Modeling in manual materials handling

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Manual materials handling (MMH) account for approximately $15.0 billion of injuries cost in the United States alone. Because of the need to establish manual handling guidelines, different approaches to achieve this goal were pursued. Such approaches are based on biomechanics, work physiology, and psychophysics. In order to better understand the MMH system's behavior, models were developed. These models can be divided into biomechanical models, physiological models, psychophysically based capacity models, safe load handling models, and simulation models. This paper will present a sample of these models and discusses their advantages and disadvantages.

A variety of occupational groups are exposed to manual materials handling (MMH) stresses, and consequently a variety of industries have significant overexertion injury claims (AYOUB et al., 1986). A generally accepted means of minimizing MMH-related injuries is to design MMH tasks such that the demands of these tasks are within the corresponding capacities of the workers (LILES et al., 1983).

For the measurement of safe and permissible lifting loads, past research has focused on three criteria, the maximum compressive force on the spine, the maximum permissible energy expenditure, and the perceived exertion using psychophysical techniques.

This paper focuses on these three approaches using the three criteria, namely
the biomechanical, physiological, and psychophysical approaches and the models developed using data generated by each of these three approaches.

1. Manual materials handling stresses

When applying the stress/strain concept to MMH, three approaches are used: biomechanical, physiological and psychophysical. The biomechanical approach focuses on the musculoskeletal system. The physiological approach, focuses on the human body's metabolic response. The psychophysical approach differs from these two; it relies on perceived exertion to determine lifting capacity. The following sections discuss each of the approaches in more detail.

2. The biomechanical approach

Biomechanically, safe lifting loads depend on several parameters: 1) ability of the muscles to develop the necessary tension, 2) maintain body balance and 3) compressive and shear forces on the spine are not high enough to cause damage.

Biomechanical models serve as a representation using some simplifications and assumptions. These models make it possible to gain further insight into how components of the system function and how they are coordinated to achieve certain outcomes. In manual lifting, biomechanical modeling has been used to predict potentially hazardous loading conditions and safe load limits.

1) Biomechanical models. Several two and three-dimensional static and dynamic models have been developed to determine stresses on the spine from manual handling tasks. These models include GARG and CHAFFIN (1975), SCHULTZ et al. (1982), JAGER (1987), AYOUB and EL-BASSOSSI (1978), LESKINEN et al. (1983), CHEN and AYOUB (1988), and KROMODIHARDJO and MITAL (1986).

Static models ignore the effects of inertia. This can seriously affect the estimated compression on the spine (DANZ and AYOUB, 1992; KIM, 1990).

2) Biomechanical simulation modeling. Simulation modeling is based on the assumption that the body performs a physically demanding task such that the total muscular effort is minimized. Results based on this approach have been reported by LEE (1988) and HSIANG (1992). Their results show that for sagittal lifting activities, such simulation models are useful for predicting the lifting motion pattern.

3. The physiological approach

In contrast to the biomechanical approach, which is applicable to occasional lifting, the physiological approach is applicable for light loads at a relatively high frequency of handling (KIM, 1990; AYOUB and MITAL, 1989). Energy expenditure and heart rate are used extensively as reliable physiological responses to the workload (ASTRAND and RODAHL, 1977).

Physiological models. Several models were developed to estimate energy expenditure for manual lifting. These models were also used to determine acceptable loads. Four different models will be briefly presented. These are FREDRICK

In comparing these models, it can be stated that each model has advantages and disadvantages. Fredrick's model is simple and relatively easy to use, but covers only limited ranges of lift. The model by Garg applies to both genders, stoop, squat and arm lifts, but it relies on the assumption of additivity to estimate the energy for higher levels of lift. Asfour's model, on the other hand, involves several variables which makes it more difficult to use, but it includes container size and angle of twist as variables. Asfour's model is also limited in the lifting ranges.

Kim's model is less complicated than Garg's model or Asfour's model, but it does not include container size and angle of twist as variables. Physiological models apply only at higher frequencies of lift (6 lifts/min or higher). At lower frequencies, errors can be as high as 200% in estimating acceptable loads.

4. Psychophysical approach

Psychophysics deal with the relationship between human sensations and their physical stimuli. Stevens (1975) found that the perception of both muscular effort and force obey the psychophysical function where the sensation magnitude $S$ grows as a powers function of the stimulus $I$.

The use of psychophysics in the study of lifting tasks requires a subject to adjust the weight of load according to his or her own perception of effort such that repetitive lifting tasks do not result in overexertion or excessive fatigue.

The final weight selected by the subject is considered to be the maximum acceptable weight of lift for the given job conditions (frequency of lift, range of lift, container size, etc.).

Psychophysical models. Several lifting capacity prediction models using the psychophysical approach have been developed in the past. These were integrated into a single model by Aghazadeh (1974). These models used operator and task variables as independent variables. More recent models were developed by Ayoub et al. (1978) and Mittal and Ayoub (1980).

5. Comparison of the three approaches

There are some disagreements among the three approaches as reported by Garg and Herrin (1979). They pointed that there are some trade-offs between the biomechanical approach and the physiological approach. The biomechanical approach tends to minimize the load by using smaller more frequent lifts while the physiological approach tends to permit larger weights at lower frequencies.

For infrequent lifting, the maximum acceptable weights of load based on the biomechanical approach are generally higher than those based on the psychophysical approach. At the same time, for highly repetitive lifting, the maximum acceptable weights based on the psychophysical approach are lower at low lifting
frequencies and are higher at high frequencies than those based on the physiological approach (KARWOWSKI, 1982).

REFERENCES


Work-related musculoskeletal problems: Some ergonomic considerations

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Musculoskeletal disorders (MSD) in industrialized and industrializing countries are situated and discussed. Considerations are made on the registration of MSD cases, on the consequences for humans, industry and society, on scientific methodology and prevention strategies. These considerations are used to develop proposals for future actions. These concern the development of structures, some ideas about training and education as well as a common method for applied field research enabling the use of data in all industries.

One of the most important issues ergonomists face almost daily is musculoskeletal problems. Though these problems have been known for many years, it is only in the 1970s and 1980s that the impact on the socio-economic system came into focus. In the same period, in industrialized countries occupational illness, and thus also musculoskeletal disorders (MSD), has been accepted as a social problem.

This recognition is the product of the awareness and conviction that occupational injuries and illness are not random and that they are unavoidable by-products of work (Putz-Anderson, 1994). For reasons of humanization and in order to reduce the economic consequences, preventive actions have to be developed which requires knowledge about existing risks and the predictive relationship between causes and effects.

Risk management and prevention policies have been developed since, mostly focussing on the problems which showed clear evidence: occupational diseases and labour accidents. Because of the direct link between effects and cause, prevention strategies were initially related to reduce injuries and damages with almost immediate and successful results by implementing individual and collective protection. However, after a successful period of action, new hazards and new types of injuries (e.g. MSD) arose from the evolution in working systems (from manual work to mechanisation and automation), the consequences of which were not so obvious and immediate as it was before.

The nature and the genesis of musculoskeletal injuries show a slow grow with an evidence only observable after longer periods of exposure.
In spite of the bulk of studies and research programs realized in the last decennia all around the world, the challenge to solve musculoskeletal problems is still present.

During the last Triennial Congress of the International Ergonomics Association (Toronto, August '94), musculoskeletal disorders has still been reported abundantly as one of the major problems in industry.

Frequency and gravity of MSD are still important. As presented at the IEA Congress in the US, 60% of all newly reported workplace diseases are work-related musculoskeletal disorders with a frightening increase in the incidence rate from 5% in 1981 up to 30% in 1991 (Silverstein, 1994). As alarming as these statistics are, they do not include back injuries which are much more prevalent and have been estimated to cost at least 11.4 billion USD in direct workers compensation costs (Webster and Snook, 1994).

Publications from all around the industrialized world report about this problem with percentages varying between 30 and 60%, all making reference to the multifactorial aspect of the causes as repetitive activities, poor workstation, equipment and tool design, inefficient work organisation with failing work-rest schedules, heavy material handling, prolonged and awkward postures, etc. (Worksafe Australia, 1986) of which some are inevitable due to the normal evolution in industrial producing activities (Kuorinka, 1994). However, in most cases it is only the tip of the iceberg on which has been reported with no awareness of the total underlying risks.

The increasing importance of MSD is a rather disappointing and frustrating outcome of all efforts developed to manage MSD problems. As ergonomists, we have to state that we failed somewhere, which is also the case for all other uni-disciplinary approaches: neither occupational physicians and paramedical expertise, nor mechanical, industrial or safety engineering, nor psychologists or sociologists, designers, economists, managers and politicians could solve the problem completely. All failed over the total line.

Without making a trial of all concerned it has to be stated that even the terminology in itself creates lots of confusion, and neologisms appear almost daily. Some refer to the type of activities where the cases appear (e.g. repetitive strain injuries RSI) or more general (as OOS, occupational overuse syndromes) others refer to the injuries (tenosynovitis, tendonitis, . . .) or to the part of the body affected (carpal tunnel syndrome, epicondilytis, cervico-brachial disorders) or also more general like one of the last terms used: work related upper limb disorders (WRULD).

Furthermore, and much more important, is the fact that under economic pressure, new technologies and "know how" are exported to low cost industrially developing countries with the consequence that work-related problems are transferred as well. The "new" phenomenon of MSD appears already now in South East Asia and everybody seems to be surprised. But, should we? And is it a "new"
In making this statement, future work should answer a few fundamental questions: are we not over- or underestimating the problem? What did we do wrong? How can we adjust our policy in the future?

About these questions there are a few considerations concerning gaps in existing policies:

- the problems of registration of musculoskeletal disorders,
- the consequences and long healing process with high relapse probability,
- the scientific approach of musculoskeletal problems, and
- prevention strategies and structures.

Registration of MSD

The fact that so little explicit, reliable and comparable data on incidence and prevalence are available is caused by a missing common registration system of musculoskeletal disorders. Indeed, in quite a lot of countries, overload diseases are not registered as such. For example in Belgium and other European countries, most of MSD and especially those caused by cumulative effects are not recognized as a "labour accident" (in clarifying "accident" as a sudden, unwanted and involuntary external occurrence which may result in a physical injury (WHO, 1957). With "labour accident" is meant all accidents causing an injury and occurring during and caused by the execution of the employment contract (Belgian Labour Legislation, 1971). Low back problems appeared in the Belgian legislation for the first time in 1974 and the list of the Fund for occupational diseases has been completed with some musculoskeletal disorders in 1989.

The workers affected with an injury caused by other factors than mentioned in the definition of "accident" or "occupational disease," consult their private physician, whether or not they receive physiotherapy and rejoin their job after healing without any explanation or justification at all within the company. Both problems are not mentioned officially and therefore not registered.

The only traces which could be found are within the private insurance companies and social health care systems, but there is no obligation to communicate the data. Again, if registration is already a problem in industrialized countries, what then in industrially developing countries where social systems are less established?

Physical consequences

The second consideration, linked to the first one, concerns the long periods of the healing process and the high relapse probability. Furthermore, whether an injury is treated or not, for quite a lot of cases "full rest" may have an almost equivalent recovery result. Once affected by an MSD, the relapse probability is almost 100% when resuming the same job, but now in a much shorter period than when the first complaints appeared.
This may have individual, socio-economic and practical consequences:
— for the affected workers: they feel uncertain and lose confidence with awareness of the physical incapacity (which may lead to leaving the job for another less interesting one) and psycho-mental effects (being lost for productive jobs). Management still often sees the problems of absenteeism and turn-over as a lack of motivation of the workers;
— the employer loses skilled and experienced employees, with corresponding losses in quality and efficiency;
— the socio-cultural system faces long recovery periods and increasing unemployment rates with extremely important social financial cost; and finally,
— a practical problem of job occupation may appear. Importation of foreign workforce or industries moving to industrializing countries both bring other social problems.

Individual coping processes and resistance against MSD have been recognized in different studies (Intaranont, 1990) but emphasis should be placed on the combination of psycho-physical reactions and work-related factors. To avoid musculoskeletal problems, workers develop an informal adapted behaviour which might be conflicting with existing procedures and standards. For example, the respect of work-rest periods during the shift influences the cumulative effect: the workforce itself decides whether to respect the schedule or not; different kinds of workload during extra-professional time, also is a voluntary workers' decision. Both have been found as causing and aggravating factors (Vanwongterghem, 1993).

In particular, in industrially developing countries the personal attitude and decision-making processes of individuals merit special attention, not only because of the pressure from socio-economic growth, but also because ethnic and cultural differences in combination with other working conditions may differ significantly. For example, as observed in Malaysia where different ethnic groups are working in systems with a favourable low workrhythm (compared to Western standards) in more and less constraining climatic conditions. What will happen, however, if 1 day the workspeed must be increased?

Scientific approach

The third consideration is about the classic methodology used in feed-back analysis of MSD. Disciplines which are forced to proceed by means of “effect to cause” principles are confronting huge problems.

Starting from diseases and injuries refer always to a series of causes, but in using these findings in the reversed direction has a much lower probability. Lung cancer, for example shows a strong correlation with smoking behaviour or asbestos exposure, but not all smokers or workers with asbestos will die because of lung cancer.

Due to cumulative aspects of some of the musculoskeletal disorders, the
initiating facts and the period in which the causes appeared cannot be appointed correctly. There might be a span of several months, even years, in between cause and effect (for example 6 to 8 years in cases of carpal tunnel syndrome).

The multifactorial causes (task, organization, environmental factors and inter- and intra-individual differences) already form a very important straighten out tangle, which will become more complex. A complementary variable factor which is the evolution and unverifiable elements such as the attribution of specific activities during and out of the professional working-time, makes quite a lot of research results unreliable, because they are not described.

Furthermore, working conditions change continuously—technical evolution in equipment and machinery, changing workforce, changing organizational measures etc.—interfering with the assessment of the problems by means of retro-active analysis. Indeed, in a few months the whole working system may have changed and will change again offering a very unstable set of study samples.

Nevertheless, in fighting musculoskeletal problems, hazards must be known and scientific research is still needed. There is a need to establish limits or thresholds of acceptable levels for duration and exposure times. Benchmarks and limits must be made available, especially with reference to the combination of factors involved establishing a significant and relevant risk. The scientific value of studies in this field might be and are often undeniable, however, for use as arguments to management, the doubtful character of the outcome can be an obstacle in determining the importance of improvement investments.

There is a strong need for reliable and practicable realistic guidelines because these will determine the future results of preventive actions.

**Prevention**

The final consideration concerns prevention strategies. Here, especially, ergonomics can make an important contribution, not only in participating in research projects about cartesian selected phenomena, but also and especially as an added-value the link to industry, to the representativeness of the real working conditions.

There is no doubt that, in using the knowledge from all kinds of research, design and redesign of work systems, workstations, tools and machinery is a first step.

Information to managers should include an arguments to which they are sensitive, namely the economic and financial justification of prevention strategies. Prevention should be an essential part of “good management,” good management meaning high efficiency on short and long term. This is an economic rule and responsibility for the company but also for the total social security systems which might be placed under an unbearable charge in the future if only company interests are taken into account. This is not representative of good management. In the problems of MSD, the only pre-signs indicating an immediate risk, are subjective.
The suspicious character of the subjective complaints must be explained by means of hard evidence, showing the impact of the diminished workload on the workforce.

The total approach of the ergonomic methodology in showing the influence of the external workload (task, organisation, environment) on the psychosomatic works (physiological fatigue) and on the subjective experienced workload and sensations, could be the most appropriate method for investigation.

Early intervention is the best means of prevention but it is only possible if problems are recognized. The objectivation of MSD cases is essential and therefore reliable statistical data must be collected on absenteeism and turn-over. Actually, statistical evidence on both phenomena is disappointing. It is also surprising that in some cases management is not aware of the economic impact of inexperienced workers in the company, of the subsequent loss of efficiency, of the expense for training and rationality of team work, etc.

Secondly, the risk cases must be studied and analyzed in their real working conditions and if risks are present, as early as possible.

In a study carried out in Belgian Mining (VANWONTERGHEM et al., 1990) it has been shown that high rates of uncontrollable absenteeism and important turn-over reflect the existence of failing coping processes unfavourable working conditions.

Since the etiology of musculoskeletal injuries, first starts with pure subjective complaints of fatigue, feelings of discomfort, annoyance and pain workers are aware of some causes and tried to adapt their occupational behaviour to the existing systems without claiming any intervention from management. Those who are reacting, are classified as difficult and unreliable workers with adverse consequences regarding career-development, salaries, etc.

In the same study it is clearly shown that workers, in their coping strategy with high workload reduce their work output, introduce in formal rest periods, and finally take a few days off, asked to be moved to another, lower paying, job or even quit the mining activities.

It has been found also that the effect of motivation-oriented preventive actions is the opposite of the desired effect: the most dedicated workers are the first affected, because they refuse to heed physical warning signs. In stead of following the natural strategy of lowering the workload, they continue their activities increasing the negative physiologic strain, reaching the breaking point much faster.

Almost all of these cases go unreported. No information is given either to management to the occupational health department and safety services, or to the human resource departments, because of the fear that, since there is no clear evidence of an injury, the complaints will be seen as a personal shortcoming; whether as a physical or as a mental failing attitude.

The development of prevention strategy should therefore include:
— analysis of figures about absenteeism and turn-over,
— paying attention to subjective complaints and detection of pre-signs,
— making a link between working conditions and psychosomatic reactions,
— proposals for improvement, justified from the work analysis,
— implementation and re-evaluation of the improved systems.

In taking these considerations into account, the next proposals could bring new life in the fight against musculoskeletal problems. They concern the establishment of a structure or a reassignment of duties of existing structures, the need for training and education as well as the necessity of applied field and fundamental research about the objectivable MSP pre-signs in using a common methodology.

**Structure**

It is important to have all hierarchic levels involved: from the workfloor up to foreman, line managers, directors and even board members; first at the company level, then industrial activity groups, the entire industry and public institutions and ministries.

Information and data banks on objective and subjective facts must be collected from the floor up to the overseeing body, where strategies and policies can be developed for the company, industry and society.

When decisions have to be made, the curing information stream has to go down to the work-spot, where the implementation of the measures (technical, organizational, guidelines, etc.) must be realized. It is important that everybody understands what should be done and why.

It is quite obvious that an established expert team could do extremely useful work in bridging the gap between the workfloor and management and, for small- and medium-sized industries, inter-factory services and consulting groups could be developed.

**Training and education**

Especially on MSD, awareness about the real problems and how to solve them should be present at each hierarchic level. This means short information sessions for workforce with emphasis on what are the pre-symptoms and what are the work-related causes. To a higher hierarchic level, these items are completed with technical and organisational improvement measures and, in going up to the highest levels in the hierarchy, planning, investment decisions and strategies of control, advise etc. are included.

It is quite obvious that the consulting experts will have the most extended training in content and duration and that the extremes (workers and directors) are informed about their concerns.

**Applied field-research**

At the same Congress in Toronto, several methods and techniques ultimately evaluating MSD problems have been discussed extensively: handgrip, pressure-pain threshold, electromyography and other methods have been presented.
In the same line, the total ergonomics system approach in activity and environmental combinations are assessed by using the worker as a dosimeter seems to open new ways in understanding the problem.

The external stressors as task, organization as well as the biomechanical and physical environment are assessed by the functional reactions of the worker: psycho-physiological reactions and subjective assessment of the experienced load (general fatigue, local fatigue, functional fatigue and subjective ratings) and converted into relative values.

The reason for this is the huge inter- and intra-individual differences which do not permit a comparison by individuals. Though this might be an important problem in the scientific setting up of reliable sample populations, it is a problem which we have to face in whatever research project we undertake (Kuorinka, 1981).

The relative values concern the evolution of the reactions in time (begin to end of shift, or a determined period (week, month,...) for the different activities, different physical environmental conditions etc., and show the variability of some psychosomatic reactions due to different stressors.

The advantage of begin-end work period analysis lies in the fact that the data refer immediately to the responsibility of management (exclusion of extra-professional activities) and in interrelating workload (causes) and psycho-physical strain (effects), the factors susceptible for improvement can be chosen.

Depending on applied threshold-levels, priorities in improvement actions can be forwarded. It has been shown that such an approach offers quite a lot of arguments to management, though for the assessment of the impact on MSD, longer periods should be considered.

From these considerations emerge that, actually, the efficiency of all efforts developed to solve the existing musculoskeletal problems can and must be improved. It seems to be a question of organization, goodwill, gathering the necessary knowledge and qualifications and promoting awareness to all concerned.

Individuals, industry and society will all benefit greatly if we succeed; if we ergonomist fail in such a rather simple problem, what is then the reason of existence of ergonomics?

REFERENCES


PUTZ-ANDERSON, V. (1994) Prevention strategies for musculoskeletal disorders: NIOSH, OSHA and
Factors affecting heat illness when working in conditions of thermal stress

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In hot working conditions, high sweat rates with excessive loss of body fluids may result in dehydration and electrolyte imbalance. It is well established that dehydration and/or electrolyte disturbances will impair work performance, and, if prolonged or severe, can pose a serious risk to health. The lesser condition of hypohydration is undoubtedly widespread in the workplace, and may be indirectly responsible for less than optimal performance and workplace accidents. With the aid of a new sweat collection method, fluid and electrolyte loss from a population of male workers with varying fitness and body composition has been documented. This has provided the basis for prescribing guidelines of fluid replacement when working in the heat. In addition, the minimum duration of heat exposure required to trigger heat acclimatization was sought using sweat sodium as an indicator. Rehydration at the rate of 500 ml/h (250 ml every 30 min) is recommended for people working in all but extreme heat (>45°C). Electrolyte supplements (sodium and potassium) are not generally required in the workplace, but may be warranted in certain circumstances to avoid hyponatremia (>3 h). The ability to predict the susceptibility of an individual to fluid and electrolyte disturbances cannot be made from age, body composition, ethnicity or \( \dot{V}O_2 \text{max} \), although a high \( \dot{V}O_2 \text{max} \) appears to enhance heat tolerance. Sodium loss in sweat varies greatly and is not significantly related to sweat rate. Acclimatization results in a significant decrease in sweat sodium and increased sweat rate during summer compared with winter. This advantageous physiological adaptation requires a minimum of 9 h of heat exposure to initiate.

During work in high ambient temperatures, blood flow to muscles must be
maintained at a level sufficient to supply oxygen and substrates. In addition, a high blood flow to the skin is necessary for thermoregulation. In the conditions of heat stress, adequate cutaneous and muscle blood flow are achieved at the expense of tissues that can temporarily compromise their blood supply, i.e. the gastrointestinal tract. In addition to these vascular adjustments, the dissipation of metabolic heat is almost totally dependent upon the cooling effect of sweat evaporation. Within a few hours of working in the heat, water loss or hypohydration can reach proportions that impede heat dissipation and severely compromise cardiovascular function and work capacity. The result of hypohydration/dehydration is often one of a number of heat-associated illnesses, such as heat exhaustion, heat strain or heat stroke (Brouns, 1991). A situation of heat stress in the workplace may result in a reduction of productivity, work performance and motivation in heat-affected workers. This may render them more prone to workplace injuries as a result of heat impaired physical and/or mental performance (Pichan et al., 1988; Gopinathan et al., 1988).

In hot working conditions, high sweat rates with excessive loss of body fluids may result in dehydration and electrolyte disturbances. It is well established that dehydration and electrolyte disturbances will impair work performance, and if prolonged or severe can pose a serious risk to health (Montain and Coyle, 1992). The loss of fluid and electrolytes while working in conditions of thermal stress may therefore necessitate their replacement to avoid fluid imbalance. Present fluid and electrolyte replacement regimes however, are questionable in their application to the workplace. The vast majority of studies on fluid and electrolyte losses in the heat have been conducted on young, well-trained individuals who are unlikely to be representative of the general workforce. The results of these studies (Robinson and Robinson, 1954; Dancaster and Whereat, 1971; Barr and Costill, 1989; Fellmann et al., 1989; Brouns, 1991; Maughan and Noakes, 1991; Gisolfi and Duchman, 1992; Meyer et al., 1992) therefore, cannot be applied to most work settings where the majority of workers do not have a high $\dot{V}O_2_{max}$ are of differing ages, and therefore may vary in their functional capacities of, for example, the renal and cardiovascular systems (Allan and Wilson, 1971; Costill et al., 1975; Barr et al., 1991; Clark et al., 1992; Fellmann, 1992). In addition, workers have differing body compositions and ethnicity. Out of the many studies conducted on the physiological effects of heat stress (Fox et al., 1963; Lind, 1963; Fortney et al., 1981; Francesconi et al., 1985; Libert et al., 1988; Deschamps et al., 1989; Gavhed and Holmer, 1989) very few have dealt with heat stress in specific industries or occupational situations. A compounding problem is the lack of understanding of how age, body composition, ethnicity and fitness can effect a person's ability to safely work in the heat, however, it is assumed in the current literature that these factors have no influence on the body's ability to maintain thermal homeostasis when working in the heat.

Despite the importance of adequate fluid replacement during work in the heat,
there is conflicting evidence in the literature regarding appropriate rehydration procedures. There are reports of overconsumption of some commercially prepared fluids (NOAKES, 1992), which have recently become popular and are available to workers ad libitum at some worksites. These commercially prepared beverages vary in their electrolyte composition mainly because the literature on which they are based is conflicting. Drinking these fluids may place the worker at risk of sodium overload if the ingested fluid is hypertonic and has been consumed in large quantities. Conversely, drinking unsalted water to replace sweat for prolonged periods may dilute the extracellular compartment and cause hyponatremia (BARR and COSTILL, 1989). The composition and quantity of the fluid used to replace sweat loss, therefore, is important.

The normal regulation of water intake is the sensation of thirst, with water excretion being controlled by the secretion and action of ADH. When free water losses are high, raising the plasma osmolality, ADH is secreted, causing the urine to become more concentrated so that water loss is minimised. At the same time, the sensation of thirst is stimulated, causing water to be ingested, and the plasma osmolality returns to normal. However, the sensation of thirst is not a good indicator of hydration status (NOSE et al., 1985; MAUGHAN, 1991). A worker will not sense when he is hypohydrated and will fail to replace body water losses, even when drinking water is readily available. Research shows that a person working in the heat will exhibit voluntary dehydration, that is they maintain themselves about 2% of body weight below their ideal hydration status without any sense of thirst. Since work performance declines significantly when water loss reaches more than 2% below ideal levels, workers must remember, or be reminded, to replace the fluid lost through sweating. Chronic dehydration has been associated with an increase in the incidence of several medical problems such as constipation, haemorrhoids, kidney stones and urinary infections, in addition to being an occupational hazard. The likelihood of these conditions occurring can therefore be reduced by maintaining fluid balance when the loss from sweating is high.

Apart from the disparities in recent heat stress studies, primarily due to subject selection, the principal reason for the paucity of current literature has been the methods used to measure fluid and electrolyte loss. The development of a new, precise, reliable and reproducible method of sweat collection has allowed this study to be undertaken (CENA and BATES, 1992).

In Western Australia, employees of the North West mining industries are often required to work a 2 week “on,” 2 week “off” shift. This requires that in winter, the workers travel between a relatively cool temperate climate, and a hot tropical climate, every 2 weeks. They may therefore be acclimatizing and deacclimatizing to heat every month. On initial arrival at the worksite they would be in a heat-intolerant state, and so be at greater risk of heat illness or work-related accidents. Appreciating the importance of being heat acclimatized is best illustrated by the two deaths which occurred in the mining industry in Western Australia during 1991.
and 1992. Both these deaths were as a result of workers coming from a cold northern hemisphere winter into a hot Australian summer. Although these cases are extreme, it can be assumed that less severe cases exist in workplaces, which could place unacclimatized workers in a higher risk category for heat associated illnesses and workplace injuries. Currently, the duration of daily heat exposure required to trigger beneficial physiological responses is not fully understood. Such findings will allow the implementation of strategies for people such as military personnel, athletes and workers, to minimise the detrimental effects of heat when going from a cool to a hot environment.

**Methods**

Thirty male subjects, employed as maintenance, site services and ground staff at a large educational institution in Perth, Western Australia, volunteered to take part in the study. Each subject was asked to complete a written informed consent form.

The subjects' ages were between 18–50 years, with a mean age of 32 years. The following physical parameters were recorded as baseline data; height, weight, percent body fat and level of physical fitness ($\dot{V}O_2\text{max}$).

The protocol, as outlined below for the experimental trials conducted over the summer months, was repeated in the winter months. All studies were conducted in Perth, Western Australia. The initial seasonal study was conducted in January and February, and using the same protocol the study was repeated in July. The two acclimatization studies were conducted in the winter (July).

The subjects' weight was recorded using a balance scale (accuracy ±5 g). The submaximal fitness test, in order to assess $\dot{V}O_2\text{max}$, consisted of exercising on a cycle ergometer at a workrate sufficient to elicit a heart rate greater than 120 beats per minute. The percent body fat of each subject was measured using a Bioelectric Impedance Analyzer.

One week following the collection of baseline data, each subject performed two exercise-heat tests in a climate chamber, on consecutive days, and at the same time of each day. All tests were conducted in the morning. The climate chamber was set for 30°C and 50% relative humidity for the tests, which is the average temperature and humidity in a Perth summer. Before entering the climate chamber the subjects were weighed in dry clothes on a balance scale. Core body temperature of each subject was recorded from the tympanic membrane using an Instant Thermometer which has an accuracy of ±0.1°C.

Upon entering the climate chamber, each subject was fitted with a heart monitor and exercised on a cycle ergometer at 40% of $\dot{V}O_2\text{max}$ for a total of 35 min. Following a 15-min warm up, the subjects were fitted with four sweat collecting devices (CENA and BATES, 1992). Subjects continued to cycle for a further 20 min after the sweat collecting devices were attached. Five minutes before the end of this exercising session (20 min of exercise), the core body temperature of each subject
was again recorded.

At the end of the exercise session, the sweat collecting devices were removed, and the subjects instructed to shower, without wetting their hair, drinking, eating, defecating or urinating. They were also instructed to ensure they were completely dry before redressing into the clothes in which they were originally weighed. The subjects were then re-weighed and the sweat rate (ml/min) was calculated from the weight loss of the subject over time. The testing session was discontinued for any subject whose core body temperature reached $>39^\circ$C.

The protocol, conducted over the summer months as outlined above, was repeated in the winter months to document water and electrolyte sweat secretion differences between these seasons.

Sweat collected during the experiments was evacuated from the sweat collecting devices with compressed air, into small weighing trays, weighed, and then diluted 1:200 in volumetric flasks. The concentration of sodium was determined by an atomic absorption spectrophotometer and that of potassium by flame photometry.

Results and discussion

A reasonably strong positive relationship between sweat rate and $\dot{V}O_2_{\text{max}}$ was demonstrated, in both summer ($r=0.573$) and winter ($r=0.598$). We postulate this relationship to be due to physiological adaptation of thermoregulatory processes, resulting from a frequent rise in core temperature due to regular physical activity. The effect of the relatively greater muscular activity of the fit, compared with the unfit person, to reach the same percentage $\dot{V}O_2_{\text{max}}$, could also have some influence on the sweat rate. However, it is likely that fitness indirectly provides the greatest protective benefit for people working in the heat. The ability to sweat at an increased rate allows for greater heat loss from the body. Such a person would be better able to maintain body temperature at normal levels, and so avoid heat-related illnesses. This capacity for an increased sweat rate associated with a higher $\dot{V}O_2_{\text{max}}$, is aided by an increased plasma volume demonstrated in fitter subjects.

The replacement of fluid lost from sweating is essential to maintain euhydration, which is vital to be able to sustain work in the heat. The most accurate assessment of individual fluid losses is weight loss following a work shift. However, the findings of this study suggest that the following fluid replacement protocol would best maintain normal body fluid balance when working, or exercising, in the heat.

Prior to the commencement of work in the heat, up to 1l of cool water should be consumed. The recommended rate of fluid replacement should be at least 500 ml/h after work has commenced. At approximately 30-min intervals, 250 ml of either cool water or a slightly sweetened beverage, should be consumed to ensure efficient gastric emptying. Heavily sweetened beverages may delay gastric emptying, and result in abdominal discomfort, so diluting these beverages is recommended.
There is a wide genetic variation in sweat sodium concentrations, with a range of 20–110 mmol/l. Accordingly, a fit person does not necessarily secrete low sweat sodium concentrations, and sweat sodium losses in fit people can be substantial, particularly if they have a very high sweat rate. Most fit people have very high sweat rates, which is a function of their high $\dot{V}O_{2\text{max}}$ levels, and also may have genetically high sweat sodium concentrations. It is not, however, necessary even for individuals reaching the maximal rates of sodium loss in sweat to have electrolyte (potassium and sodium) supplements, provided standard meal breaks are taken during the working shift, and the prescribed fluid intake is consumed.

It is reasonable to postulate that sodium loss in sweat is not altered by changes in dietary sodium, as the sweat is derived from interstitial fluid which is isotonic to plasma. For diet to have an effect on sweat sodium concentrations, the plasma concentration of sodium would have to decline or increase to abnormal levels. This has not been reported in people on low sodium diets. In addition, the use of sweat as an excretory route for excess sodium intake is unreliable, and its contribution to electrolyte homeostasis is questionable. There is no reason why people on low salt diets should be at a greater risk when working in the heat.

There appears to be little detrimental effect of age on the thermoregulatory process, at least up to the age of fifty. There was no correlation between age and sweat rate, rise in core temperature, and sweat electrolyte losses. People of all ages working in hot climates, however, should be provided with guidelines outlining the importance of fluid replacement and the detrimental effects of alcohol- and caffeine-containing beverages on fluid balance.

The minimum duration required for the physiological indicators of heat acclimatization to change from baseline, appears to be at least 3 h a day for 3 days (a total of 9 h heat exposure), for relatively fit people ($\dot{V}O_{2\text{max}} > 40\text{ ml/kg\cdot min}$). The relative importance of work intensity cannot be determined or predicted, although active work, as opposed to passive thermal exposure, enhances the acclimatization process. In addition, fit subjects have an advantage over less fit individuals in thermoregulatory responses to exercise in the heat, by the reduced time required to trigger heat adaptation processes.

In summary, effective thermoregulation during work in the heat necessitates adequate replacement of sweat losses. This can be achieved by ensuring euhydration before the commencement of work in the heat, and rehydrating with water during the work shift at a rate of 500 ml/h, consumed at regular intervals (i.e. 250 ml every 30 min). Sodium and potassium supplements are not indicated during a work shift, provided meal breaks are taken during the shift. Heat acclimatization and a relatively high fitness level offers protection against the development of heat-related illnesses. Dehydration, however, negates the protective effects of acclimatization and fitness in the heat.
REFERENCES


143–152.


DANCASTER, C. P. and WHEREAT, S. J. (1971) Fluid and electrolyte balance during the Comrades 

infusion on body temperature and endurance during heavy exercise. *J. Appl. Physiol.*, 66: 2799– 
2804.

fluid and electrolyte changes during a 72-h recovery from a 24-h endurance run. *Int. J. Sports Med.*, 


FOX, R. H., GOLDSMITH, R., KIDD, D. J., and LEWIS, H. E. (1963) Acclimatization to heat in man by 
controlled elevation of body temperature. *J. Physiol. (Lond.)*, 166: 530–547.

FRANCESCONI, R. P., SAWKA, M. N., PANDOLF, K. B., HUBBARD, R. W., YOUNG, A. J., and MUZA, 

GAVHED, D. C. E. and HOLMER, I. (1989) Thermoregulatory responses of firemen to exercise in the 

GISOLFI, C. V. and DUCHMAN, S. M. (1992) Guidelines for optimal replacement beverages for different 


506.

Physiol.*, 18: 57–60.

142.


An improved method for describing the effects of heat radiation on men

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At industrial workplaces radiant heat load is often the dominant heat stress factor. Based on 900 climatic chamber experiments on humans, this study was conducted to develop a physiologically validated index-method to evaluate climates with intensified heat radiation. A comparison shows that the international recommended heat stress indices are not suitable to evaluate such climates correctly. By application of the new index-method into the commonly used indices, the improvement for the prediction of thermal stress effects in view of climates with increased heat radiation is discussed.

Heat stress depends on climatic and non-climatic variables. Climatic variables consist of air temperature, radiant temperature, air velocity and humidity. Non-climatic variables include activity level (heat production in the body) and thermal resistance of clothing. In order to predict thermal effects using heat stress indices, it is necessary to know what combinations of the variables produce the same physiological effects.

Good scientific findings exist to those climatic conditions, in which air temperature and radiant temperature are nearly equal. At many workplaces, however, radiant temperature exceeds the air temperature considerably. The knowledge about such climates is comparatively very low. Systematic studies could not be carried out, mainly because an experimental simulation of such climatic conditions requires a technically complicated and expensive test room. A suitable test room was constructed in the Institute of Occupational Physiology at the University of Dortmund, Germany (Wenzel et al., 1980), and comprehensive experiments were carried out to study the physiological effects produced by heat radiation (Wenzel et al., 1980).