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Albert P. C. Chan, Y. P. Guo, Francis K. W. Wong, Y. Li, S. Sun & X. Han. *The development of anti-heat stress clothing for construction workers in hot and humid weather.* Pages 479-495.

The purpose of this study was to develop anti-heat stress clothing for construction workers in hot and humid weather. Following DeJonge's functional clothing design process, the design situation was explored, including clothing fabric heat/moisture transporting properties and UV protection and the aspects of clothing ergonomic design (mobility, convenience, and safety). The problem structure was derived from the results of the surveys in three local construction sites, which agreed well with the task requirements and observations. Specifications were consequently described and 30 commercially available fabrics were identified and tested. Fabric testing data and design considerations were inputted in S-smart system to predict the thermal functional performance of the clothing. A new uniform prototype was developed and evaluated. The results of all measurements suggest that the new uniform which incorporated fabrics with superior heat/moisture transporting properties and loose-fitting design could reduce the workers' heat stress and improve their comfort and work performance. **Practitioner Summary:** The construction workers' uniform currently used in Hong Kong during summer was unsatisfactory. Following DeJonge's functional clothing design process, an anti-heat stress uniform was developed by testing 30 fabrics and predicting clothing thermal functional performance using S-smart system. The new uniform could reduce the workers' heat stress and improve their comfort and work performance.

- **Keywords:** Construction workers, hot and humid weather, anti-heat stress clothing, functional clothing design process, strategy for design situation

Siyeon Kim & Joo-Young Lee. *Skin sites to predict deep-body temperature while wearing firefighters' personal protective equipment during periodical changes in air temperature.* Pages 496-503.

The aim of this study was to investigate stable and valid measurement sites of skin temperatures as a non-invasive variable to predict deep-body temperature while wearing firefighters' personal protective equipment (PPE) during air temperature changes. Eight male firefighters participated in an experiment which consisted of 60-min exercise and

10-min recovery while wearing PPE without self-contained breathing apparatus (7.75 kg in total PPE mass). Air temperature was periodically fluctuated from 29.5 to 35.5 °C with an amplitude of 6 °C. Rectal temperature was chosen as a deep-body temperature, and 12 skin temperatures were recorded. The results showed that the forehead and chest were identified as the most valid sites to predict rectal temperature ($R^2 = 0.826$ and 0.824 , respectively) in an environment with periodically fluctuated air temperatures. This study suggests that particular skin temperatures are valid as a non-invasive variable when predicting rectal temperature of an individual wearing PPE in changing ambient temperatures. **Practitioner Summary:** This study should offer assistance for developing a more reliable indirect indicating system of individual heat strain for firefighters in real time, which can be used practically as a precaution of firefighters' heat-related illness and utilised along with physiological monitoring.

- **Keywords:** Firefighters, personal protective equipment (PPE), heat strain, prediction, skin temperature, deep-body temperature

Liz de Rome, Elizabeth A. Taylor, Rodney J. Croft, Julie Brown, Michael Fitzharris & Nigel A. S. Taylor. *Thermal and cardiovascular strain imposed by motorcycle protective clothing under Australian summer conditions.* Pages 504-513.

Motorcycle protective clothing can be uncomfortably hot during summer, and this experiment was designed to evaluate the physiological significance of that burden. Twelve males participated in four, 90-min trials (cycling 30 W) across three environments (25, 30, 35 °C [all 40% relative humidity]). Clothing was modified between full and minimal injury protection. Both ensembles were tested at 25 °C, with only the more protective ensemble investigated at 30 and 35 °C. At 35 °C, auditory canal temperature rose at 0.02 °C min^{-1} (SD 0.005), deviating from all other trials ($p < 0.05$). The thresholds for moderate ($>38.5\text{ °C}$) and profound hyperthermia ($>40.0\text{ °C}$) were predicted to occur within 105 min (SD 20.6) and 180 min (SD 33.0), respectively. Profound hyperthermia might eventuate in ~ 10 h at 30 °C, but should not occur at 25 °C. These outcomes demonstrate a need to enhance the heat dissipation capabilities of motorcycle clothing designed for summer use in hot climates, but without compromising impact protection. **Practitioner's Summary:** Motorcycle protective clothing can be uncomfortably hot during summer. This experiment was designed to evaluate the physiological significance of this burden across climatic states. In the heat, moderate ($>38.5\text{ °C}$) and profound hyperthermia ($>40.0\text{ °C}$) were predicted to occur within 105 and 180 min, respectively.

- **Keywords:** Core temperature, heat loss, heat strain, metabolic heat production, motorcycle clothing, protective clothing, protective equipment

Sohini Paul, Debojyoti Bhattacharyya, Tirthankar Chatterjee & Dhurjati Majumdar. *Effect of uphill walking with varying grade and speed during load carriage on muscle activity.* Pages 514-525.

Indian soldiers, while guarding the mountainous border areas, often carry loads in steep uphill gradients. This activity may predispose the risk of muscle injury. The present study aimed to examine the effects of an increasing load, speed and gradient during incremental uphill treadmill walking on different muscles. Twelve infantry soldiers walked on a treadmill at two speeds (2.5 and 4 km/h) with no load, and carrying 10.7, 17 and 21.4 kg loads at 0, 5, 10, 15, 20, 25% gradients. Electromyographic responses of erector spinae ($>240\%$) and vastus medialis ($>240\%$) were mostly affected, followed by soleus ($>125\%$) and gastrocnemius medialis ($>100\%$) at maximum speed, load and gradient combination compared to 0% gradient. Carrying 10.7 kg at 15% gradient and above was found to be highly strenuous and fatiguing with the risk of muscle injury. Uphill load

carriage in slower speed is recommended for the maintenance of combat fitness of the individual at higher gradients. **Practitioner Summary:** The present article has evaluated the stress encountered by soldiers during load carriage at incremental uphill gradients while walking at different speeds by recording the muscular activities. Load carriage in steep uphill gradients is highly strenuous and may lead to muscle injury thus compromising the combat fitness

- **Keywords:** Military load carriage, uphill walking, electromyography, muscle injury

Calvin Or, Jia-Hua Lin, Hailiang Wang & Raymond W. McGorry. Normative data on the one-handed static pull strength of a Chinese population and a comparison with American data. Pages 526-533.

We assess the one-handed static pull strength of a Chinese population and compare it to that of an American sample. Fifty men and 50 women in five age groups were asked to exert their maximum one-handed pull strength in three pulling directions (across, front and side) and from four pulling heights (61 cm, 76 cm, waist height and above-shoulder height). The results showed that women had less pull strength than men under all of the conditions tested. The front and side pulling resulted in the greatest pull strength, with a decrease detected when the pulling height was increased. The American sample exhibited greater strength than the Chinese. Body mass and men's handgrip force were also associated with the pull strength. These variables should be taken into account in the development of tasks related to one-handed pulling. **Practitioner summary:** In this paper, we report a laboratory-based experiment conducted to assess the one-handed static pull strength of a Chinese population and compare the results with those of an American population. The variables associated with pull strength included gender, pulling direction, pulling height, race, body mass and men's handgrip force.

- **Keywords:** One-handed pull strength, Chinese, pulling direction, pulling height

Amy Y. Chow & Clark R. Dickerson. Determinants and magnitudes of manual force strengths and joint moments during two-handed standing maximal horizontal pushing and pulling. Pages 534-544.

Pushing and pulling are common occupational exertions that are increasingly associated with musculoskeletal complaints. This study focuses on the sensitivity of shoulder capacity to gender, handle height, exertion type (push or pull) and handle orientation for these tasks. All factors except for handle orientation influenced unilateral and total manual force strength ($p < 0.01$), with exertion type being the most influential. Interaction effects also existed between handle height and exertion type. Additionally, joint moments at the shoulders and low back were influenced by all factors studied ($p < 0.01$), with exertion type again being most influential. Knowledge of the relative influence of multiple factors on shoulder capacity can provide guidance regarding these factors when designing or evaluating occupational pushing and pulling tasks for a diverse population. **Practitioner Summary:** pushing and pulling comprise nearly half of all manual materials handling tasks. Practitioners often assess, design or modify these tasks while incorporating constraints, including manual force direction and handle interface. This study provides guidance to aid design of pushing and pulling tasks in the context of shoulder physical capacity.

- **Keywords:** Pushing, pulling, manual force strength, joint moments

Samuel J. Howarth, Diane E. Grondin, Nicholas J. La Delfa, Jocelyn Cox & Jim R. Potvin. Working position influences the biomechanical demands on the lower back during dental hygiene. Pages 545-555.

This investigation monitored the biomechanical demands on the lower back during simulated dental hygiene work. A total of 19 female, registered dental hygienists performed 30 continuous minutes of manual scaling (plaque removal) of a manikin's teeth while seated. We monitored the working location and orientation of the dental hygienists, with respect to the manikin, along with their spine kinematics, spine extensor muscle activities and seat pressure, throughout the 30 min. A clock representation was used to express the working location. The location significantly influenced the dental hygienists' pelvic orientation with respect to the manikin, spine posture, erector muscle activity and pressure distribution. Findings from this study suggest that the prevalence of lower back pain amongst dental hygienists may be directly related to low-level tonic activity of the spine's extensor musculature, and the combined flexed and axially rotated spine postures. **Practitioner Summary:** Low back pain (LBP) is prevalent in dental hygienists, yet occupational demand on the low back has not been investigated. Posture, muscle activity and seat pressure were monitored. Combined spine rotation and flexion, and tonic activity of the extensor musculature may be related to LBP in dental hygienists.

- **Keywords:** Spine posture, electromyography, lower back pain, injury, sitting

Lingling Hu, Bob Tackett, Onder Tor & Jilei Zhang. *Analysis of sitting forces on stationary chairs for daily activities.* Pages 556-567.

No literature related to the study of sitting forces on chairs sat on by people who weighed over 136 kg was found. The Business Institutional Furniture Manufacturers Association needs force data for development of performance test standards to test chairs for users who weigh up to 181 kg. 20 participants who weighed from 136 to 186 kg completed 6 tasks on an instrumented chair in the sequence of sitting down, remaining seated and rising. Effects of sitting motion, armrest use and seat cushion thickness on vertical sitting forces and centre-of-force were investigated. Results indicated hard sitting down yielded the highest sitting force of 213% in terms of participants' body weights. Armrest use affected sitting forces of normal sitting down, but not of rising and hard sitting down. Cushion thickness affected sitting forces of normal and hard sitting down and shifting, but not of rising, static seating or stretching backward situations. **Practitioner Summary:** Results of the sitting force and centre-of-force data obtained for this research can help furniture manufacturers develop new product performance test standards for creating reliable engineering design and manufacturing quality and durable products to meet a niche market need.

- **Keywords:** Sitting force, body weight, centre-of-force, stationary chair

Jonathan DeShaw & Salam Rahmatalla. *Predictive discomfort of supine humans in whole-body vibration and shock environments.* Pages 568-581.

This work presents a predictive model to evaluate discomfort associated with supine humans during transportation, where whole-body vibration and repeated shock are predominant. The proposed model consists of two parts: (i) static discomfort resulting from body posture, joint limits and ambient discomfort; and (ii) dynamic discomfort resulting from the relative motion between the body segments as a result of transmitted vibration. Twelve supine subjects were exposed to single and 3D random vibrations and 3D shocks mixed with vibrations. The subjects' reported discomfort and biodynamic response were analysed under different support conditions, including a rigid surface, a stretcher and a stretcher with a spinal backboard. The results demonstrated good correlations between the predictive discomfort and the reported discomfort for the different conditions under consideration, with $R^2 = 0.69-0.94$ for individual subjects and $R^2 = 0.94$ for the group mean. The results also indicated a strong relationship between the head-neck and trunk angular velocities and discomfort during supine transportation. **Practitioner Summary:** The quantification of discomfort of supine humans under

vibration and shocks by using a predictive model is an important contribution to this field, whereby the efficacy of different transport systems can be compared. The predictive discomfort model can be used as design criteria for ergonomic enhancement in supine transportation of humans.

- **Keywords:** Transportation, stretcher, spinal backboard, discomfort model

Daniel Jinzhao Chen, Beisheng Bao, Yue Zhao & Richard H. Y. So. *Visually induced motion sickness when viewing visual oscillations of different frequencies along the fore-and-aft axis: keeping velocity versus amplitude constant.* Pages 582-590.

Exposure to visual oscillations (VOs) can lead to visually induced motion sickness (VIMS). The level of VIMS among viewers has been shown to vary when the frequency of the VOs is changed either by manipulating their amplitude or velocity. The present study investigates whether the level of VIMS would change if we keep the root mean square (rms) velocity or amplitude of VOs constant while manipulating the VO frequency. A total of 25 individuals were exposed to random-dot and checkerboard VOs along the fore-and-aft axis in two experiments. Changing the amplitude (or frequency) of VOs while keeping the rms velocity constant did not affect the level of VIMS; however, increasing the rms velocity (or frequency) of VOs while keeping the amplitude constant made VIMS significantly worse. **Practitioner Summary:** Exposure to VOs of the same frequency can cause different levels of nausea depending on the combination of oscillation amplitude and velocity. Results suggest an opportunity for game designers to reduce symptoms of game sickness by using the correct combinations of velocity and amplitude of the visual motions.

- **Keywords:** Visually induced motion sickness, visual oscillations, frequency responses, control of velocity and amplitude, fore-and-aft axis

Mark C. Schall Jr., Nathan B. Fethke, Howard Chen, Sakiko Oyama & David I. Douphrate. *Accuracy and repeatability of an inertial measurement unit system for field-based occupational studies.* Pages 591-602.

The accuracy and repeatability of an inertial measurement unit (IMU) system for directly measuring trunk angular displacement and upper arm elevation were evaluated over eight hours (i) in comparison to a gold standard, optical motion capture (OMC) system in a laboratory setting, and (ii) during a field-based assessment of dairy parlour work. Sample-to-sample root mean square differences between the IMU and OMC system ranged from 4.1° to 6.6° for the trunk and 7.2°–12.1° for the upper arm depending on the processing method. Estimates of mean angular displacement and angular displacement variation (difference between the 90th and 10th percentiles of angular displacement) were observed to change <4.5° on average in the laboratory and <1.5° on average in the field per eight hours of data collection. Results suggest the IMU system may serve as an acceptable instrument for directly measuring trunk and upper arm postures in field-based occupational exposure assessment studies with long sampling durations. **Practitioner Summary:** Few studies have evaluated inertial measurement unit (IMU) systems in the field or over long sampling durations. Results of this study indicate that the IMU system evaluated has reasonably good accuracy and repeatability for use in a field setting over a long sampling duration.

- **Keywords:** Ergonomics tools and methods, musculoskeletal disorders, agriculture ergonomics, back pain, upper limb disorders

Okey Francis Obi. *Hand anthropometry survey of rural farm workers in south-eastern Nigeria. Pages 603-611.*

The importance of hand anthropometry as it relates to design of hand tools particularly for farm workers have been established; however, anthropometric data for this group of agricultural workers have continued to remain scarce. A survey of hand anthropometry relevant in design of agricultural hand tools was carried out on 200 male and 100 female adult farm workers in south-eastern Nigeria. Comparison of the male and female data obtained showed that male dimensions were higher than that recorded for the females. The hand anthropometric data of the male and female farm workers were compared with that of other populations but no clear distinction was observed. It was however clear that the following hand dimensions, 2nd Joint to root digit 3 and width at tip digit 3 recorded for Nigerian farm workers were highest and lowest, respectively, compared to other populations. **Practitioner Summary:** Hand anthropometric data relevant in design of hand tools have continued to remain scarce particularly for farm workers. Hand anthropometry survey of farm workers carried out in south-eastern Nigeria revealed higher dimensions for males than females; however, no clear distinction was observed in comparison with other populations.

- **Keywords:** Hand anthropometry, ergonomic, farm worker, Nigeria