Abstract
Like other areas of occupational health and safety (OHS) ergonomics is evolving and becoming more integrated into overall work management systems. As we learn more about the complex interaction between psychosocial and physical factors in the aetiology of work-related illness and injury the more we rely on managers to 'get it right' if we are to prevent these conditions. Risks to health and safety in the mining industry posed by longer shift lengths, higher work loads, less task variation and decision latitude have not really been well researched. Heavy physical workloads and stresses are still areas of concern, but are likely to be intermittent rather than constant. Recent research confirms current thinking rather than shedding new light on the subject. The contribution of slips, trips and falls and increasing age of miners to manual handling injuries is still not clear. In some cases sedentary work and the operation of machinery has completely replaced heavy physical work. The issues of machinery design for operations and maintenance and whole-body vibration exposures when operating machines and vehicles are becoming more critical. The link between prolonged sitting, poor cab design and vibration with back and neck pain is being recognized but has yet to be addressed in any systematic way by the mining industry. On the plus side some mining companies have well-developed participative approaches to problem solving and these need to be extended to areas such as ergonomics.

Key words
Ergonomics; manual handling; mining; risk management; vibration.

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Introduction
Ergonomics is a science, but it is also a philosophy—a way of thinking. It is a user-centred approach to design. It focuses on the design of equipment, processes and environments so that tasks and activities required of humans are within their limitations, but also make the best use of their capabilities. In the workplace, the application of ergonomics promotes health, efficiency and well being in workers. Ultimately, it is an applied science and it needs to respond to real-world needs.

Mining is similar to other heavy industries: the same principles apply to machinery and tool design, control rooms, lifting and heavy work, design to reduce the risks and consequences from slips, trips and falls, rough rides and errors. While the prevention of mining disasters and fatalities is still the highest priority in mining, the emphasis is now changing to a broader occupational health and safety (OHS) focus. However, there still appears to be a poor understanding about the contribution of ergonomics to mining, the range of factors that it includes and how these might be addressed. The differences in application lie in the different systems that have arisen specifically for mining and that may need to be accommodated through planning and design.

There are a range of emerging issues in ergonomics in mining, mainly arising from changes to work practices and a drive for greater productivity. Unfortunately, some of the practices appear to be at odds with the need to improve general OHS.

Changes in mining work practices
In the last 25 years the practice of mining has changed
significantly. Physically heavy work is now likely to be intermittent and limited. Workers still manually install overhead pipes, cables, ventilation and roof support systems (in underground mines); dismantle and erect conveyor systems; clean up; and maintain machinery. However, many of these jobs are partially or fully mechanized and much more time is spent operating machinery and driving vehicles. Appropriate machinery design is becoming more critical to successful mining, as is the training and skills of the mineworkers.

The move in mining towards longer work hours is part of a drive for greater worker productivity. A feature of many mining jobs now is extended work hours, i.e. shift lengths of 10–12 h and generally higher workloads. The issues of stress and fatigue are receiving much attention at present but the concerns go further than this. Longer shifts have highlighted the need for more research and information on the effects of daily exposures to different hazards for 8 h for which there are many standards and codes. While some can be adjusted mathematically, there appears to have been little appreciation of the difficulty of estimating the impact of physical underloading or overloading on workers and effects such as fatigue, monotony, errors and musculo-skeletal disorders. As well, there appears to have been little, if any, research into the role, design and efficacy of work breaks and their impact on different exposures. These could be critically important in the reduction of risks of injury and ill health and the improvement of worker well-being.

Ergonomics recommends varied work activities to help overcome the problems of prolonged sitting, heavy work or intense concentration. However, in mining the trend appears to be towards less rather than more task variety and many jobs are now much more sedentary. Longer hours of work and perceived increases in job demands both on a daily and weekly basis are compounding the negative effects of these.

**Machinery and vehicle cab design standards**

Modern OHS legislation requires detailed risk assessment of plant and equipment to ensure that it is designed, manufactured, supplied, installed and used in such a way that it poses no significant risks to the health and safety of workers associated with it [1–3]. There is extensive information on ergonomics design criteria in textbooks [4–6] but, by necessity, most OHS regulations and standards for heavy equipment define ‘design’ only in terms of broad principles to reduce risks to health and safety [7]. Standards that specify design parameters are usually those that deal with basic human dimensions that do not change significantly over time [8–12]. Even these may become out-of-date or inconsistent with current practice quite quickly. Therefore, risk assessments on machinery and equipment for particular sites and types of work constantly have to reconsider basic user performance standards and there is a sense of ‘reinventing the wheel’.

Many large international machinery manufacturers have developed design criteria and they guard these closely as commercially sensitive material. The better their designs the greater their market edge. However, this does not provide guidance for purchasers who are often left with a confusing array of conflicting design features when trying to select a machine suitable for their needs and budgets. The machine’s price, its capabilities in terms of power, running costs, availability/costs of spares and replacement parts and its reliability are the most important features to most purchasers. In some cases brand loyalty may be a factor. Rarely are comprehensive ergonomics specifications included in the list of criteria. To make matters worse, good design may be replaced with poor design in subsequent models because specific user needs have not been identified and feedback has not be sought.

In some cases, the mining industry itself has produced basic ergonomics dimensions and design criteria for cabs particularly for underground mining [13,14]. There are many design criteria that need to be specified and met including design for safe access, operation, operator space, seating, environmental conditions, training and maintenance.

**Whole-body vibration (WBV) exposures in mining (rough rides)**

In broad terms we know that a significant number of low back and neck injuries in mining have been precipitated by ‘rough rides’. In a study in open-cut and underground mines in Australia, WBV exposures in mining personnel were measured and analysed [15,16].

From the results there appear to be three different scenarios where symptoms arise. The first is prolonged sitting, the second is where injuries result from a one-off severe jolt in an otherwise reasonable ride and the third situation is where the onset of pain occurs after an extended period of moderate to severe jolts and jars.

These exposures are believed to contribute to low back and neck injury and may also be recognized by operators as damaging. However, the question still arises: ‘how much is too much’? At this point it is difficult to answer this question although rides with a vibration dose value (VDV) of ≥17 are likely to cause injury if exposure is prolonged and/or repeated. Interestingly, in this study, there was a reasonable correlation between operators’ ratings of ride roughness and the VDV, as Figure 1 indicates [15,17].

Results also indicated that the type of vehicle, its speed and condition (particularly its age and suspension
system) and the condition of roads strongly influenced ride roughness.

Controls recommended included: regular monitoring of vibration levels; operator training; limiting speed; prompt communication and correction of road problems; effective road maintenance programs; appropriate design of vehicles including the isolation of the cab in vehicles where vibration can be excessive; effective maintenance of vehicles; task variation; and regular breaks out of the seat [15,17]. There is little evidence that the mining industry has acknowledged or addressed these issues as a whole in order to reduce vibration exposures.

Manual handling and other heavy work

Worker capacities and age

There is strong evidence to suggest that task and workplace design factors are the most important in controlling the occurrence and severity of musculo-skeletal injuries. Much less is known about the contribution of individual and organizational factors, although these are believed to be important [18,19]. Age is one factor for which there appears to be conflicting information and where a lot more research is needed.

Mines may vary considerably in the average age of their workforce depending on where they are located and the age of the mine. In some cases the average is 40 years and this leads to questions regarding the impact of this on work capacity. Physical capacity decreases with increasing age [20–22]. This is due to decreasing physiological capacity, often in association with the effects of musculo-skeletal disorders such as back, shoulder and knee injuries [23]. Likewise sensory, perceptual and cognitive abilities decline, although these are not as obvious until the mid-50s [21,24]. Many mine workers over the age of 45 years are likely to demonstrate a decreased physical and mental capacity, especially where new or different demands are placed on them. Despite this, research indicates that, overall, older workers perform as well as younger workers [25], although there seems to be little research into the impact of the ‘healthy worker effect’ or ‘self selection’. It is plausible to assume that these are strong influences on mine workers’ demographics and somewhat offset the effects of aging.

An additional aspect to consider is the assessment of risks when undertaking demanding work and the physical and mental preparation for it. Job knowledge, skills and better coping strategies are important in this regard in older workers [25] and it is likely that it contributes to more conservative and safer work practices in older workers.

Combined effects of different exposures on the musculo-skeletal system

The combined effects on the musculo-skeletal system of irregular, heavy work and sedentary work such as operating machinery appear not to have been addressed by researchers, possibly because it is so difficult to control and quantify these different exposures at work and to draw conclusions on causality. However, this combination could be more damaging than constant, self-paced physical work on its own because there is a reduced training effect.

Another area that seems to need further research is that of the contribution of slips, trips and falls to manual handling injuries either as one of several initial ‘causes’ or precipitating factors or as contributing to the
exacerbation of an injury. Part of the problem is that most injury statistics list ‘agent of injury’ and ‘employee activity’ separately and not in combination. However, in reality, the dynamic nature of manual handling means that several forces are usually at work. Uneven floors, slippery surfaces, narrow, cramped or otherwise inadequate access and poor lighting are often found together with manual handling tasks in mining. Attention to all these areas may be required.

**Load factors in manual handling in mining**

Weight of objects is a big issue in mining, especially in the coal industry in Australia where aluminium is not permitted to be used underground. Therefore, it is impractical in some situations to consider reducing the weight of certain items. As a result, other approaches to reducing load have had to be examined and this has been useful in understanding and controlling manual handling hazards and risks overall. The load experienced by an individual is influenced not just by the nature of the object to be lifted but also by design, organizational and personal factors.

Load should not be confused with weight. Load is force. The weight of an item may be considerable, but with appropriate lifting aids the force required to move or hold it might be minimal.

Principal physical factors that have been recognized for some time are:

- distance of load from the body (moment), including handling above shoulder height [23,26,27] (see Figure 2);
- range through which weight is lifted [23];
- origin and destination of lifts [23];
- postures assumed in order to lift (bent, and bent and twisted postures are the ones to which most risk is attached) [23,28];
- speed of movement [29].

Moment, bent and twisted postures and speed of movement appear to be the physical factors that create the greatest risks for injury.

For repetitive lifting, added factors are:

- frequency of lifts [30];
- duration of lift [19];
- cumulative loading (leading to fatigue) [26].

**Identifying high risk manual handling tasks**

Determining and matching job demands with the range of capacities of employees is particularly important in manual handling, but is also very difficult. Where job demands exceed the individual’s capacity to meet them, errors, fatigue, stress and injuries may result. In the short term, individual workers may cope with demands that exceed their capabilities in one or more of the following ways:

- short cuts in work procedures leading to unsafe practices;
- consistently working at a higher pace than is healthy, with an increased risk of chronic or accumulated fatigue and injury especially as they age;
- self-selection out of the job by those who are unable to meet work demands imposed.

Therefore, it is important to establish which tasks have the highest risks for injury or accidents for the majority of workers. This is where participatory approaches to risk assessment and management can be most useful.

**Physical and psychosocial factors in work-related disorders**

Physical disorders may not arise purely from physical stresses. Psychosocial factors can contribute to the development of symptoms in some individuals at particular times [18,27,31,32]. The interrelationship between job and personal factors in the development of disorders in the workplace is complex. In order to understand these issues, managers have to examine work and its organization more broadly and understand how various factors may interact. In some ways it is easier now as there is considerable crossover between management and ergonomics theories and practice. In ergonomics it has been variously referred to as organizational design

![Figure 2. Height ranges for lifting actions—after Pheasant and Stubbs (27).](https://academic.oup.com/occmed/article-abstract/54/5/297/1399616)
and management (ODAM), systems ergonomics and now macro-ergonomics.

One illustration of this is the proposed link between stress, ill health and work. Known sometimes as the Karasek model, it argues that job demands need to be balanced with a degree of job control (decision latitude) by the worker. Those employees who have high demands placed on them but who have little say in how and when the work will be completed are the most likely to be at risk of developing psychological or physical disorders [33]. Figure 3 illustrates this.

A modifying influence in this theory can be social support at work. It is argued that support, or the lack of it, can either reduce or magnify the effects of problems at work. Conversely, those who have high demands and a high degree of control over how they meet those demands contribute to what Senge calls the ‘learning organisation’ [34]. There are a number of issues that flow from this view, most notably how ergonomics fits with OHS and the cause–effect relationship in occupational disorders.

**Risk management and participatory methods in ergonomics problem solving**

The application of the risk management approach for all types of risks is becoming increasingly important to reduce the probability that corporate objectives will be jeopardized by unforeseen events. The focus is one of positive and directed due diligence rather than negative compliance and for many mining companies this is a significant change in direction. Risk management techniques, commonly used in business and safety management systems, can be adapted easily to ergonomics. They have the added advantage that systems safety personnel understand the process and can integrate it into a company’s OHS program.

Participative techniques have been used successfully by designers and in safety management systems for many years [24]. They now are proving to be an interesting and productive method for systematically identifying workplace ergonomics problems and developing solutions. The concept of ‘participatory ergonomics’ has been promoted for ~20 years [35] and refers to the cooperative interchange between expert and non-expert to find satisfactory solutions to a range of problems especially where there needs to be trade-offs and compromises. It arose from the need to involve workers, who did not have an expert working knowledge of ergonomics, in the process of change and occurred simultaneously in Asia, Europe and North America. It has proven useful in helping organizations find real ergonomics solutions in the workplace and is another application of macro-ergonomics.

Participatory ergonomics takes many forms. One that the author has found useful in mining is the participative risk assessment workshop. This forum allows a focus group to devote uninterrupted time to a problem using a systematic approach with a view to solving it. In particular it allows ergonomics issues to be aired with respect to the wider work system and therefore provides a perspective that may not be possible when an ergonomist works as conventional consultant. It also gives the company a documented starting point for change [36]. This approach has the added advantage that systems safety personnel understand the process and it can be integrated into a company’s safety program.

Risk assessments can be carried out on tasks, locations, roles or processes but using job steps, tasks or activities is the most common approach. They involve as many key stakeholders as is feasible because a crucial factor in their effectiveness is the availability of relevant knowledge and expertise of a cross-section of people who are familiar with a particular work situation. Outcomes are critically dependent on the team being representative and providing a balanced view at a level of expertise appropriate to the nature of the subject under review. The ergonomist as the facilitator is independent within the team but can also provide background information on ergonomics. This is different to most facilitators’ functions. In some cases, specific expertise may be required to advise and/or supplement the core team.

In addition this process can be used for training, disseminating information and successfully achieving change in complex areas such as ergonomics. It can also provide the opportunity for full and constructive consultation with all stakeholders, something that is difficult and time-consuming to achieve with other processes.

**Conclusions**

Mining work practices are changing and therefore the hazard exposures for mine workers are...
changing. Longer shift lengths and fatigue, mental overload and underload, intermittent heavy physical work, reduced task variation, sedentary work in fixed postures and whole-body vibration all have risks for health and safety. The increasing age of some of the workforce is also of concern. However, there appears to be little recognition of these as potential causes of health problems in the mining industry. It is likely that some of these at least will lead to greater stress and morbidity in mineworkers if they are not balanced by well-informed decisions by managers.

Nevertheless, the development of participative approaches to problem solving in some parts of the mining industry is encouraging.

References

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