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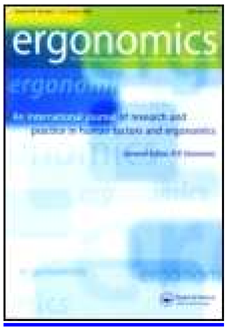

Don B. Chaffin. *The evolving role of biomechanics in prevention of overexertion injuries*. S. 3–14.

This paper describes occupational biomechanics as an evolving body of knowledge that has required not only a sophisticated development of fundamental biomechanical principles and human failure data, but also has required epidemiological information to enable a more complete understanding of how certain types of musculoskeletal injuries can be caused by specific physical work requirements. It also is argued that even with adequate biomechanical and epidemiological information, the ability to change working conditions and manual task requirements in companies required management and workers to become organised into formal ergonomics teams that could be trained and empowered to reduce the known biomechanical risk factors present in various jobs. It is demonstrated that in the last 35 years occupational biomechanics research continues to provide the intellectual machine that is driving the development of important ergonomics guidelines. Despite these successes, however, some major limitations in contemporary biomechanics knowledge are discussed, particularly related to situations where high-speed motions and repetitions are involved. Finally, the evolving importance and limitations in occupational biomechanical simulation models for proactive ergonomics are presented.

- **Keywords:** occupational biomechanics; musculoskeletal injury; digital human models

Amrish O. Chourasia; Mary E. Sesto; Walter F. Block; Robert G. Radwin. *Prolonged mechanical and physiological changes in the upper extremity following short-term simulated power hand tool use*. S. 15–24.

This study investigated in-vivo changes in upper limb dynamic mechanical properties and magnetic resonance imaging (MRI) parameters following short-term power hand tool operation. Previous studies have found reduction in mechanical properties following short-term power tool usage at long build-up times. This study advances that work by having participants operate a simulated pistol grip power hand tool and evaluating changes in mechanical properties, strength, discomfort level and MRI prior to tool operation and daily for 3 d after tool operation. Twenty-four participants were randomly assigned to operate a simulated power hand tool for either a high peak reaction force of 123 N (peak torque = 8 Nm, build-up time = 250 ms) or at a low peak reaction force of 5 N (peak torque = 2 Nm, build-up time = 50 ms). Subjects operated the tool for 60 min at the rate of six times per min. A reduction in stiffness (27%, $p < 0.05$) was observed

24 h after tool operation for the high force group and this change persisted (26%, $p < 0.05$) up to 72 h after tool operation. Similar changes were not observed for the low force group. No changes were observed in mass moment of inertia, damping, isometric strength and damping for either group ($p > 0.05$). There was a signal intensity increase (12%, CI 19%, 5.06%) in the supinator muscle MRI for both groups 24 h after tool operation but only the high force group remained elevated (10%, CI 13.7%, 0.06%) 72 h after tool operation. Persistent short-term changes in mechanical and MRI parameters at high force levels could indicate increased strain on the upper limb and may negatively affect ability to react during rapid forceful loading of the upper limb. This research can ultimately lead to better ergonomic interventions through quantitative power hand tool design guidelines and work practices based on understanding the damaging effects of exposure to specific levels of reaction force, build-up time and repetition, as well as providing new outcome measures for epidemiological studies.

- **Keywords:** power hand tool; mechanical parameters; eccentric exertions; oedema

Steven L. Fischer; Richard P. Wells; Clark R. Dickerson. *The effect of added degrees of freedom and handle type on upper limb muscle activity during simulated hand tool use*. S. 25–35.

The human upper limb serves a number of functions ranging from coarse movements such as supporting a load when lifting overhead to the fine motor control required when painting a portrait. However, there are limited data available that address upper extremity function and performance when using hand tools in situations where the tool endpoint is not fixed but can move translationally or rotationally. The goal of this study was to examine variation in arm muscle activity when added degrees of freedom (DOF) were introduced through the use of a force application apparatus with two different handle designs (D-handle or screwdriver). Electromyography of seven forearm muscles and five muscles crossing the shoulder joint were measured to determine relative activity from a reference (0 DOF), most stable condition, to combinations of DOF ranging from 1 to 4. Substantial and statistically significant increases in muscle activity resulted from adding DOF. The screwdriver handle increased forearm muscle activity compared to the D-handle, except in the highest DOF condition. These findings have significance in the planning of work and design of tools because of the potential for increased fatigue that accompanies increased DOF at the tool endpoint. Handle type also influenced the magnitude of the muscular activity.

- **Keywords:** upper limb; electromyography; tool handle; interface stability; fatigue

Arun Garg; Jay M. Kapellusch. *Applications of biomechanics for prevention of work-related musculoskeletal disorders*. S. 36–59.

This paper summarises applications of biomechanical principles and models in industry to control musculoskeletal disorders of the low back and upper extremity. Applications of 2-D and 3-D biomechanical models to estimate compressive force on the low back, the strength requirements of jobs, application of guidelines for overhead work and application of strain index and threshold limit value to address distal upper extremity musculoskeletal disorders are presented. Several case studies applied in the railroad industry, manufacturing, healthcare and warehousing are presented. Finally, future developments needed for improved biomechanical applications in industry are discussed. The information presented will be of value to practising ergonomists to recognise how biomechanics has played a significant role in identifying causes of musculoskeletal disorders and controlling them in the workplace. In particular, the information presented will help practising ergonomists with how physical stresses can be objectively quantified.

- **Keywords:** compressive force; physical strength; biomechanical applications; distal upper extremity job analysis; overhead work

Gregory G. Knapik; William S. Nadras. *Spine loading at different lumbar levels during pushing and pulling*. S. 60–70.

As the nature of many materials handling tasks have begun to change from lifting to pushing and pulling, it is important that one understands the biomechanical nature of the risk to which the lumbar spine is exposed. Most previous assessments of push-pull tasks have employed models that may not be sensitive enough to consider the effects of the antagonistic cocontraction occurring during complex pushing and pulling motions in understanding the risk to the spine and the few that have considered the impact of cocontraction only consider spine load at one lumbar level. This study used an electromyography-assisted biomechanical model sensitive to complex motions to assess spine loadings throughout the lumbar spine as 10 males and 10 females pushed and pulled loads at three different handle heights and of three different load magnitudes. Pulling induced greater spine compressive loads than pushing, whereas the reverse was true for shear loads at the different lumbar levels. The results indicate that, under these conditions, anterior-posterior (A/P) shear loads were of sufficient magnitude to be of concern especially at the upper lumbar levels. Pushing and pulling loads equivalent to 20% of body weight appeared to be the limit of acceptable exertions, while pulling at low and medium handle heights (50% and 65% of stature) minimised A/P shear. These findings provide insight to the nature of spine loads and their potential risk to the low back during modern exertions.

- **Keywords:** spinal loading; electromyography; push and pull; biomechanical modelling

S. A. Lavender; Y. C. Li; R. N. Natarajan; G. B. J. Anderson. *Does the asymmetry multiplier in the 1991 NIOSH lifting equation adequately control the biomechanical loading of the spine?* S. 71–79.

The aim of this research was to evaluate whether the asymmetry multiplier incorporated in the 1991 National Institute for Occupational Safety and Health lifting equation adequately controls the biomechanical spine loads during asymmetric lifting. Sixteen male subjects lifted a box from four initial locations varying in terms of the angular deviation from the mid-sagittal plane (0, 30, 60 and 90°). From each location, boxes that weighed the recommended weight limit (RWL) and three times the RWL were lifted at two qualitatively defined lifting speeds. Ground reaction forces were combined with kinematic data in a linked-segment model to quantify the 3-D moments at the base of the spine (L5/S1) and the spine compression forces. The results show that the twisting and lateral bending moments increased with task asymmetry despite the lessening of the RWL ($p < 0.01$). The flexion moment and the spine compression decreased with asymmetry, although at a slower rate than the RWL. When the dynamics were removed from the linked segment spine model to approximate the assumption of slow and smooth lifting, the estimated compression remained approximately 3400 N across all asymmetry conditions. Thus, the reduction in the RWL due to asymmetry multiplier appears appropriate and should not be changed, as been suggested by recent psychophysical studies.

- **Keywords:** manual materials handling; NIOSH lifting equation; lifting; spine biomechanics

Stuart M. McGill. *Evolving ergonomics?* S. 80–86.

The theme developed in this position paper follows the current evolution of injury prevention in the backs of workers. Job change or 'fitting the task to the person' has come far, but will probably not result in zero injury rates. This is because the cause of injury is heavily influenced by the way that a worker moves. A review of injury mechanisms reveals the need for the biomechanist/ergonomist to incorporate features in biomechanical models that recognise these injury mechanisms. The implication of one such model is that the next leap toward a zero injury rate may be approached with 'fitting the person to the task' or at least retraining the way that workers move. A few examples of movement-based back injury prevention strategies are provided. Finally, some thoughts on implementing such an approach are expressed. This is a review and position paper written in honour of Professor Don Chaffin's career.

- **Keywords:** worker training; back injury; ergonomics; biomechanics

Maury A. Nussbaum; John P. Shewchuk; Sunwook Kim; Hyang Seol; Cheng Guo. *Development of a decision support system for residential construction using panellised walls: Approach and preliminary results*. S. 87–103.

There is a high prevalence of work-related musculoskeletal disorders (WMSDs) among residential construction workers, yet control in this industry can be difficult for a number of reasons. A decision support system (DSS) is described here to allow early assessment of both ergonomic and productivity concerns, specifically by designers. Construction using prefabricated walls (panels) is the focus of current DSS development and is based conceptually on an existing 'Safety in Construction Design' model. A stepwise description of the development process is provided, including input from end users, taxonomy development and task analysis, construction worker input, detailed laboratory-based simulations and modelling/solution approaches and implementation. Preliminary results are presented for several steps. These results suggest that construction activities using panels can be efficiently represented, that some of these activities involve exposure to high levels of WMSD risk and that several assumptions are required to allow for ease of mathematical and computational implementation of the DSS. Successful development of such tools, which allow for proactive control of exposures, is argued as having substantial potential benefit.

- **Keywords:** residential construction; ergonomics; task analysis; risk assessment; prevention through design

David Rempel; Dan Nathan-Roberts; Bing Yune Chen; Dan Odell. *The effects of split keyboard geometry on upper body postures*. S. 104–111.

Split, gabled keyboard designs can prevent or improve upper extremity pain among computer users; the mechanism appears to involve the reduction of awkward wrist and forearm postures. This study evaluated the effects of changes in opening angle, slope and height (independent variables) of a gabled (14°) keyboard on typing performance and upper extremity postures. Twenty-four experienced touch typists typed on seven keyboard conditions while typing speed and right and left wrist extension, ulnar deviation, forearm pronation and elbow position were measured using a motion tracking system. The lower keyboard height led to a lower elbow height (i.e. less shoulder elevation) and less wrist ulnar deviation and forearm pronation. Keyboard slope and opening angle had mixed effects on wrist extension and ulnar deviation, forearm pronation and elbow height and separation. The findings suggest that in order to optimise wrist, forearm and upper arm postures on a split, gabled keyboard, the keyboard should be set to the lowest height of the two heights tested. Keyboard slopes in the mid-range of those tested, 0° to -4°, provided the least wrist extension, forearm pronation and the lowest elbow height. A keyboard opening angle in the mid-range of those tested, 15°, may provide the best balance between reducing ulnar deviation while not increasing forearm pronation or elbow separation. These findings may be useful in the design of computer workstations and split keyboards. The geometry of a split keyboard can influence wrist and forearm postures. The findings of this study are relevant to the positioning and adjustment of split keyboards. The findings will also be useful for engineers who design split keyboards.

- **Keywords:** keyboard design; input device design; upper extremity posture

Martin S. Rice; Sandra M. Woolley; Thomas R. Waters. *Comparison of required operating forces between floor-based and overhead-mounted patient lifting devices*. S. 112–120.

This study investigated the differences in required push, pull and rotating forces for moving fully loaded, floor-based and overhead-mounted full body patient lifting devices with simulated patients of varying weight on a floor of optimal design (i.e. level vinyl tile over concrete). A single person operated the lifting devices for all of the tests. Eighteen male and female volunteer participants, ranging in weight from 51 to 146 kg, acted as patients during the lifting tests. For each test, the simulated patients were pushed and pulled for 3.7 linear metres and were rotated while sitting in the lift slings. Force measurements were acquired using two single axis dynamometers affixed to the lifting devices. Results revealed that, in general, operator input force and torque increased with patient weight category and floor-based lifts required greater force and torque compared to the overhead-mounted lift. Comparison of the required forces with published force limits reveals that the required push and pull force from the various patient lift systems, across all weight categories, were generally acceptable to 90% of the female population. The required forces for these patient transfer tasks, however, could exceed maximum acceptable force limits if the floor surfaces were less than ideal, such as floors composed of carpet, wood, or inclined surfaces. Additional research is needed to assess these conditions. The findings and conclusions in this report are those of the author(s) and do not necessarily represent the views of the National Institute for Occupational Safety and Health.

- **Keywords:** back injury; patient lifts; patient handling; patient lifting devices

Na Jin Seo; Thomas J. Armstrong; Philip Drinkaus. *A comparison of two methods of measuring static coefficient of friction at low normal forces : a pilot study*. S. 121–135.

This study compares two methods for estimating static friction coefficients for skin. In the first method, referred to as the 'tilt method', a hand supporting a flat object is tilted until the object slides. The friction coefficient is estimated as the tangent of the angle of the object at the slip. The second method estimates the friction coefficient as the pull force required to begin moving a flat object over the surface of the hand, divided by object weight. Both methods were used to estimate friction coefficients for 12 subjects and three materials (cardboard, aluminium, rubber) against a flat hand and against fingertips. No differences in static friction coefficients were found between the two methods, except for that of rubber, where friction coefficient was 11% greater for the tilt method. As with previous studies, the friction coefficients varied with contact force and contact area. Static friction coefficient data are needed for analysis and design of objects that are grasped or manipulated with the hand. The tilt method described in this study can easily be used by ergonomic practitioners to estimate static friction coefficients in the field in a timely manner.

- **Keywords:** skin friction; hand friction; friction measurement; hand; coefficient of friction