limit (AL) is 764 pounds.

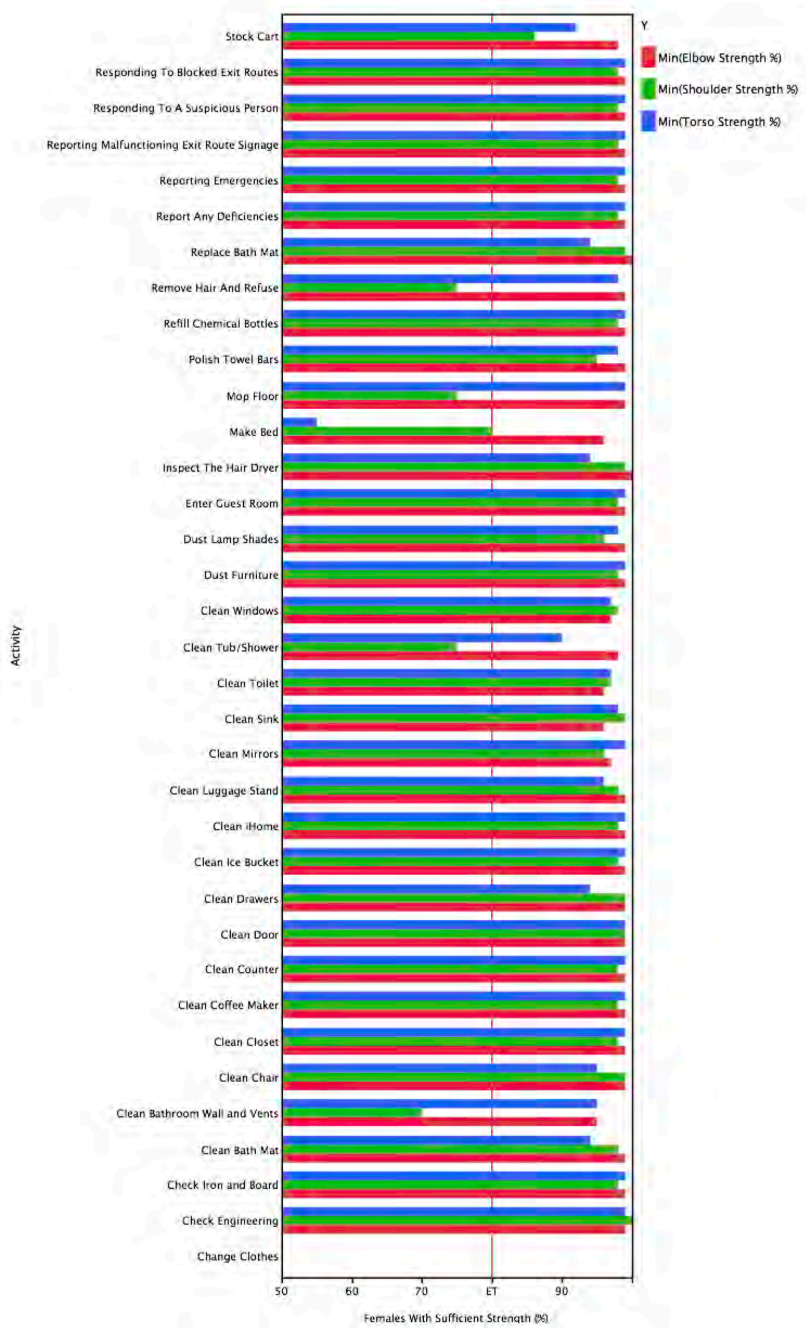


Figure 45: Plot of female population strength requirements for all housekeeper tasks. Exertions following below 80 percentile were deemed excessive from a MSD hazard perspective.

5.3.1 Vacuuming

Housekeepers vacuumed the hotel room carpet while standing atop of the Kistler portable force plates that were level with the carpeted surface. Lifting the Oreck XL vacuum onto and off of the cart required a lifting force of approximately 10.3 ± 0.3 lb. Push and pull hand forces applied to the handle of the vacuum when pushing and pulling the effector across the carpet were largely symmetric and averaged 4.6 $\pm$ 2.7 lb. in magnitude.

Measured hand forces fell well below human strength design limits published in Human Factors Engineering design standards, the NIOSH Work Practices Guide for Manual Lifting, and other sources of push/pull and lifting force guidelines (See Wiker (2012b) for a bibliography of applicable standards). Body postures and hand forces produced disc compression that was well below the NIOSH Action Limit. See Figures 45 and 45 on page 80. Thus, the vacuuming task, along with mounting and dismounting to and from the housekeeper's cart, would be deemed safe by NIOSH and the ergonomics community.

5.3.2 Moving Furniture

Some hotel guests move furniture about the room. Vacuuming require sliding some of the room's furniture across the carpet. If beds are moved or there is substantial rearrangement of furniture, the housekeepers are expected to pass furniture repositioning onto housemen or room engineering personnel and return to clean the room after the furniture repositioning is performed by others.

Desk chairs with rolling carpet casters required very little effort to slide about the room to enable vacuuming. However, some rooms have large chairs that housekeepers are expected to move short distances to reposition or to enable cleaning of the carpet around the chairs if required.

To gage the stress associated with typical sliding of furniture across carpeted floors, housekeepers were asked to push and then pull a 58-pound chair one-foot from the resting position and then pull the chair back to its resting position. The push and pull efforts were performed with housekeepers facing the chair and standing atop a force plate.

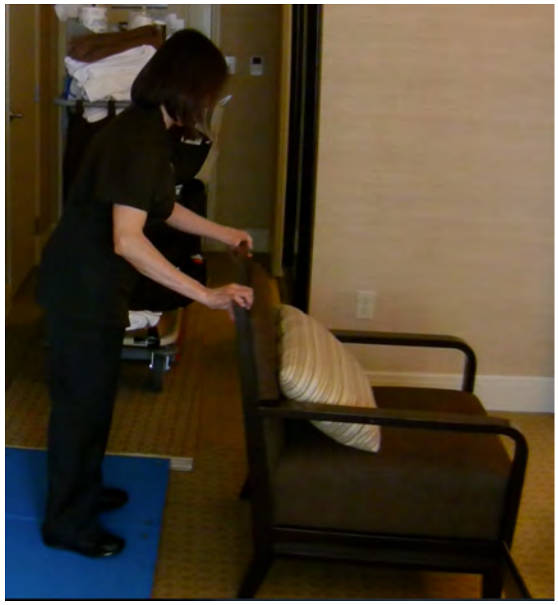


Figure 46: The smallest housekeeper pushing the room chair.

Figure 47: The smallest housekeeper pulling the room chair back into position.

Hand forces averaged 22.5 $\pm$ 2.3 and 12.0 $\pm$ 2.2 lb. for push and pull efforts respectively. The upper 95 percent confidence limit for the push exertion produced a required coefficient of friction of:

$$COFreq. = (22.5+4.5) \text{ lb.} / 58 \text{ lb.} = 0.46 \qquad \text{EQ. (3)}$$

The COF required fell below OSHA's static COF minimum of 0.5. The carpeting provided adequate frictional resistance to enable the housekeepers to move the chair without inducing perceived or observable foot sliding.

Unequal push and pull forces reflects a tendency for housekeepers to exert both horizontal and downward hand forces when pushing the chair away from their body. The direction of hand forces served to push the legs of the chair into the carpet--increasing frictional resistance during the push effort. When pulling chairs toward them, hand forces were more horizontal with a tendency to pull slightly upward concomitantly. This effort vector caused the chair's feet to slide more easily across the carpet thereby reducing required hand forces.

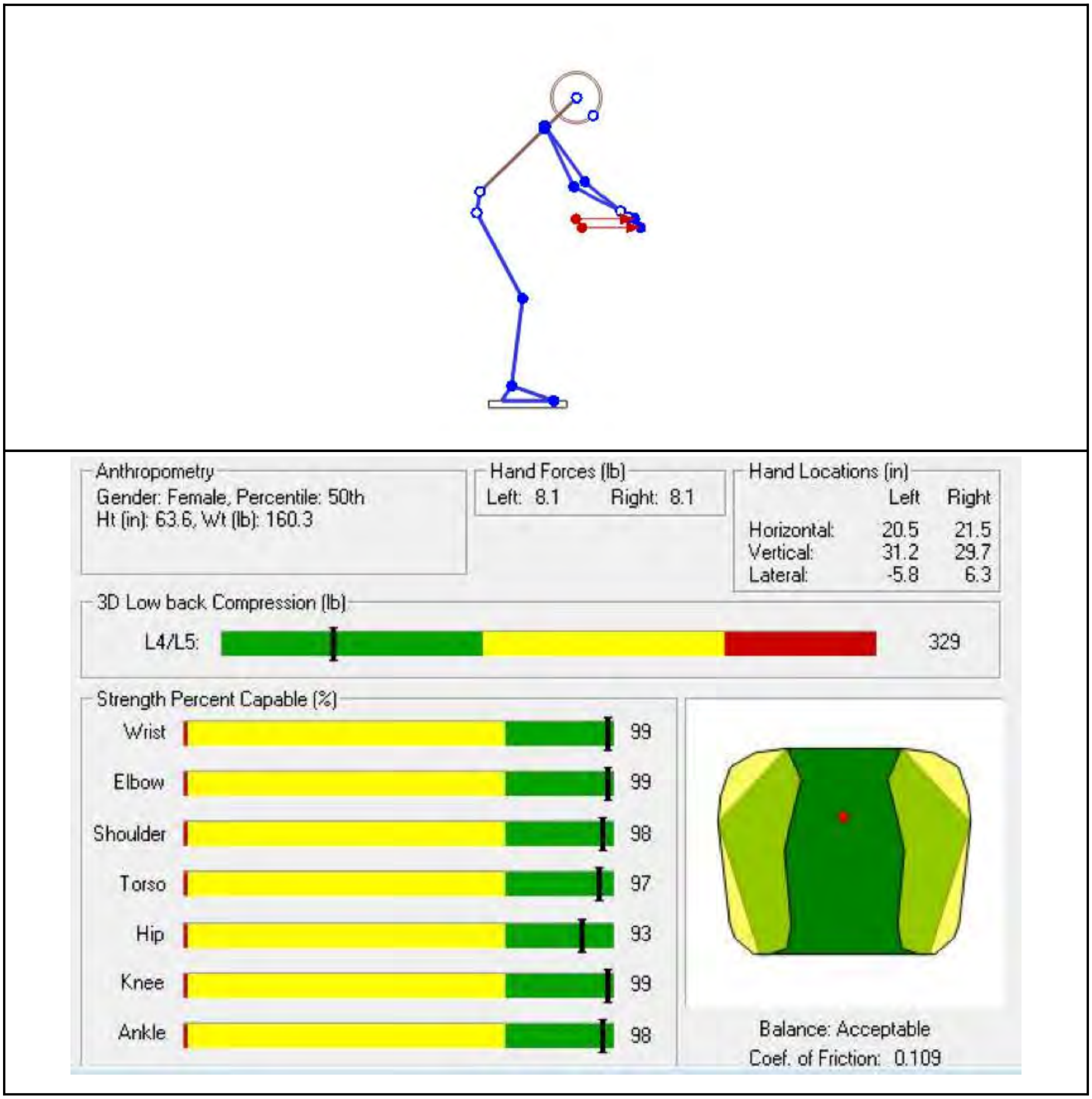


Figure 48: Disc compression and strength demands for the upper 95 confidence limit of measured chair pulling force.

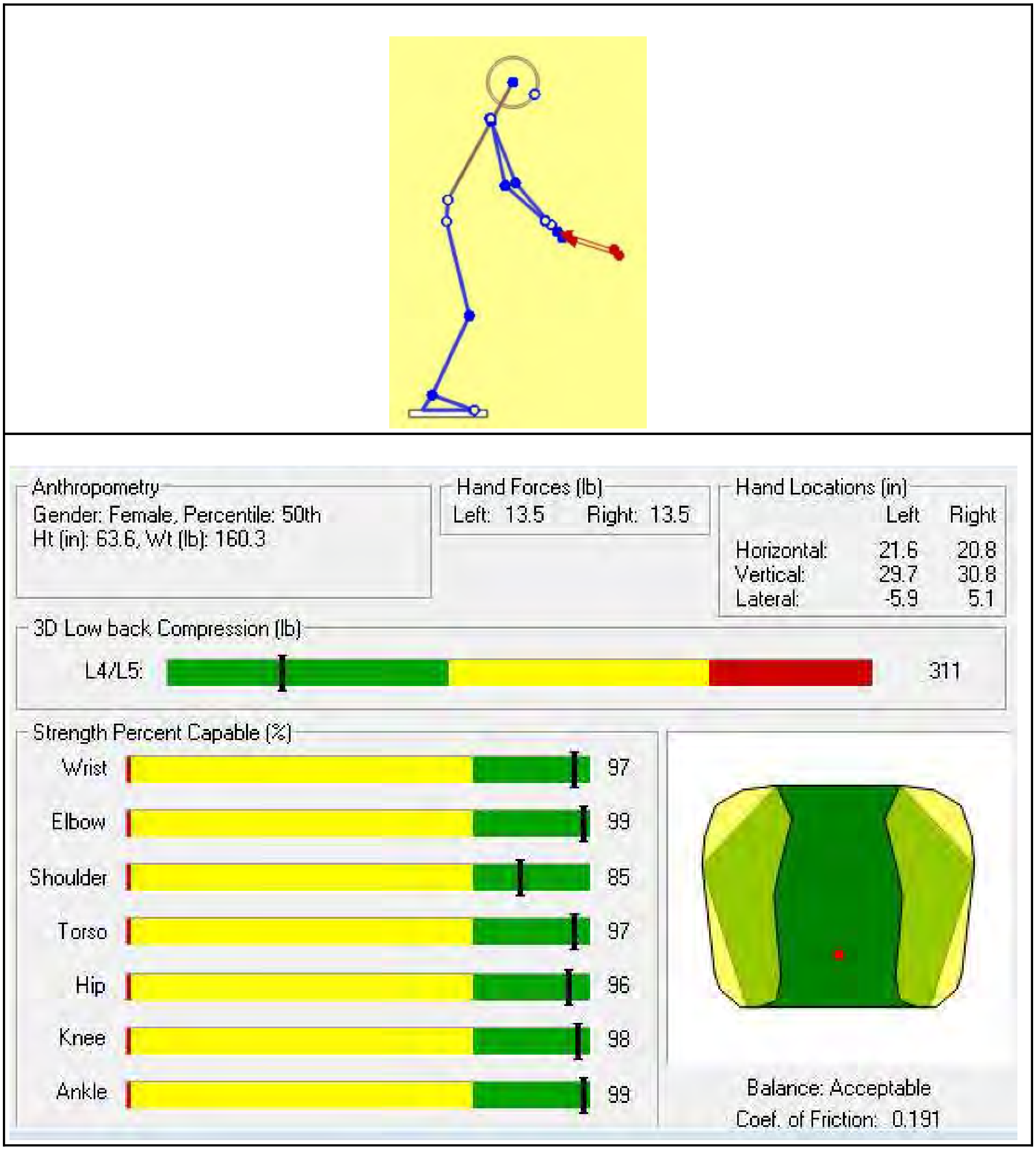


Figure 49: Disc compression and strength demands for the upper 95 confidence limit of measured chair pushing force

5.3.3 Bathroom Cleaning Tasks

With most bathroom cleaning activities, housekeepers were observed reducing biomechanical stresses to their bodies by using the free hand and arm to brace against walls or horizontal surfaces, or leaning against fixtures, to support part of the weight of their upper body, torso or arms. These strategies materially reduced the load moments acting upon the spine and risk of low back disorders, injuries and aerobic power demand. Material reductions in resultant forces and moments, and corresponding reductions in lumbar disc compression, were observed with the torso bracing strategy. See Figures 45 and 45 on page 80 for a summary of biomechanical stress metrics.

Hand wiping activities, mirror cleaning with long-handled tools, and mopping occurred without body bracing behaviors. Force transducers were placed between the hand and scrubbing linens and sponges to obtain hand force measurements during wiping activities. Hand forces measured in those activities were very low. The postures in those activities were very nearly upright and, thus, the biomechanical stresses were quite low as shown in the following figures.

In tasks where body bracing was involved (e.g., leaning on counters, toilets and bathtubs), bracing effectively reduced transfer of comparatively low hand forces through the body. Even if the hand forces were high, bracing created force-couples and fulcrums that protected the spine from injurious biomechanical stresses.

Forces required to wipe the surfaces of the toilet, sink and tub were well within the desired strength zones. Low back disc compressive forces were also low because of the bracing behaviors discussed above.

The principal problems found with use of long-handled scrubbing tools were undesirable upper body postures. As shown in the following figures, placing the tool in a scrubbing position around tub fixtures, the tub and lower wall surfaces, produced undesirable hand and wrist, arm and shoulder postures with greater amounts of torso flexion than were observed with manual cleaning of those surfaces.

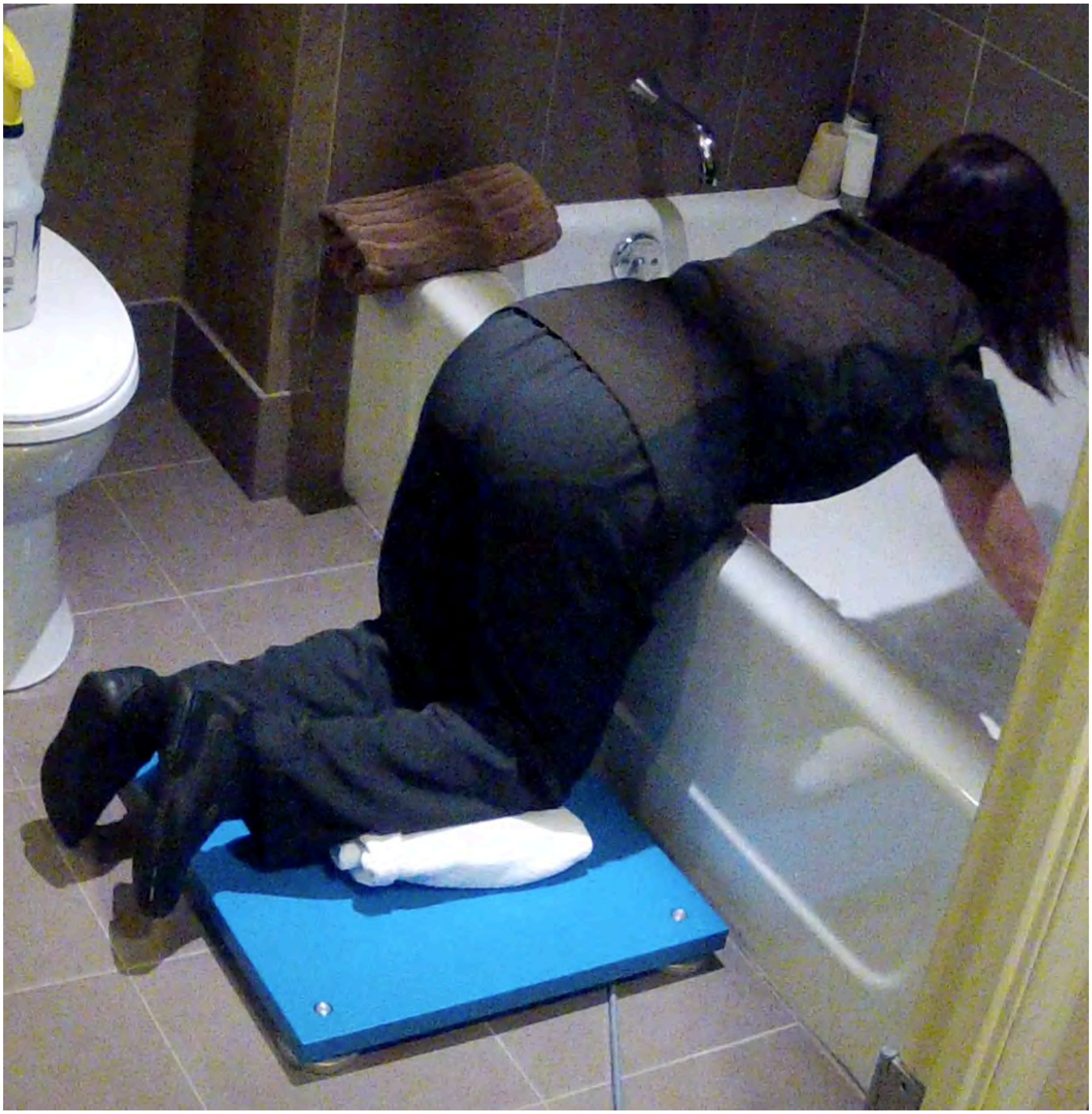


Figure 50: An exemplar of postures used by housekeepers in which they use the tube wall and other hand to brace the torso and, thereby, reduce mechanical strain and strength demands when cleaning the tub.

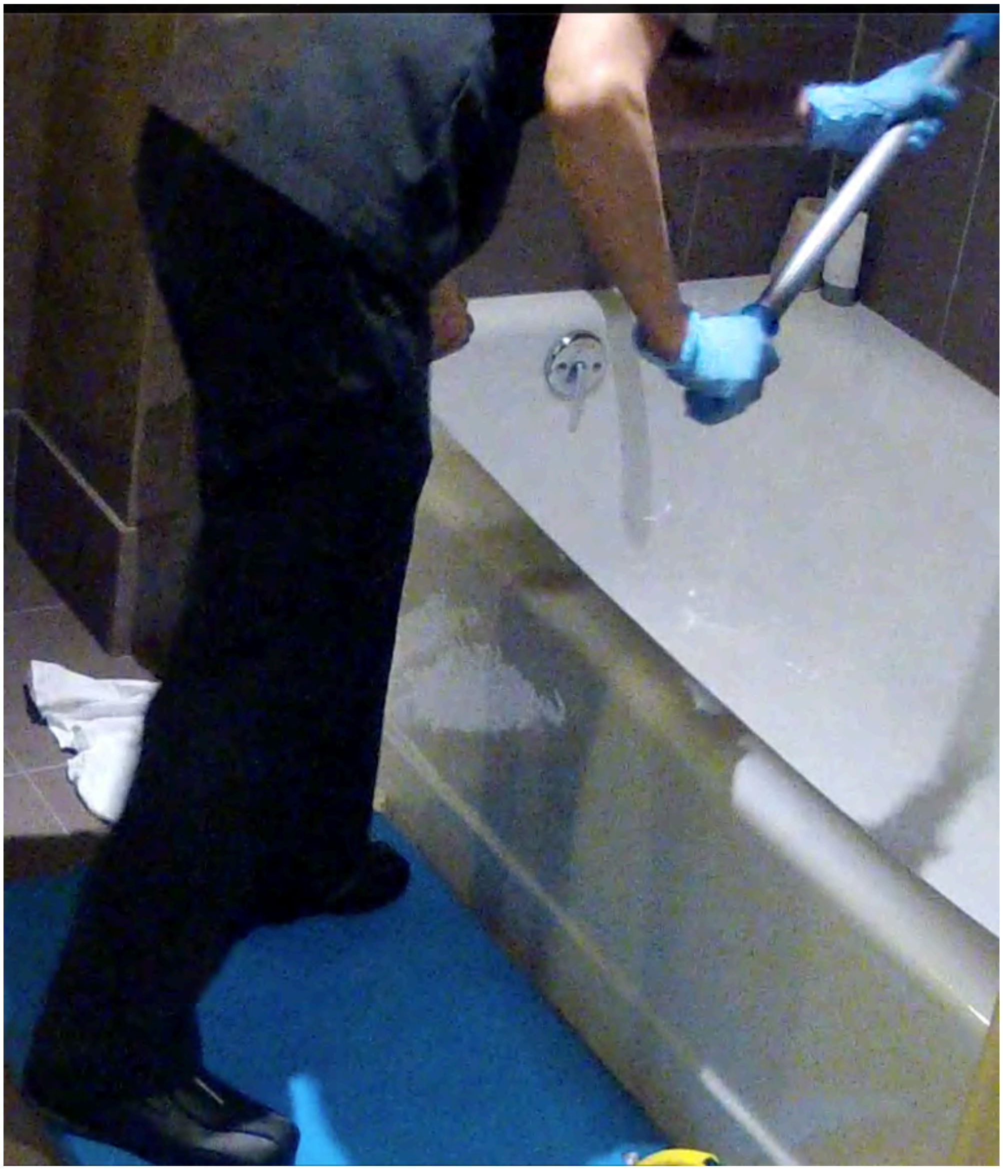


Figure 51: Excessive dorsiflexion of the right wrist and torso flexion observed when housekeepers were using the long-handled scrubbing tool. The left hand is used to apply pressure to the end-effector while the right hand applies thrusting forces.

Figure 52: Exemplar view of typical posture observed with housekeepers when attempting to clean middle sections of the bath/shower walls.

Figure 53: An exemplar view of a housekeepers using another tool handling stratagem for cleaning the middle to lower wall surfaces. The housekeeper reported that she needed sufficient force at the scrubber-wall surface to achieve satisfactory quality of cleaning. Note the shoulder and elbow postures and torso lean into the tool and wall surface.

Figure 54: Exemplar view of housekeeper stooped over using a long-handled scrubbing tool to clean the bathroom tub floor.

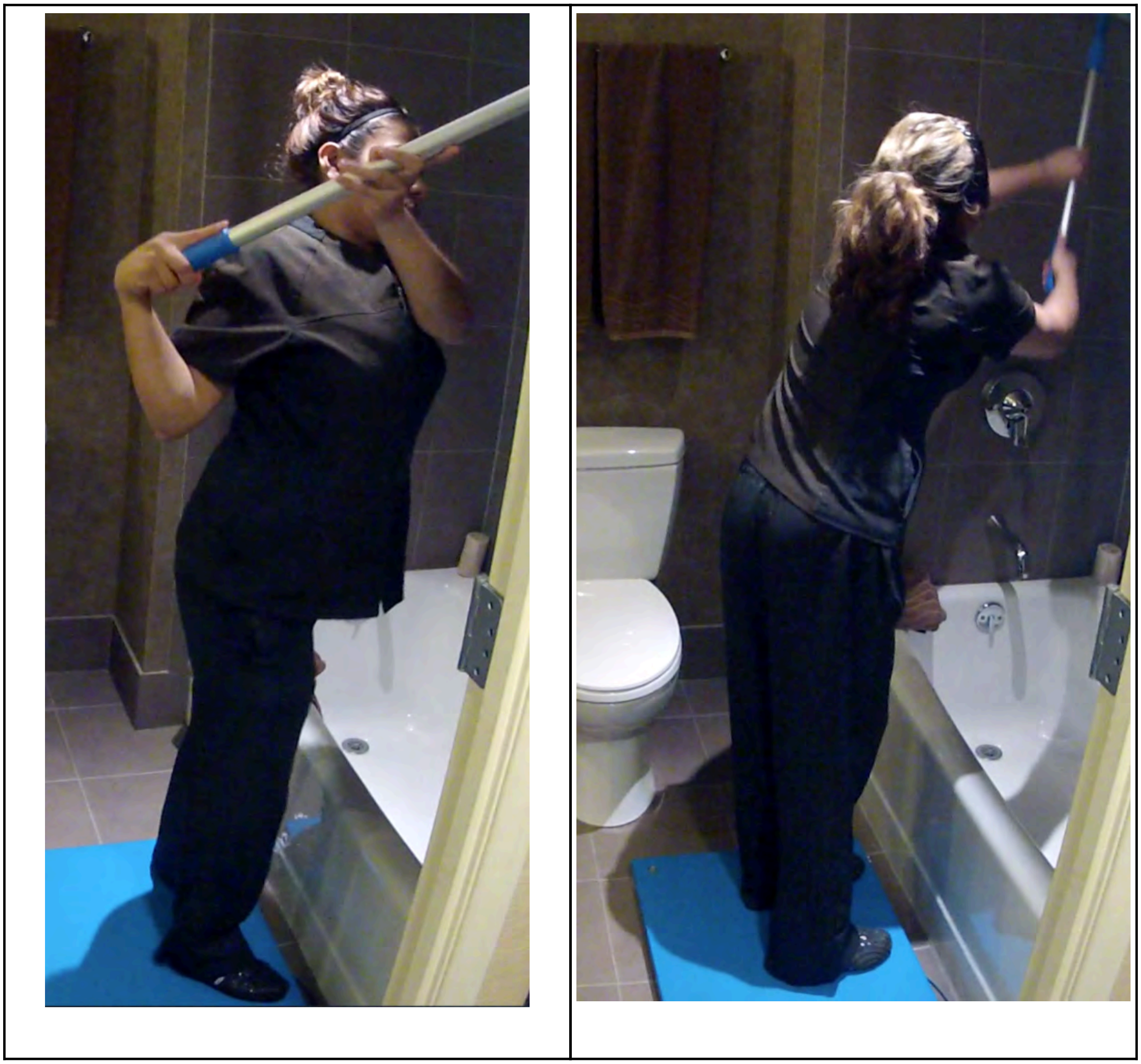


Figure 55: Exemplar views of housekeepers using a long-handled scrubbing tool to clean the upper surfaces of shower wall. Note housekeepers are leaning into the wall and attempting to use the base of the palm to increase the scrubbing force at the tool-wall interface.

5.3.3.1. Wiping Forces

Vertical and horizontal surface wiping is required to clean bathroom and bedroom surfaces. Light vertical dusting wipes produced dynamic hand forces that averaged 2.5 ± 0.7 lb. which increased during hard scrubbing to 6.5 ± 2.1 lb. The level of measured forces between dusting and scrubbing differed ($t=4.3$; $df=1$; $p<0.05$).

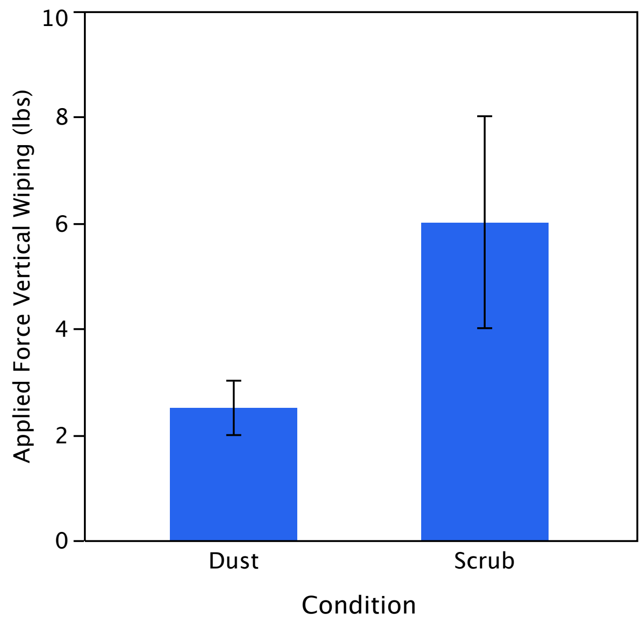


Figure 56: Dynamic hand force resultants for dusting and scrubbing vertical surfaces using hand-held rag.

Light dusting of horizontal surfaces produced dynamic resultant hand forces that averaged 8.5 ± 0.71 lb. When asked to scrub a horizontal surface mean dynamic resultant forces averaged 17.0 ± 2.8 lb. Differences between the means were statistically significant ($t=4.03$; $df=1$; $p<0.05$). Increased horizontal forces were linked to body lean causing greater transfer of body weight into hand force components. When leaning upon the dusting or scrubbing hand, the torso was supported to some degree because the arm was effectively a brace.

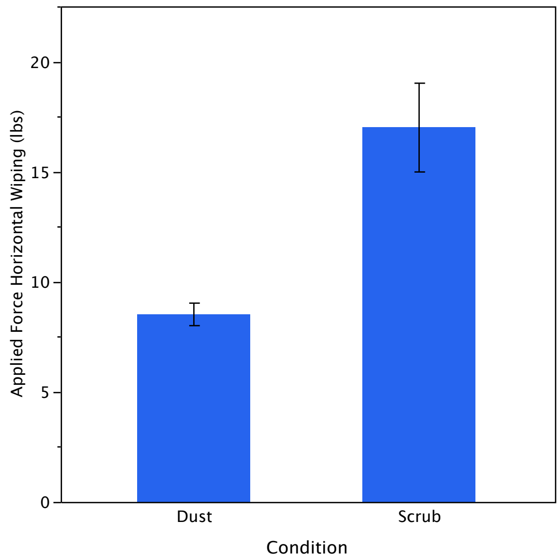


Figure 57: Dynamic hand force resultants for dusting and scrubbing horizontal surfaces using a hand-held rag.

Measured dynamic hand forces and body postures were entered into the Michigan 3DSSP biomechanical model to compute disc compression and load:strength moment ratios. Results showed that neither disc compression or strength demands exceeded recommended safe limits. See following figures.

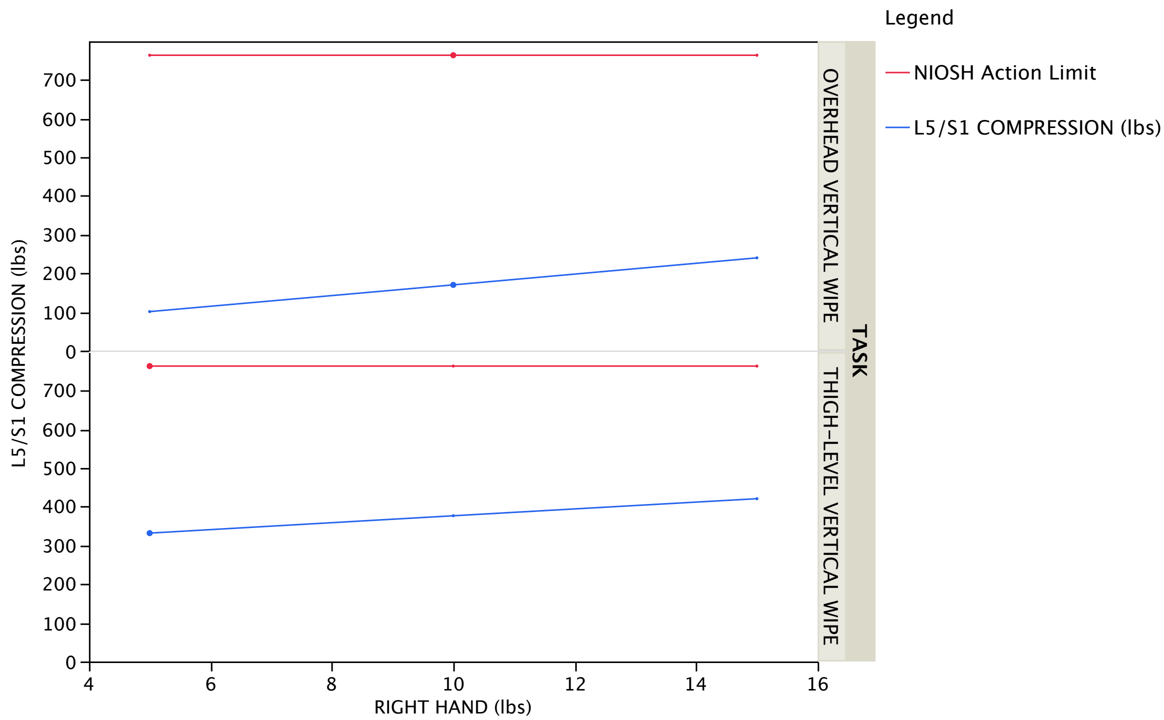


Figure 58: Lumbar disc compression force predictions for vertical wiping tasks fell well below NIOSH's Action Limit for disc compression--indicating nominal risk of musculoskeletal injury.

Vertical wiping did not tax population strength capabilities until wiping forces were increased to 15 pounds. That value was well above maximum measured scrubbing forces. Similar findings were obtained for wiping and scrubbing of horizontal surfaces. See dusting and counter top cleaning strength demands in Figure 45 on page 80.

If housekeepers attempted to wipe bathtub vertical wall surfaces that were near thigh-level by bending their torso to the side to enable reach, then scrubbing forces of 15 pounds would be excessive. The maximum forces measured during heavy scrubbing of vertical surfaces was approximately half of that level of effort. Thus, housekeeper strength demands fell into desired design limits as shown in the following figure.

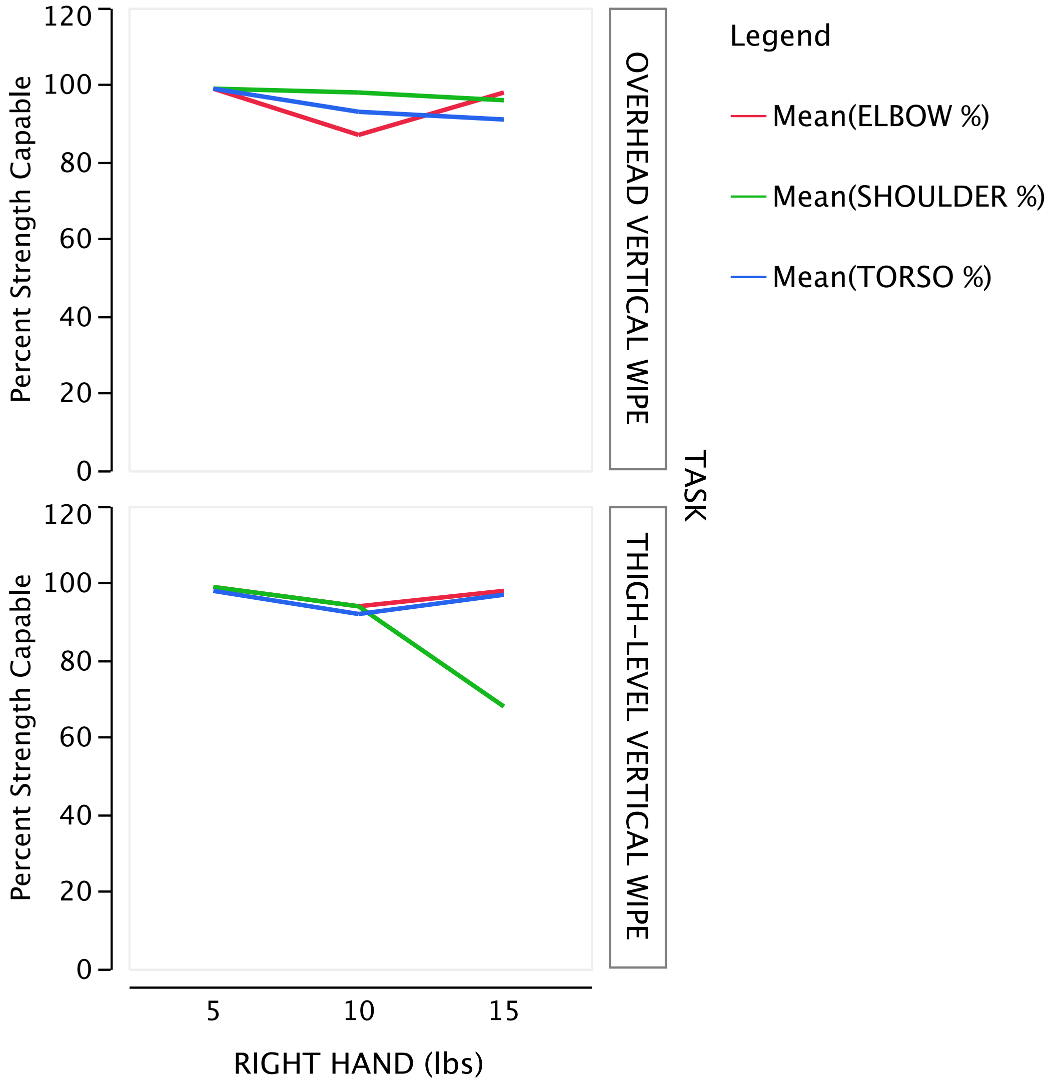


Figure 59: Vertical surface dusting and scrubbing task strength demands for the elbow, shoulder and torso.

5.3.3.2. Sink Cleaning

Wiping and scrubbing sinks produced peak dynamic resultant hand forces of 19.2 ± 9.5 lb. The resultant hand forces were split between a hand that rested upon the counter surface and the other hand scrubbing the sink bowl. Resultant forces were unrelated to housekeeper body mass ($r=.03$; $p>0.10$), indicating that the scrubbing forces are not simply a result of leaning into the sink and using torso, head and arm mass to contribute to perform scrubbing exertions.

Static biomechanical analysis showed that strength demands were below 20 percent of population MVC; a threshold for hand and wrist MSDs. Lumbar disc strain is at levels that NIOSH considers to be safe; producing only nominal risk of low back injury. Results showed that distribution of hand forces between hands produced no material change in biomechanical analysis outcomes. See Figure 60.

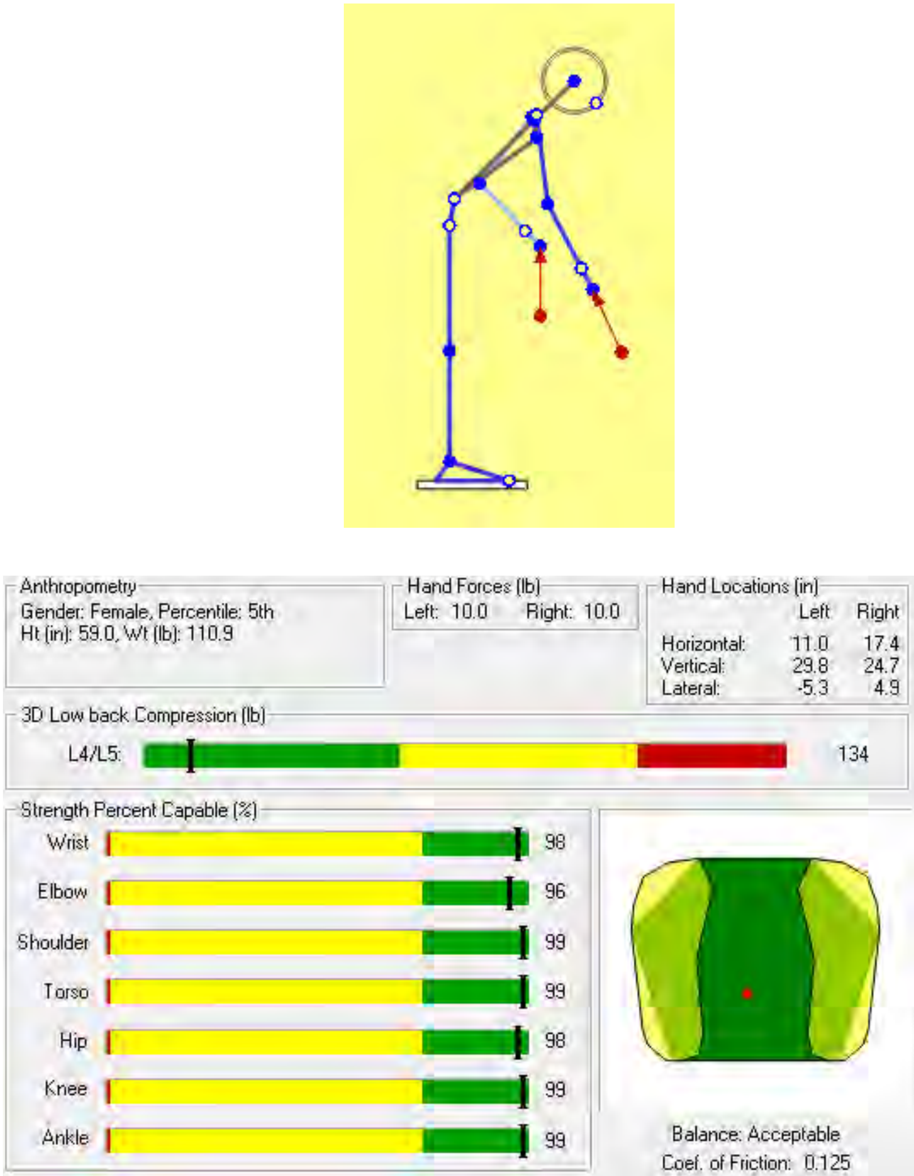


Figure 60: Static biomechanical model predictions using maximum measured dynamic resultant hand forces in housekeepers cleaning sinks.

5.3.3.3. Mirror Cleaning

Housekeepers cleaned top and bottom halves of a bathroom vanity mirror by hand, and using a long-handled cleaning tool as shown in Figure 61.

Figure 61: Mirror cleaning zones and tools with exemplar postures observed

No differences were found in force requirements between top and bottom of the mirror ($p>0.10$). However, use of the long-handled tool produced material reductions in resultant forces ($F(3,7)=4.3$; MSE $= 257.9$; $p<0.05$).

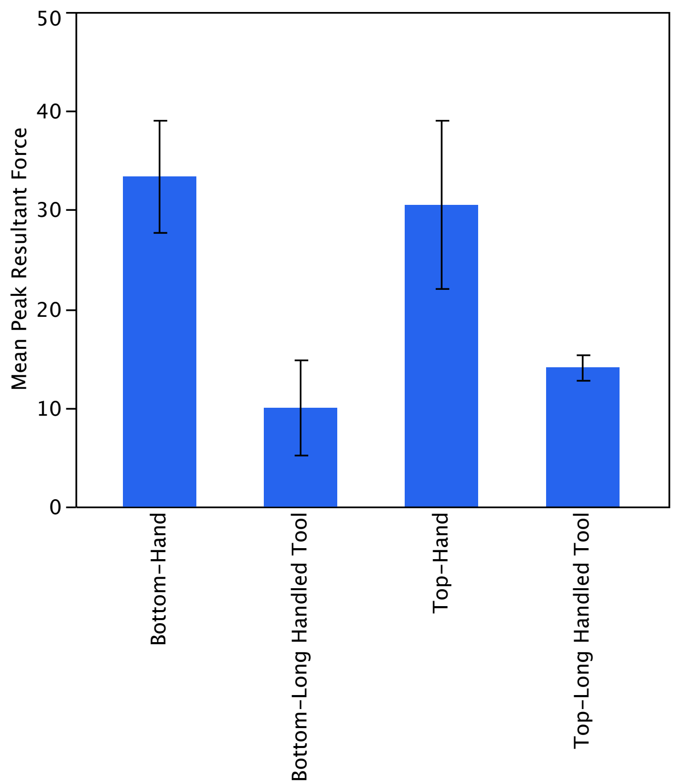


Figure 62: Mean peak resultant forces when cleaning top and bottom halves of bathroom mirror using either a hand-held rag or long-handled scrubbing tool.

As one would expect, mirror cleaning with hands required greater dynamic COFs than did use of long-handled tools. No differences were found between mirror regions (i.e., top versus bottom) ($p>0.10$). However, use of the long-handled tool reduced required COFs regardless of mirror region ($F(3,7)=20.9$; $MSE= 0.05$; $p<0.05$). Cleaning mirrors produced required static COFs that were well below 0.5 design requirements.

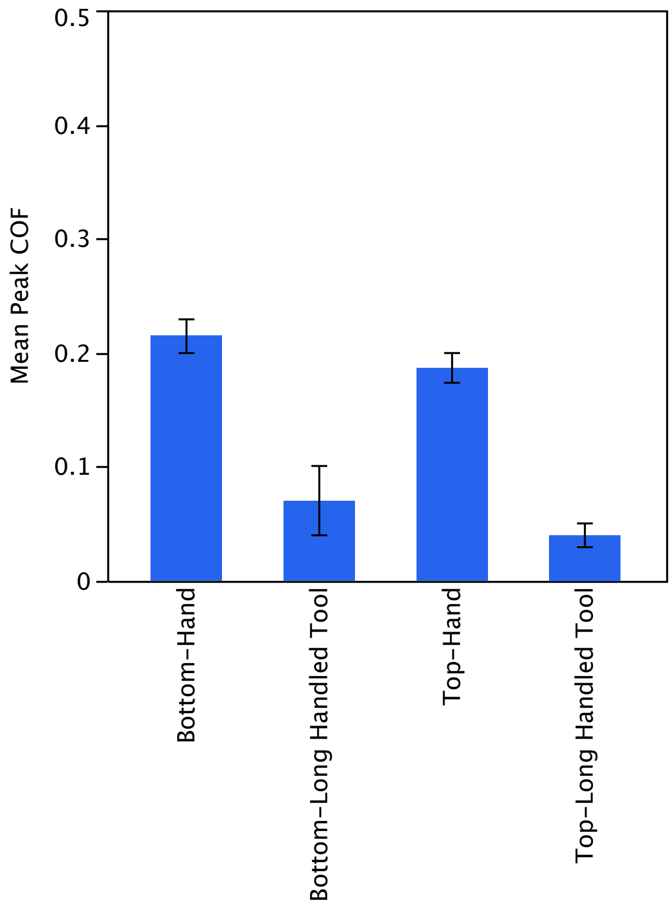


Figure 63: Mean peak dynamic COF recorded when cleaning top and bottom sections of bathroom mirrors using hand-held rag or long-handled tool.

Biomechanical analyses showed that the task, whether performed by hand or using long-handled cleaning tools, presented nominal risk of a low-back injury and did not tax population upper extremity or torso strength capabilities. The principal differences in lumbar disc compression resulted from housekeepers leaning forward to reach the mirror. See Figure 45 on page 80.

5.3.3.4. Mopping

Housekeepers use lightweight mop tools, as shown below, to combine with a surface chemical cleaner, when cleaning bathroom floors. No "traditional" wet mop activities are involved as demonstrated in the following figure.

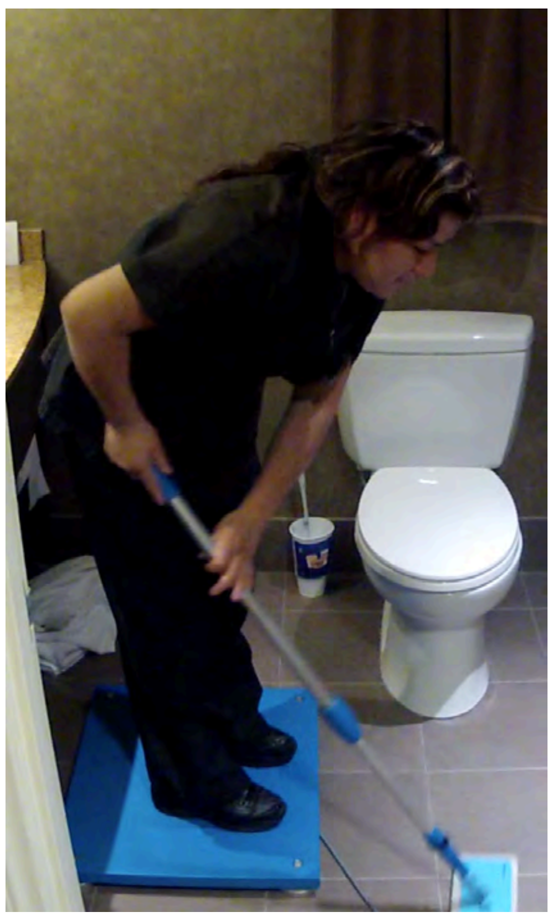


Figure 64: Representative image of housekeepers mopping bathroom floor with long-handled mop tool.

Three lengths of mop handles; a short, medium and fully-ended or long length shown in Figure 23 on page 53. Mop handle length produced material differences in hand forces with medium lengths producing the greatest dynamic hand forces.

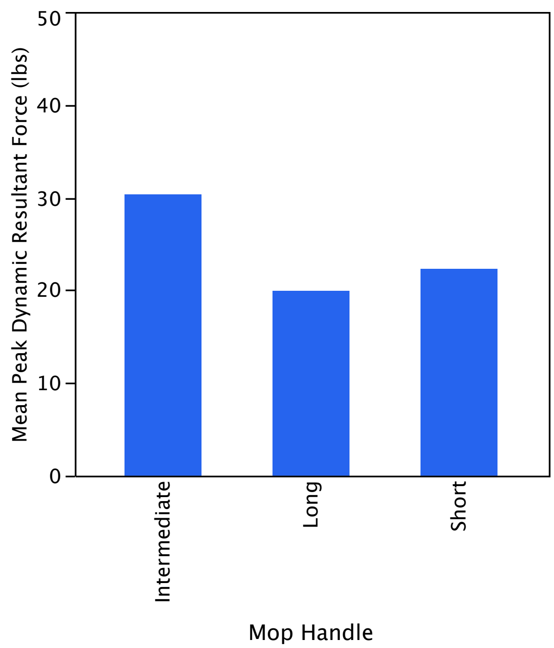


Figure 65: Mean peak dynamic resultant forces produced when housekeepers used short, medium and long handled mop tools.

Housekeepers reported that they only used the longest mop handle to clean bathroom floors because it reduced torso flexion and was more comfortable. Peak recorded dynamic resultant ground reaction forces acting along the axis of the mop handle were used for biomechanical analysis. The mopping posture used in biomechanical analyses is shown in Figure 66.

Static biomechanical analyses were performed to determine if exertions exceeded 20 percent MVC, or lumbar disc compression levels exceeded NIOSH Action Limits. Results showed that strength demands were below risk thresholds for MSDs, and lumbar disc strain was at levels that NIOSH considers to be safe. Sensitivity analyses showed that distribution of hand forces between hands produced no material change in biomechanical analysis outcomes. See Figure 66.

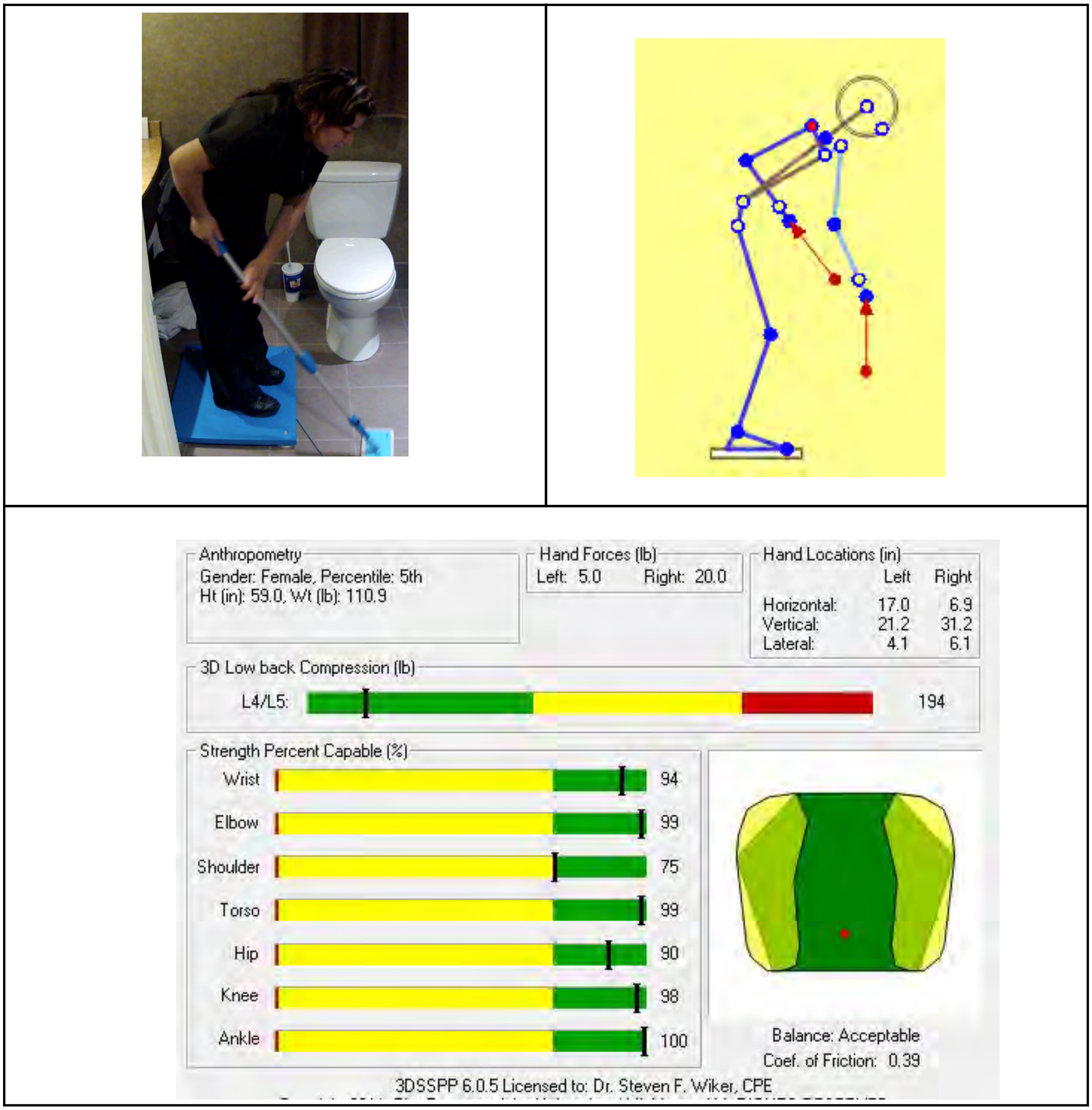


Figure 66: Static biomechanical analysis results for long handle mopping using maximum resultant dynamic hand forces.

5.3.4 Pushing Carts

Housekeepers push linen carts that range from empty to fully-ladened under the following conditions: a) from a standstill to a typical pushing velocity with all four wheels aligned and straight, b) from a standstill to typical pushing velocity with the rear steering wheels turned 90 degrees at the start of the push, c) sideways from left-to-right and right-to-left, d) over door sill transitions that presented short or tall abrupt or step elevations above the carpeted path, and e) when pushing the cart continuously while walking. Box plots of the force plate resultant ground reaction forces are provided in the following figure.

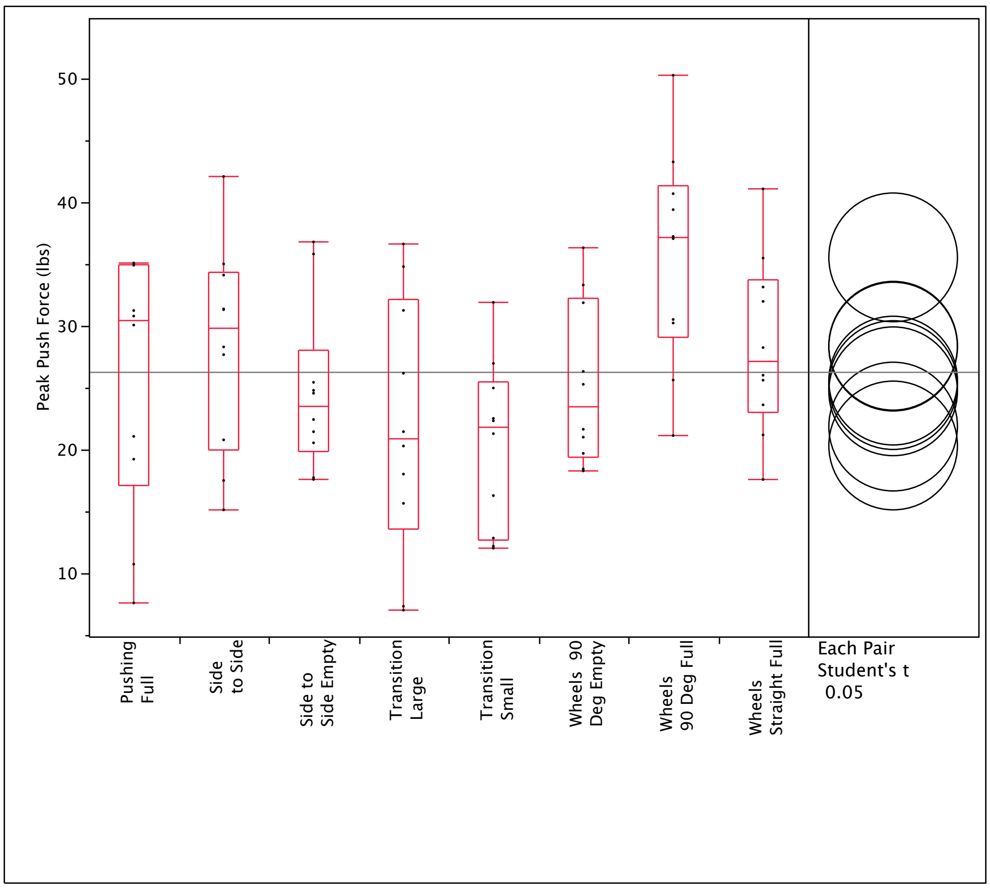


Figure 67: Box plots of resultant ground reaction forces for various cart pushing tasks performed by housekeepers.

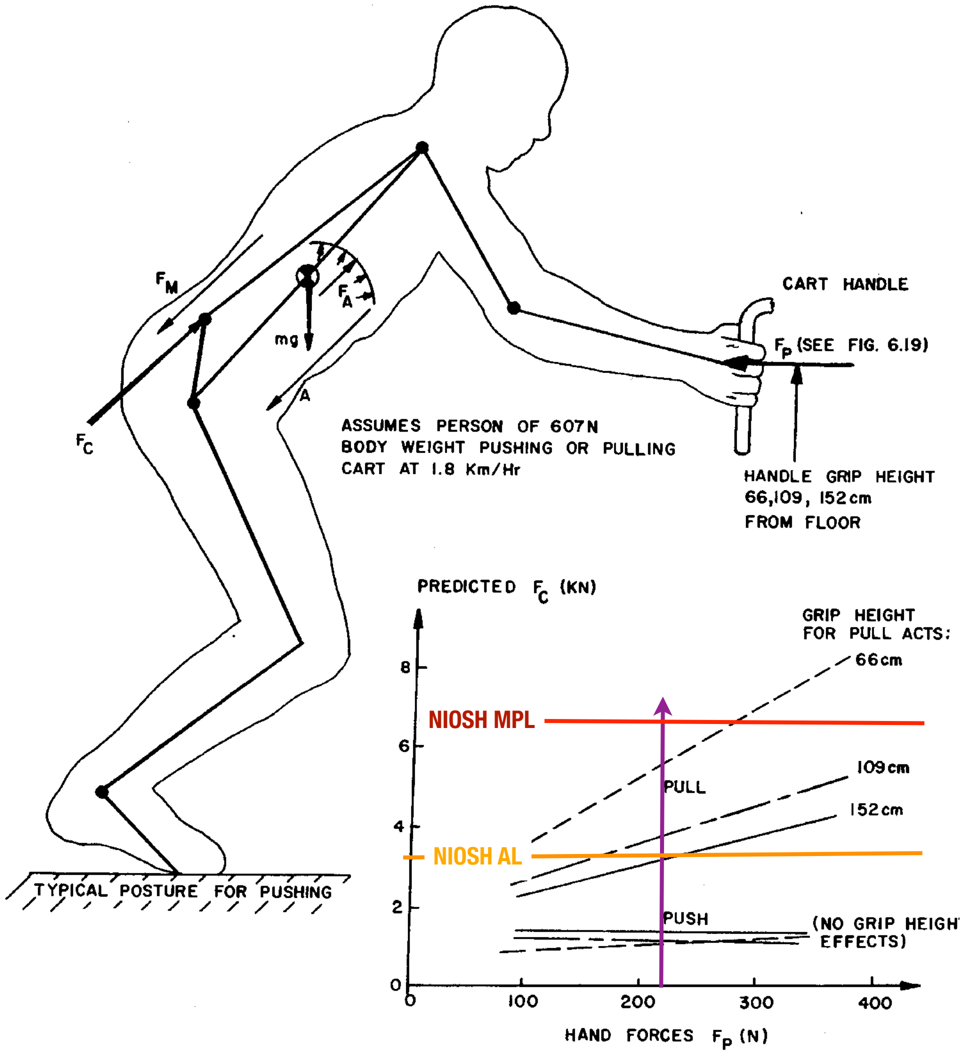


Figure 68: Lumbar disc compression versus hand forces and cart pushing and pulling strategies (Adapted from Lee et al., 1991).

Resultant ground reaction force magnitudes were analyzed using a one-way ANOVA. A summary of the findings is provided in the table below.

Table 4: Results of a one-way ANOVA of maximum resultants (lb.) obtained from ground reaction force measurements taken for each cart pushing task.

Summary of Fit

Rsquare	0.238158
Adj Rsquare	0.16409
Root Mean Square Error	8.256377
Mean of Response	26.22414
Observations (or Sum Wgts)	80

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
Condition	7	1534.3086	219.187	3.2154	0.0051*
Error	72	4908.0789	68.168		
C. Total	79	6442.3875			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
Pushing Full	10	25.5568	2.6109	20.352	30.762
Side to Side	10	28.3064	2.6109	23.102	33.511
Side to Side Empty	10	24.6927	2.6109	19.488	29.897
Transition Large	10	21.8389	2.6109	16.634	27.044
Transition Small	10	20.3107	2.6109	15.106	25.515
Wheels 90 Deg Empty	10	25.1940	2.6109	19.989	30.399
Wheels 90 Deg Full	10	35.5207	2.6109	30.316	40.725
Wheels Straight Full	10	28.3730	2.6109	23.168	33.578

Std Error uses a pooled estimate of error variance

Table 5: Paired differences and 95 percent confidence limits for observed differences in the maximum resultant of ground reaction forces (lb.) found among cart pushing conditions.

Level	- Level	Difference	Std Err Dif	Lower CL	Upper CL
Wheels 90 Deg Full	Transition Small	15.21000	3.692364	7.84941	22.57059
Wheels 90 Deg Full	Transition Large	13.68186	3.692364	6.32127	21.04245
Wheels 90 Deg Full	Side to Side Empty	10.82806	3.692364	3.46747	18.18865
Wheels 90 Deg Full	Wheels 90 Deg Empty	10.32668	3.692364	2.96609	17.68728
Wheels 90 Deg Full	Pushing Full	9.96392	3.692364	2.60333	17.32451
Wheels Straight Full	Transition Small	8.06227	3.692364	0.70167	15.42286
Side to Side	Transition Small	7.99568	3.692364	0.63509	15.35627
Wheels 90 Deg Full	Side to Side	7.21432	3.692364	-0.14627	14.57491
Wheels 90 Deg Full	Wheels Straight Full	7.14774	3.692364	-0.21286	14.50833
Wheels Straight Full	Transition Large	6.53413	3.692364	-0.82647	13.89472
Side to Side	Transition Large	6.46754	3.692364	-0.89305	13.82813
Pushing Full	Transition Small	5.24608	3.692364	-2.11451	12.60667
Wheels 90 Deg Empty	Transition Small	4.88332	3.692364	-2.47728	12.24391
Side to Side Empty	Transition Small	4.38194	3.692364	-2.97865	11.74254
Pushing Full	Transition Large	3.71794	3.692364	-3.64265	11.07853
Wheels Straight Full	Side to Side Empty	3.68032	3.692364	-3.68027	11.04092
Side to Side	Side to Side Empty	3.61374	3.692364	-3.74685	10.97433
Wheels 90 Deg Empty	Transition Large	3.35518	3.692364	-4.00542	10.71577
Wheels Straight Full	Wheels 90 Deg Empty	3.17895	3.692364	-4.18164	10.53954
Side to Side	Wheels 90 Deg Empty	3.11236	3.692364	-4.24823	10.47296
Side to Side Empty	Transition Large	2.85380	3.692364	-4.50679	10.21440
Wheels Straight Full	Pushing Full	2.81618	3.692364	-4.54441	10.17678
Side to Side	Pushing Full	2.74960	3.692364	-4.61099	10.11019
Transition Large	Transition Small	1.52814	3.692364	-5.83245	8.88873
Pushing Full	Side to Side Empty	0.86414	3.692364	-6.49645	8.22473
Wheels 90 Deg Empty	Side to Side Empty	0.50137	3.692364	-6.85922	7.86197
Pushing Full	Wheels 90 Deg Empty	0.36276	3.692364	-6.99783	7.72336
Wheels Straight Full	Side to Side	0.06658	3.692364	-7.29401	7.42718

Standard cart pushing efforts are typically evaluated by measuring forces that are needed to just initiate cart movement, or to keep cart movement continuous. Housekeepers performed cart push tasks in a dynamic manner that provided information for both the initial exertion, acceleration to a momentum control state, and slowing the cart to a stop. As shown in Figure 67 on page 105, cart pushing forces were quite variable among housekeepers. This finding reflects different strategies used among the housekeepers tested. Some attempted to ballistically accelerate the cart while others initiated movements with slower force ramp rates; thereby reducing the peak force required to initiate and maintain cart movement.

5.3.5 Bed Making

Housekeeper postures were recorded when they made the bed's head and foot corners as well as the sides of the bed. The bed making task involved tucking the bottom flat sheet and then tucking the remaining bedding as a grouped tuck.

5.3.5.1. Barrier Induced Body Clearance Limitations

Principal bedding tucking strategies observed were: 1) stooped standing with body turned to the side of the mattress, mattress bottom grasped and lifted slightly with one hand, and sheets and other bedding tucked underneath the mattress with the nonlifting hand; 2) stooped facing the mattress and used one hand to slightly lift the mattress while the other hand tucked the linens underneath the mattress and; 3) squatting or kneeling facing the mattress, hands and forearms lift the mattress like a wedge as they and the linens are pushed between the mattress and box springs. See the following figures.

All three of the strategies were found to be safe or present only nominal risk of low-back injury and did not challenge population strength capabilities. Biomechanical analyses were based upon the hand forces summarized in Table 6 on page 113.

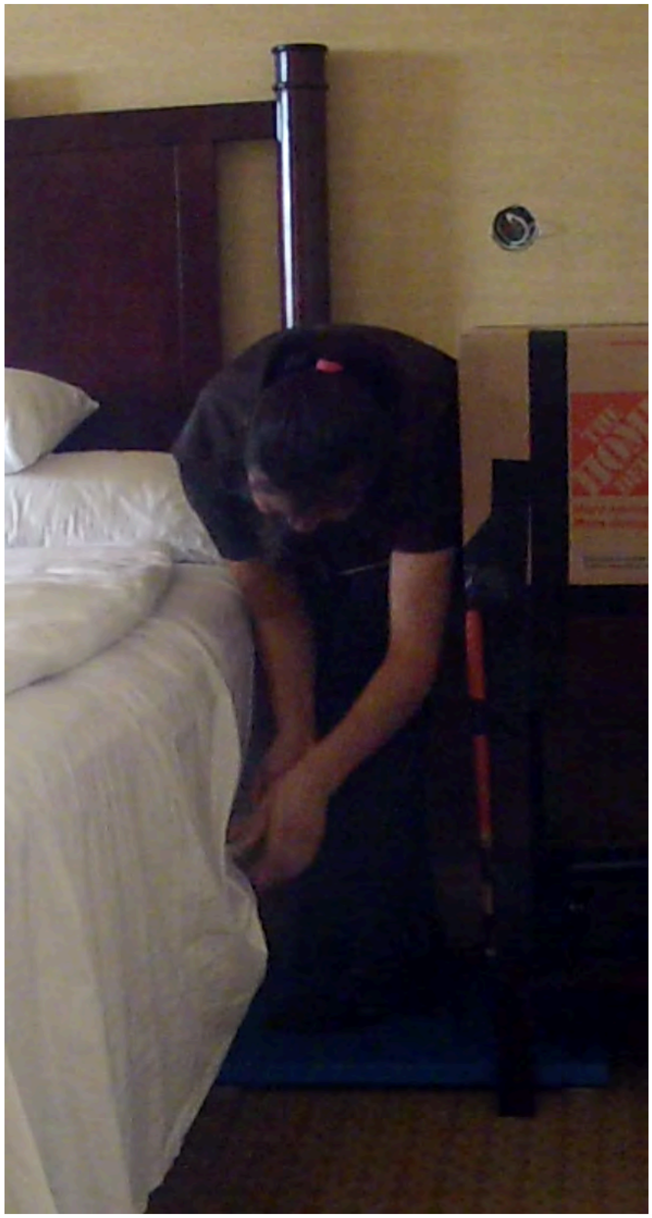


Figure 69: Exemplar of a sideways stoop-lift and tuck linen posture when body interference was present.

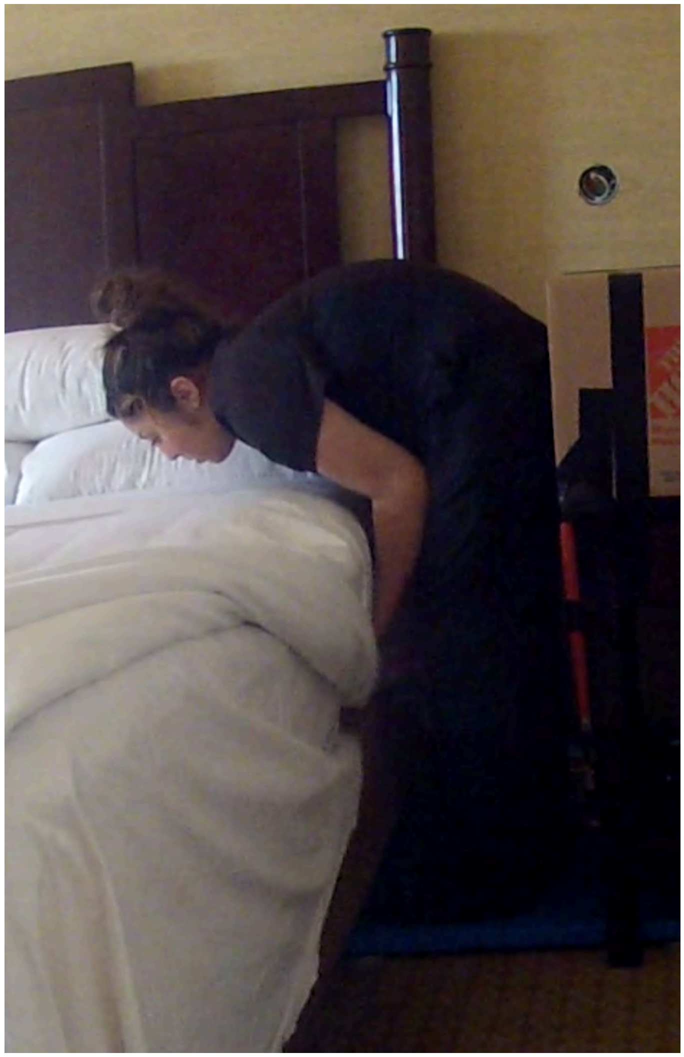


Figure 70: Exemplar of stooped lift and tuck when facing bed without body interference.

Figure 71: Exemplar of housekeeper using squat and tuck posture facing the bed.

Table 6: Hand forces used in biomechanical analyses.

Task/Exertion (lb.)	Minimum Lift Force (R Hand)	Maximum Lift Force (R Hand)	Minimum Horizontal Tuck Force (L Hand)	Maximum Horizontal Tuck Force (L Hand)
Stoop-Lift Tuck Aligned Sideways to Bed (Barrier Condition)	0	25	0	15
Stoop-Lift Tuck Facing Bed	0	25	0	15
Squat Tuck Facing Bed	5	15	5	15

Means and variances, along with individual data, are plotted in the following figure. An ANOVA showed that the squat tuck produced the lowest disc compression force. Forcing housekeepers to stand side ways to the bed produced the greatest level of disc compression. All conditions fell below the NIOSH Action Limit and would be deemed safe by NIOSH.

Tukey pairwise comparisons showed that barrier-induced sideways stoop lift and tucks produced greater disc compression than did squat tucks facing the bed (209 lb. difference, $p<0.01$), and a statistically marginal difference was found between the two stoop tucking postures (146 lb., $p=0.08$). The principal difference was associated with lower lifting requirements in the squat or kneeling posture. The hands and arms were effectively serving as wedges with the body part displacement of the mattress rather than lifting it.

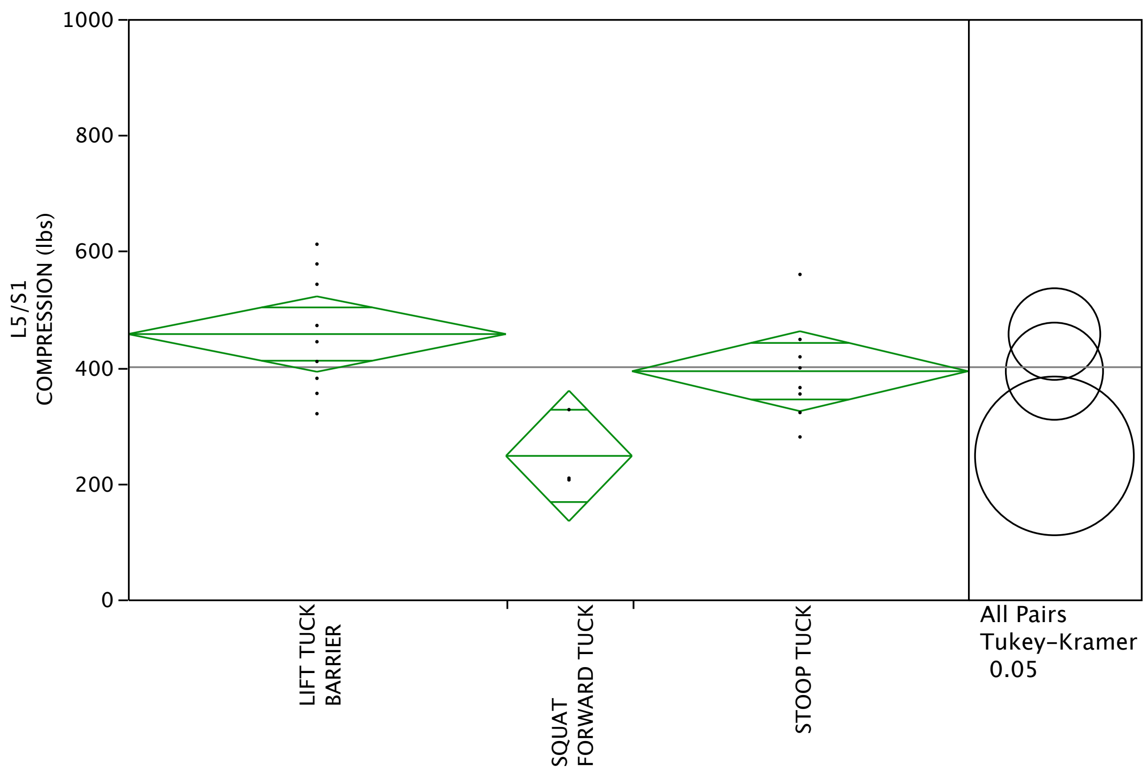


Figure 72: Plots of lumbar disc compression force for the three different tucking postures observed. Note NIOSH Action Limit defining onset of risk is 764 lb.

Table 7: One-way ANOVA table comparing lumbar disc compression (lb.) when using different bed tucking using individual housekeeper postures and hand forces.

Oneway Anova

Summary of Fit

Rsquare	0.407858
Adj Rsquare	0.338194
Root Mean Square Error	92.29993
Mean of Response	400.15
Observations (or Sum Wgts)	20

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Ratio	Prob > F
TASK	2	99754.83	49877.4	5.8547	0.0116*
Error	17	144827.72	8519.3		
C. Total	19	244582.55			

Means for Oneway Anova

Level	Number	Mean	Std Error	Lower 95%	Upper 95%
LIFT TUCK BARRIER	9	457.222	30.767	392.31	522.13
SQUAT FORWARD TUCK	3	247.333	53.289	134.90	359.76
STOOP TUCK	8	393.250	32.633	324.40	462.10

Std Error uses a pooled estimate of error variance

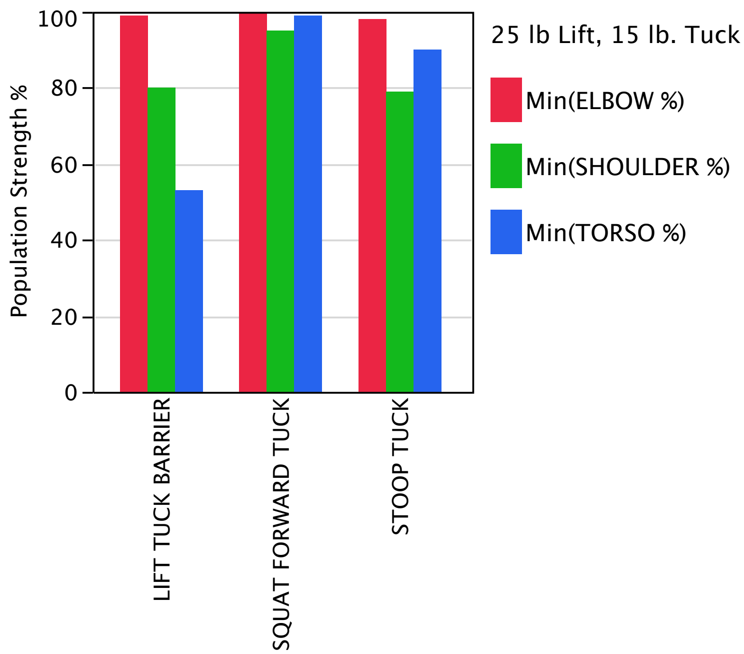


Figure 73: Minimum population strength capability for elbow, shoulder and torso when performing bed making.

5.3.5.2. Rice Paddles and Tuck Tools

A one-way ANOVA showed no meaningful differences between using bed making tools and handmade beds in terms of lumbar disc compression ($p<0.10$). We also found no material differences in postures used by the housekeepers when using either the rice paddles or the commercially-available bed tucking tools. Whatever posture they used with their hands alone was essentially the same posture used with the tools. Thus, no differences in the biomechanical stress indexes were found among bed making with hands or tools. See Figure 74.

The tools did not alter the biomechanical stresses imparted to the housekeeper's bodies when faced with limited body clearance because they still required horizontal thrusts from a stooped posture. If the housekeeper had sufficient clearance to use the squat or kneeling posture when tucking, the horizontal thrust requirements were essentially the same in magnitude.

The rice paddle's handle was sufficiently long that it would be operated with two hands in reasonably good wrist posture. The commercially-available tuck tool had a spherical handle that only one hand could grasp. Material dorsiflexion of the wrist was experienced when the housekeeper wished to tuck with it in the squat or kneeling position.

Uniformly, the housekeepers reported that they did not use or want to use the commercial tucking tool because it took extra time to walk around the bed inserting and removing the wedges about the bed. They didn't feel that the benefits proffered by the commercially-available tuck tool warranted the increased effort or extra time needed to accomplish bed making. The tuck handle design made use awkward when attempting to extend their tucking away from the immediate sides of the body. The housekeepers reported that the tuck device was difficult to generate force in comparison to the rice paddles.

The housekeepers preferred the rice paddle when tucking beds because it spared their fingers from axial forces when tucking sheets under the mattress and reduced skin abrasion. Many, but not all, housekeepers also wore thin gloves to protect their hands from abrasion when tucking linen.

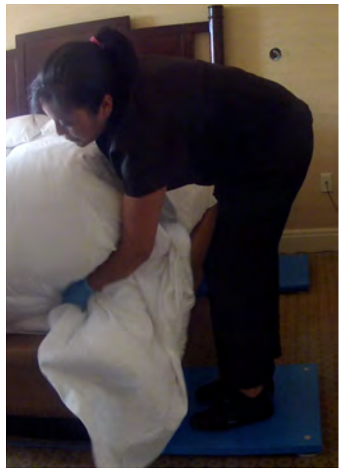
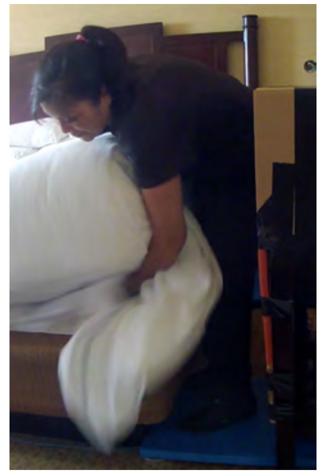
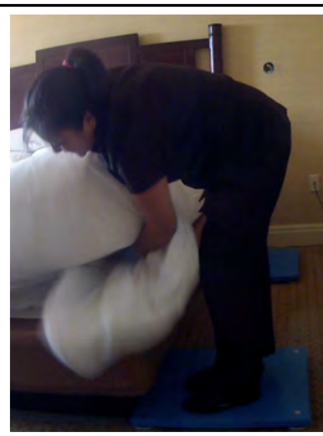
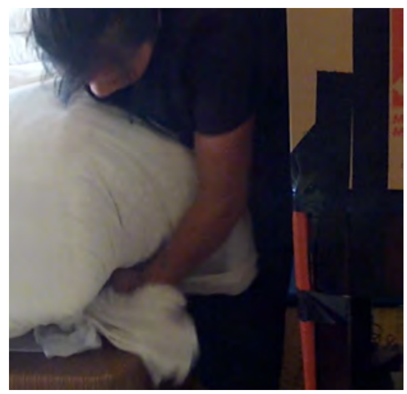
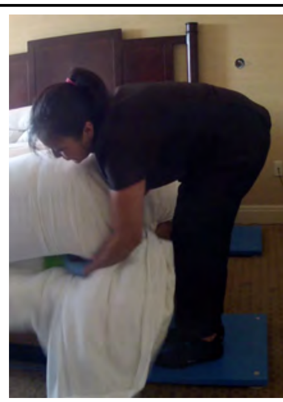
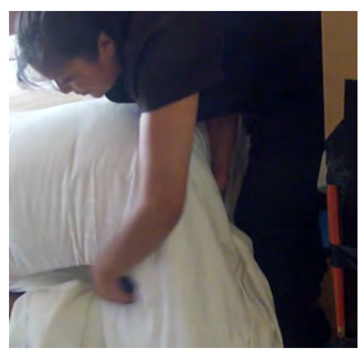
Tool Condition	No Body Interference	Body Interference
Hand		
Rice Paddle		
Tuck Tool		

Figure 74: Representative images of a housekeeper using two linen tucking aids showing no material impact upon tucking posture.

5.4. Cumulative Upper Extremity MSD Risk Assessment

Work sampling analyses determined exposure durations for each room's cleaning activity. Potential MSD risk activities were tagged if exertions were sufficient that population strength design limits for women were exceeded (i.e., less than 80 percent of working women would have sufficient strength capability to perform the exertion) in joint postures that approached range of motion limits (i.e., deviated from neutral posture ranges).

Time spent performing MSD risk tagged tasks was evaluated individually and collectively to determine if the total activity duration exceeded the MSD risk threshold of 50%. When all activities with some degree of MSD risk factor exposure were aggregated, the aggregated exposure was only 41%. If one added break and meal times, the aggregated exposure fell to 36%. Had the work sampling not been activity-based (i.e., we monitored only epochs of excessive forces in provocative postures), exposures would have been well below 36%.

This level of MSD risk factor exposure fell well within epidemiological control group definitions. Thus, incidence of occupationally-induced MSDs should be no greater than that of jobs deemed safe by NIOSH.

Table 8: Individual and aggregated MSD risk exposure for individual and collective housekeeping task activities.

Activity	MSD Risk	Percent (%)	MSD Risk x Percent (%)
Move Desk Chair	0	0.5	0
Sink	0	1	0
Stand	0	1	0
Fabreze[6]	1	1	1
Vertical Wiping	0	1	0
Wiping	0	2	0
Mopping	0	2	0
Shower Wall	1	2	2
Toilet	0	2	0
Tub	1	4	4
Carry Linen	0	6	0
Vacuum	1	8	8
Missing (Behind Bathroom Door)	0	10	0
Dusting	0	11	0
Other (Clipboard, Trash, Arrange)	0	11	0
Walk	0	12	0
Make Bed	1	26	26
			Sum = 41%

6. Very remote risk of trigger finger if sustained spraying occurred.

6. Discussion

The objective of this study was to determine whether or not typical hotel room cleaning exposed housekeepers to acute or cumulative musculoskeletal disorder hazard. Low-levels of MSD risk factors were found for some but not most of the housekeeping tasks. Work sampling of experienced housekeepers cleaning rooms showed that less than 41 percent of the job involved limited exposure to MSD risk factors when cleaning rooms. When meal and break times and meetings were included in the total shift exposure exposures declined to 36 percent.

This study has overestimated exposures because computations were activity based. Had the work been sampled for actual MSD risk factor occurrence, collective exposure estimates would have been well below 36 percent. For example, with bed making, brief exposures to exertions that approached 20 percent MVC and wrist flexion and extension that exceeded published neutral zone ranges of motion. This result led to classification of the entire bed making interval as MSD risk ladened. In reality, most of the bed making activity time was spent walking, carrying bedding, and other elements that did not expose housekeepers to MSD risk factors.

The vast majority of housekeeper tasks failed to exceed exertion thresholds used to define cases for MSD epidemiological studies (i.e., exertions greater than 20 percent than the population's strength capacity). For 75 percent of the activities performed by the housekeepers, exertions were not coupled with exposure to joint ranges of motion that exceeded recommended limits for upper extremity joints. Without concurrent exposure to high-force, excessive postural excursions and adequate durations MSD risk factor exposure, occupational risk for MSDs fails to develop (Putz-Anderson, 1988).

Force, posture, and exposures for the housekeeper job fell into exposures that are consistent with epidemiological control groups—indicating that the job is safe from MSD hazard. This result is supported by the aforementioned nominal incidence housekeeper MSDs characterized by sprains and strains, Carpal Tunnel Syndrome, tendonitis, and muscle soreness including back pain within BLS reports.

Along with a lack of provocative MSD risk factor exposure, the housekeeper's job was compliant with NIOSH administrative controls advocated for elimination or mitigation of workplace MSDs. NIOSH recommends engineering jobs to: a) require low strength demands, b) elimination or substantial reduction of joint postures that deviate from high-strength zones and approach joint range of motion limits, and c) introduction of task variety and material exposure to micro-breaks for working muscle groups. Housekeeper jobs are characterized by high task variety (e.g., job enrichment and task rotation), substantial exposure to micro-breaks, and some degree of scheduling flexibility for sequencing rooms to be refreshed or cleaned.

Analysis of work sampling tapes showed that housekeepers performed a variety of short duration activities that were cycled or rotated fourteen times during a shift. The vast majority of housekeeping tasks were completed in less than two minutes before housekeepers rotated into the next activity. The next activity was typically very different in terms of postures and muscle groups used. Rotation among many different activities occurred every 20 to 30 minutes.

Shadowing many housekeepers in preparation for this study showed that housekeepers have some degree of control in scheduling the sequence and timing of rooms cleaned. Room cleaning sequence and distribution of room checkout and refresh cleanings is influenced by guest checkout timing and use of rooms. The housekeepers work independently and are largely unsupervised—giving them reasonable decision latitude in accomplishing their work. Our observations of working housekeepers across several hotels, including the one selected for this study, showed no sign of negative psychosocial working condition.

Housekeepers, as a BLS occupation code, exhibit nominal incidence of MSDs and MSIs. This outcome is attributed to: a) nominal exposure to MSD and MSI risk factors, and b) jobs that are highly compliant with NIOSH recommended Administrative Controls for MSDs and MSIs. The absence of hazardous MSD and MSI risk factor exposure, compliance with several administrative controls for such injuries and the lack of MSD and MSI incidence support a conclusion that the job presents nominal risk for acute or cumulative MSDs.

Aerobic power demand of the housekeeper job was examined using heart rates to assess the risk of systemic fatigue onset during housekeeping work. Heart rates were recorded when housekeepers performed refresh and checkout cleaning of king and double rooms with wide ranges of tidiness. Those exposures were typical of their working shift.

Physical workload, as indicated by heart rate indices of cardiac output and aerobic power, would be classified as “moderate” during maximum exertions and “light” when performing dusting and other less taxing activities (Borg, 1983), with an average of "light-moderate." Heart rates were greatest when performing bed making and fell to comparatively low values when performing tasks that did not involve walking or lifting.

Use of heart rate as an index of aerobic power demand showed that the job's physical demand was less than one-third of the cardiac reserve. This level of exertion is compliant with ergonomic design guidelines for shift-long physical workloads (NIOSH, 1981). The typical workload experienced by housekeepers in this study was acceptable for women performing housekeeping activities for eight-hours in the class of room, room size and room layout addressed in this study.

Static biomechanical analyses were conducted for all tasks regularly performed during room cleaning as well as tasks that would be performed on an irregular basis (e.g. responding to fires, potential security issues, etc.). Peak dynamic hand forces measured when performing each element of room cleaning activities were combined with observed postures to perform static biomechanical analyses.

Using peak dynamic hand forces instead of static components of those exertions inflated exertions entered into the biomechanical model. Thereafter, the model overestimated static resultant forces and load moments acting at major articulations within the body. The model inflated lumbar intervertebral disc compression and intra-abdominal pressures as well. Peak dynamic exertions were used because it reduced the time and cost of the study. If inflated estimates of static exertions were safe, errors produced by using greater dynamic hand force estimates simply added safety margins to our results.

Biomechanical analyses estimated stresses acting upon the major articulations and lumbar spine. The predicted stresses fell below thresholds for hazard in every task. This finding provides direct support for the very low incidence of acute low back injuries found nationally in housekeepers (BLS, 2011).

Strength demands for housekeepers using observed postures were always acceptable for more than 80 percent of working women. Each housekeeper studied was allowed to use their preferred methods for each of the housekeeping tasks. Variations in their methods might have been a result of many factors (e.g., anthropometry, strength, training and experience, etc.) that were not studied for causality.

Measured housekeeper postures and peak dynamic hand forces showed that vacuuming, cleaning of bathroom sinks and counter surfaces, shower walls, tubs, toilets, mopping floors, cleaning mirrors, walking and cart pushing were all compliant with ergonomic design guidelines for prevention of low back injuries. This was true whether or not ergonomic aids were used (e.g., long-handled scrubbing tools, commercially available tucking tools, rice paddles, etc.).

Housekeepers preferred to use their hands to clean surfaces because they reported that they preferred improved feel or haptic assessment of surface cleanliness. Knowing when the surface felt clean, they could stop wiping as early as possible and thereby avoid unnecessary wiping and save time. Housekeepers also elected wiping and scrubbing postures that enhanced strength (i.e., reduce load moments at the elbow and shoulder), reduced the required coefficient of friction, and kept the lumbar disc compressions well below the NIOSH Action Limit.

In the main, housekeepers were unhappy about using long-handled scrubbing tools because they felt the tools do not clean well, and that the geometry of the bathtub and shower walls and organization and placement of tub/shower fixtures compelled use of awkward arm and hand tool handling postures with excessive force. Our study found the latter complaints to be true in nearly all cases. Cleaning mirrors with long-handled tools provided material ergonomic improvement when the entire mirror required cleaning. However, housekeepers typically spot cleaned mirrors quickly by hand.

Except for cleaning the upper regions of bathroom mirrors, long-handled tools provoked uncomfortable upper extremity postures and forceful exertions. Postures observed have been associated with Thoracic Outlet Syndrome and shoulder complex fatigue and discomfort (Wiker et al., 1989).

Housekeepers reported that the cleaning inefficiency and reduced comfort with use of such long-handled tools resulted in rare use. Time required to fetch and return tools, regrasping or repositioning the tools, and with adjusting the tool's handle length between tasks to obtain a more ideal working posture, added to additional time needed to obtain satisfactory cleanliness. Tool handles extending behind the housekeeper were observed making inadvertent contact with shower walls where space was limited.

Use of long-handled tools such as paint rollers save considerable amount of time and effort when rolling on paint to vertical and horizontal surfaces. However, there is a material difference between forces of application, tool positioning and body postures required to deliver those forces when one compares laying on paint to scrubbing surfaces in tight quarters inside or next to the bathtub/shower stall. Use of the tools in the bathroom for tub/shower surface scrubbing provoked postures that are not found when performing painting or mopping tasks. Postures recorded when using tools that they were provided were exemplars for poor ergonomic design.

Efforts aimed at forcing housekeepers to always use such tools should be abated. It is doubtful that housekeepers would willingly comply with a hotel's requirement to use long handled tools because of their perception of poor outcome quality, greater time needed to perform the job, higher force:strength ratio requirements, and general discomfort. The workers acknowledged that they have access to the tools and carry them on their carts. However, they rarely use them.

The tools can be of use when cleaning above shoulder surfaces that are difficult to reach for shorter housekeepers. The strategy of making the tools available to the housekeepers and demonstrating preferred use or application is acceptable. Allowing housekeepers to make decisions about when they want to use the tools is best. Hand wiping offered less stress and allowed the housekeepers to complete their work faster with better perceived quality. This is particularly true on wall surfaces adjacent to bathtub and shower fixtures.

Pushing forces needed to initiate cart movement, combined with typical short cart pushing distances, were compliant with current psychophysically-derived ergonomic design guidelines published by Liberty Mutual Insurance, and with force guidelines aimed at protecting the low back from injury (Lee et al., 1991). To initiate cart motion, inertial and friction forces were overcome along with any additional resistance associated with caster wheel initial misalignment with direction of movement. Once rolling, the housekeeper applied reduced force to keep the cart in motion. Typically, housekeepers allow carts to coast to a stop based upon experience.

Housekeepers were asked to initiate cart motion, to push a cart while moving across crossing force plates, and to push across representative step-like transitions of two different heights using their personal methods. Results showed wide variation in dynamic pushing force strategies. Some of the housekeepers initiated cart movement slowly and capitalized upon momentum to cross over transitions with relatively small hand forces. Others aggressively initiated cart movements or failed to capitalize upon cart momentum when crossing transitions—experiencing safe but greater pushing forces.

Estimated lumbar disc compression and strength demands were well within ergonomic design limits and deemed safe regardless of strategies used to initiate cart movement, maintaining cart movement, or when parking carts. Pushing carts across surface irregularities (e.g., crossing door transition with elevated sills) produced variable but low push forces. Housekeepers capitalized upon cart momentum to allow crossing discontinuities comparable to doorway sills without material effort.

While worst case perpendicular crossing of simulated doorway sills was safe, we consistently observed housekeepers pushing carts slowly across transitions at an angle such that one wheel crossed the elevated sill at a time. That approach was not tested; however, it appeared easier to complete and resulted in less impulse jostling of the cart as it crossed the discontinuity.

Housekeepers made king sized and double beds using individual methods. In this study, housekeepers made king-sized beds with and without body interference created by bed placement. The no barrier and vertical barrier (e.g., created by placing the bed 14 inches away from a vertical barrier similar to a wall) test conditions produced systematic impact upon bed making postures and methods.

For the no barrier condition, many housekeepers squatted or kneeled adjacent to the bed and inserted one hand between the mattress and box springs to create a gap. They used their other hand to sweep the linens into the gap created to complete the tuck. This approach allowed tucking without directly lifting the mattress (i.e., the arm was used as a wedge). Those housekeepers moved along the side of the bed squatting or kneeling while performing the described bedding tucks.

This strategy served to keep the torso near vertical. At times, the torso leaned against the mattress for support when performing tucks. The upper arms were dependent, and wedging and minimal lifting exertions were performed with the forearms and hands. Arm postures used approached maximum flexion strength postures. We were able to use the biomechanical model when housekeepers initiated the tuck, before body contact with the mattress, and when they pulled their torso away from the mattress. Sweeping motions associated with arms working in different directions created force-couples. The force couple, and leaning against the mattress for support of the torso, and the upper arm postures materially reduced mechanical forces acting upon the spine and shoulder complex. Such exertions and postures produced very low levels of biomechanical stress—levels deemed safe by NIOSH.

Another no barrier bed making method used incorporated a semi-squat/stoop posture. Here, the housekeepers entered a semi-squat/stoop posture and leaned into the mattress, or rested their elbows upon their thighs just above their knees, as they used their forearms to lift the mattress a short distance upward to permit tucking with the nonlifting hand.

With this strategy, the arms supported some of the torso's mass and transferred much of the forearm's resultant forces directly into the thighs and lowering articular load moments passed into the shoulders. Biomechanical model outcomes showed comparable spinal stresses to those obtained in an earlier studies of bed making (Milburn and Barrett, 1999; Wiker, 2011). The spinal compression forces did not exceed the NIOSH Action Limit in this and previous studies and, therefore, demonstrated nominal risk of injury.

When the clearance between the bed and wall was reduced to 14 in., bed making postures altered systematically. Smaller housekeepers used either a semi-squat posture facing the bed, while others turned their body to align it with the long axis of the bed. Whether turned or not, housekeepers used one hand to grasp the underside of the mattress, lifted it just enough to allow the other hand to insert the bedding between the mattress and box springs.

At the foot of the bed the arms were inserted underneath the mattress, the mattress raised as the housekeeper leaned into the side of the mattress supporting their torso as their free arm was used to sweep the bedding underneath the mattress. When housekeepers decoupled their torso from the mattress and were freestanding, hand forces and observed postures produced biomechanical stresses that were within ergonomic guidelines for task design and prevention of low-back injury (NIOSH, 1981).

Housekeepers reported that they preferred making beds with the rice paddles. Rice paddles allowed deeper tucks than the commercial tucking tool studied, and did so without having to insert hands underneath the mattress. Tucking bedding between the mattress and box springs with bare hands reportedly axially-stressed extended fingers during tucks, and bedding rubbed against the skin of the tucking limb. Rice paddles and a commercially-available tuck tool studied, spared housekeepers from such stresses. Rice paddles extended the functional reach and tucking range without creating stressful wrist postures and reduced the number of body repositions needed to make the bed. Finally, the tools were easily carried in their uniform pockets and were readily available when needed.

The commercial tucking device tested came with three wedges to help space the mattress so that mattress lifting could be avoided. The design worked well near the middle of the mattress sides where the wedges were inserted. However, housekeepers still lifted the mattress corners to complete tucking of bedding at the corners.

The commercial tucking tool possessed a spherical grip that promoted good hand-wrist postures when tucking immediately in front of the housekeeper. However, when housekeepers attempted to tuck away from the front of the body, the spherical grip provoked excessive dorsiflexion of the wrist. To avoid the dorsiflexion problem, housekeepers performed more body repositions to enable them to tuck in the approximate plane of the shoulder.

Aside from additional body repositioning when using the commercial tuck tool, housekeepers had to transport the tools from the cart to the bed(s), walk about the bed(s) inserting the wedges before starting bed linen tucking. Upon completion of tucking, the wedges were removed and had to be returned to the cart.

Use of rice paddles, or the commercial bed tucking tool studied, did not materially alter bed making postures, or manual forces, from those observed manual bed making. Thus, use of these aids did not present material advantage or disadvantage from low back injury prevention, preferred posture, or strength demand perspectives. Absent biomechanical benefits, housekeepers reported that the additional walking time and effort required to make beds with the commercial tucking tools reduced their utility. Use of either the rice paddles or commercial tuck tools do not present a hazard when used to make beds.

Reducing body clearance between a bed and adjacent wall to 14 inches allowed housekeepers to make beds without material risk of musculoskeletal injury. However, the reduction in clearance forced adoption of stooped postures in each case and slowed housekeeper movement about the bed. Alternative postures that further reduced biomechanical stresses were infeasible with reduced clearance.

Slowing movement about the bed is a penalty incurred each time the room is cleaned or refreshed. Limited body clearance also limits egress options for guest(s) using the bed. From an industrial engineering perspective, hotels should make efforts to avoid incurring productivity challenges by positioning beds too close to walls or other barriers.

Computations of biomechanical stress obtained in this study were comparable to those of Milburn and Barrett (1999) and Wiker (2011). Milburn and Barrett examined the most challenging posture with the greatest load moments. Their computed lumbar disc compression values were below NIOSH Action Limits and within proximity to those observed in this and a previous study (Wiker, 2011).

These findings argue that although a variety of bed making postures have been catalogued across investigators and studies, none produced excessive strength demands or hazardous lumbar disc compressions. Differences in bed making strategies may have resulted from individual housekeepers attempting to optimize anthropometry, age, strength, time management, and other performance-mediating factors. No efforts were made to understand the bases for differences in housekeeping methods found among housekeepers participating in this study.

In this study we found material variations in times to clean or refresh rooms among housekeepers, between rooms with different bed types, and between rooms with material differences in guest tidiness. However, many other factors can affect times required to clean or refresh hotel rooms. Differences in room decor and furniture layout, sink and bathroom fixture designs, nature of materials and cleaning agent requirements, tub/shower combinations, and bedding design and presentation. From an industrial engineering perspective, hotels should consider the impact of such factors using scientific and engineering methods when selecting among candidate room and decor designs, or when setting quotas for room refresh and checkout cleaning.

Some have proposed setting systemwide room quotas for hotel housekeepers based simply upon room size. A room that is 350 sq. ft. may take longer to clean than a 500 sq. ft. room because of differences in layouts affecting lengths of walking paths, differences in body clearances that affect walking speeds and distances, distance that linens have to be carried to and from carts, variations in vacuuming paths, degree of path obstructions, variety in numbers and types of decor elements, and differences in surface areas requiring dusting, scrubbing and visual inspection.

Such variances in performance demands and completion times may appear to be trivial from a single room basis. However, collectively they affect times required to clean an individual or population of rooms. An arbitrary decision aimed at setting workload limits by simply setting room quotas based upon room size alone can be expected to produce uneven workloads for housekeepers within and among hotels. Setting arbitrary room quotas not based upon industrial engineering analysis is ill-advised if scientific management of housekeeper workload is the goal.

Results obtained in this study are applicable to, and representative of, this class of hotel room and its layout. While these rooms are broadly representative of rooms throughout the hotel industry, one should take care not to overextend the findings to rooms that do not fall into the category studied.

It was very clear from housekeeper debriefings that they are adamant about performing their jobs in a manner that produces the highest quality of cleanliness, appearance and efficiency. Any training program or operational policy that conflicts with those goals is likely to encounter problems with compliance. Scientific methods and thorough analyses will have to demonstrate superior efficiency and quality of performance before proposed tools, alternative performance strategies, etc., are willingly adopted by the housekeepers.

Previous job analysis reports suggested that even if the job's MSD risk factor exposure was not hazardous, that further reduction in nonhazardous exposures would further reduce risk. That implication has never been verified or validated. Reducing exposures to MSD risk factors below those that are deemed safe proffers no measurable or guaranteed improvement in safety or health as some have claimed. If a hotel chooses to pursue improved productivity and quality of work through further reduction of safe levels of MSD risk factor exposure, the hotel cannot anticipate any change in nominal MSD incidence or severity rates.

Moreover, some exposure to putative risk factors for MSDs is necessary for musculoskeletal health. Clinicians direct physical therapists to move joints through their ranges of motion in bedridden patients to prevent development of MSDs. Medical societies for sports medicine and arthritis advocate regular exercises at specific levels to stave off development or exacerbation of MSDs, arthritis and other musculoskeletal maladies. Ergonomists recommend appropriate workplace stretch and physical warmup exercises that present MSD risk factor exposures to reduce risk of MSDs. Some exposure to MSD risk factors is healthful if exposures are limited or not excessive.

This phenomenon is very similar to systemic physical workload. If workloads are reduced too much, the worker detrains and becomes less able to work. However, excessive physical workload results in performance-robbing fatigue, and if taken to extremes cardiopulmonary or thermoregulation system failures and death. Ergonomists are tasked with avoiding both extremes and with determining jointly optimal levels of effort from productivity and health and safety standpoints. Setting housekeeper workloads should be based upon ergonomic and industrial design principles.

7. Conclusions and Recommendations

All jobs present some degree of exposure to MSD risk factors. Housekeeping jobs are no exception. However, we found exposures were sufficiently low that the job was compliant with NIOSH guidelines for prevention of occupational musculoskeletal injuries and disorders.

Aside from exposure to safe levels of MSD risk factors, housekeeping activities and job design are strongly compliant with administrative controls for prevention of MSDs. Housekeepers perform a variety of different tasks that are short in duration (most less than 2 minutes) before moving onto different activity, and activities are peppered with micro-breaks[7].

Very low musculoskeletal injury incidence reported by the U.S. Department of Labor (DOL) supports our finding that MSD risk factor exposures were inadequate to present MSD or MSI hazard. Housekeeper musculoskeletal injury and illness incidence was comparable to jobs with nonoccupational background rates for MSD incidence.

Recommendations that MSD risk factor magnitudes be reduced below safe levels sounds helpful, but offers little hope to produce measurable improvement in housekeeper MSD incidence. If decisions are made to further reduce any MSD risk factor exposure in this job, it is recommended that such decisions be based upon opportunities for improved housekeeper performance or quality of work. This approach will provide cost recovery and allow investment of cost savings in other arenas of housekeeper health and safety.

Aerobic power demands of housekeeping jobs ranged between light and moderate levels of workload during the working shift. Heart rates showed that the shift's workload was less than one-third of the housekeeper's physical work capacity for an eight hour duration. This level of physical workload is compliant with extant ergonomic design guidelines (Chaffin et al., 2006). Any material increase in

7. Micro-breaks result when muscle groups are given short breaks between exertions that allow adequate perfusion of contracting tissues. The breaks permit adequate supply of nutrients and washout of metabolic end-products from working muscle. Changing arms when wiping surfaces, separating tasks with walks, rests arms, and so forth. Micro-breaks do not refer to periods where work is stopped and the worker sits down and rests.

workloads beyond current levels should be tested to confirm that aerobic power demands remain compliant with ergonomic design guidelines.

We did not measure available coefficients of friction. All housekeeper task required coefficients of friction did not exceed the design limit of 0.5. The vast majority of tasks yielded required coefficients of friction that were well below the hazard threshold.

Room layout and types and numbers of beds, as well as initial room tidiness, materially affected room refresh and checkout cleaning times. Any changes made to housekeeping tasks, tools, or paradigms from those studied here, should be evaluated using standard industrial engineering and ergonomics methods to determine their worthiness before implementation.

Housekeepers exhibited a very strong work ethic and commitment to the highest quality of cleanliness, appearance and efficiency. Housekeepers adopted use of rice paddles because they improved their efficiency, comfort and quality of bed making. Other tools studied either increased aerobic power demand, forced use of uncomfortable postures or excessive force, required more time to complete the task, compromised cleanliness, or produced some combination of these outcomes. As a result, while the hotel provided the aids to the housekeepers, they refused to adopt the tools tested save that of the rice paddles.

Hotel room designs and decor, not area, determine housekeeper workloads and musculoskeletal demands. Attempts to set production standards or restriction of workloads based solely upon the average size of a hotel room could produce large variations in housekeeper workloads and exposures to MSD risk factors. Workloads depend upon room and furniture layout, bathroom design, construction and decor materials, and other room features. Quotas for room cleaning should be based upon scientific and industrial engineering analysis of individual hotel designs to determine whether workloads fall within acceptable ergonomic and engineering design guidelines.

Hotel housekeepers tested and observed during these studies and evaluations showed very strong work ethos and commitment to the hotel's goal of providing very clean and inviting rooms. The hotel provided a number of untested aids to assist housekeepers in the performance of their job. Tools that demonstrated industrial engineering and ergonomics-related improvements in performance, comfort and quality of work were readily adopted. "Ergonomic" aids that created greater physical workloads, provoked uncomfortable working postures, required excessive force application, slowed room cleaning rates, or that compromised room cleanliness, were not adopted or used by housekeepers.

To the extent that hotel rooms, work assignments, and work methods match those of this study, one can use our evaluations of workloads, biomechanical stresses and risks of MSD development. If material differences exist in work assignments, room layout and design, production requirements, or introduction of ergonomic aids that were not addressed in this study, then comparisons should be avoided.

8. References

Åstrand, Per-Olof, and Kåre Rodahl. Textbook of Work Physiology: Physiological Bases of Exercise. New York: McGraw Hill, 1986.

Bernard, B. P. "Musculoskeletal Disorders and Workplace Factors: A Critical Review of Epidemiologic Evidence for Work-related Musculoskeletal Disorders of the Neck, Upper Extremity, and Low Back." Washington, DC: NIOSH, 1997.

BLS (2012) Nonfatal Occupational Injuries and Illnesses Requiring Days Away From Work. U.S. Department of Labor: USDL-12-2204.

Borg, G. (1983) A category-ratio perceived exertion scale: relationship to blood and muscle lactates and heart rate. Med. Sci. Sports Exerc.,15(6):523-528

Buchanan, S, Vossenas, P., Krause, N., Moriarty, J., Frumin, E., Shimek, J., Mirer, F., Orris, P. and Punnett, L. (2010) "Occupational Injury Disparities in the US Hotel Industry." American Journal of Industrial Medicine 53(2).

Chaffin, D. B., Andersson, G., & Martin, B. J. (2006). Occupational Biomechanics (pp. xv, 360). New York: Wiley-Interscience.

Ciriello, V. M., Snook, S. H., & Hughes, G. J. (1993). Further studies of psychophysically determined maximum acceptable weights and forces. Human Factors, 35(1), 175-86.

Freivalds, A., Chaffin, D. B., Garg, A., & Lee, K. S. (1984). A dynamic biomechanical evaluation of lifting maximum acceptable loads. Journal of Biomechanics, 17(4), 251-62.

Hennekens, C. H., Buring, J. E., & Mayrent, S. L. (1987). Epidemiology in Medicine (Vol. 515). Little Brown & Company.

Hernberg, S. (1992). Introduction to Occupational Epidemiology. CRC.

Jager, M., & Luttmann, A. (1989). Biomechanical analysis and assessment of lumbar stress during load lifting using a dynamic 19-segment human model. Ergonomics, 32(1), 93-112.

Kutner, M., Nachtsheim, C., Neter, J., and Li, W. (2004) Applied Linear Statistical Models. New York: Mc-Graw-Hill.

Konz, Stephan A, and Steven Johnson. Work Design: Industrial Ergonomics. Holcomb Hathaway, 2000.

Lee, K. S., Chaffin, D. B., Herrin, G. D., & Waikar, A. M. (1991). Effect of handle height on lower-back loading in cart pushing and pulling. Applied Ergonomics, 22(2), 117-23.

Marras, W. S., Allread, W. G., Burr, D. L., & Fathallah, F. A. (2000). Prospective validation of a low-back disorder risk model and assessment of ergonomic interventions associated with manual materials handling tasks. Ergonomics, 43(11), 1866-1886.

Marras, W. S., Lavender, S. A., Leurgans, S. E., Rajulu, S. L., Allread, W. G., Fathallah, F. A., & Ferguson, S. A. (1993). The role of dynamic three-dimensional trunk motion in occupationally-related low back disorders. The effects of workplace factors, trunk position, and trunk motion characteristics on risk of injury. Spine, 18(5), 617-28.

Milburn, P. D., & Barrett, R. S. (1999). Lumbosacral loads in bed making. Applied Ergonomics, 30(3), 263-73.

NIOSH. Work Practices Guide for Manual Lifting. Washington, D.C.,: GPO, 1981.

O'Sullivan, K., O'Sullivan, L., Campbell, A., O'Sullivan, P., & Dankaerts, W. (2012). Towards monitoring lumbo-pelvic posture in real-life situations: Concurrent validity of a novel posture monitor and a traditional laboratory-based motion analysis system. Manual Therapy, 17(1), 77-83.

O'Sullivan, K., Verschueren, S., Pans, S., Smets, D., Dekelver, K., & Dankaerts, W. (2012). Validation of a novel spinal posture monitor: Comparison with digital videofluoroscopy. European Spine Journal 21(12), 2633-9.

Pope, M. H., & Novotny, J. E. (1993). Spinal biomechanics. Journal of Biomechanical Engineering, 115(4B), 569-74.

Putz-Anderson, V. (1988). Cumulative Trauma Disorders: A manual for musculoskeletal diseases of the upper limbs. New York: Taylor and Francis.

Sachs, L., & Reynarowych, Z. (1984). Applied Statistics: A handbook of techniques. Springer-Verlag New York. Retrieved from Google Scholar.

Troup, J. D. (1978) "Driver's Back Pain and Its Prevention. A Review of the Postural, Vibratory and Muscular Factors, Together with the Problem of Transmitted Road-shock." Applied Ergonomics 9(4): 207-14.

Wasserman, N. J. W., & Kutner Michal, H. (1974). Applied Linear Statistical Models. New York: Irwin.

Waters, T. R., Putz-Anderson, V., Garg, A., & Fine, L. J. (1993). Revised NIOSH equation for the design and evaluation of manual lifting tasks. Ergonomics, 36(7): 749-76.

Wiker, S. F., and J. M. Miller. (1983) Acceleration Exposures in Forward Seating Areas of Bowrider Recreational Boats. Human Factors 25(3): 319-27.

Wiker, S. F., D B Chaffin, and G. D. Langolf (1989) Shoulder Posture and Localized Muscle Fatigue and Discomfort. Ergonomics 32(2): 211-37.

Wiker, S. F. (2011) Evaluation of Hotel Housekeeper Physical Workload and Overexertion Injury Risk Reduction Proffered by Use of Fitted Bottom Sheets for Hotel Bed Making. Report No. 1-2011 Ergonomic Design Institute, Seattle, WA.

Wiker, S. F. (2012) Ergonomic design and overexertion injury risk. In Li, G. and Baker, S. (Eds.) Injury Research: Theories, Methods and Approaches. New York: Springer.

Wiker, S. F. (2012) Promoting Safety Through Effective Application of Human Factors Engineering, in Haight, J. (Ed.) Safety Professional's Handbook. Second Ed. Des Plaines: American Society of Safety Engineers.