'Fitness for work': an eclectic perspective of its application in the South African mining industry

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ABSTRACT

'Fitness for work', as a strategic extension of dedicated ergonomic structures to enhance productivity, appears to be a feature of many modern industries, notably the labour-intensive South African deep-level gold and platinum mines. In any such dispensation it follows that minimum levels of physical fitness should be established and implemented within the context of well-designed health and safety risk management programmes. In this respect the key ingredients are, firstly, the adequacy of existing legislation, i.e. the Mine Health and Safety Act (Act 29 of 1996) and, secondly, the derivation and application of assessments of 'fitness for work', and on international trends and precedent. The purpose of this review is to provide a critical perspective of these issues with the overall objective of establishing a more equitable basis for enhancing the health, safety and productivity of South African miners.

Key words: **physical fitness, work capacity, heart rate, fatigue risk, mining industry**

INTRODUCTION

The Mine Health and Safety Act[1] (MHSAct) is generally held as an excellent example of non-prescriptive legislation, the implied quid pro quo being that mine owners and management assume responsibility for health and safety on the basis of 'best practice'. This is accomplished, notably in specialised areas, by means of mandatory Codes of Practice (COPs) based on formal guidelines issued by the Department of Mineral Resources (DMR). A specific feature of the MHS Act is the directive to establish meaningful health and safety risk management programmes (Sections 11 to 13). The fundamental issue is the precise nature of the risk, which in current context, according to Kew and Ehrlich,[2] can be regarded as 'risks associated with failure to meet the (physical) capabilities required of a particular occupation…', the most basic requirement being '…the employee's ability to perform work in a manner that does not increase the likelihood of injury or illness to the employee or co-workers.'

Further perspectives may be gained from the Department of Mineral Resources' guideline[3] on standards of minimum fitness. Section 8.3.11 specifies that 'there should be **sufficient musculo-skeletal integrity** to undertake the required physical exertion **for a particular category of work'** (Author's emphasis). Section 8.3.12 of the same document deals with fitness for work in hot environments, the requirement being that such employees '…must meet **all physical requirements** and **pass the necessary screening tests . . .** before declared fit to work' (Author's emphasis). Legislation therefore establishes a clear precedent for the introduction of screening tests and minimum physical requirements to ensure that health and safety are not compromised by inadequate levels of physical fitness. 'Best practice' is an implied requirement but there appears to be very little consensus between major role players (government, industry and labour) on exactly what it comprises and how it should be applied. Disputes, a present reality, undermine health, safety, productivity and ultimately even career opportunities. The purpose of this review is to provide a critical perspective on the derivation of current standards of fitness, their application and on international trends and precedent, with the overall objective of establishing a more equitable basis for enhancing the health, safety and productivity of South African miners. Literature, a description of approaches used in mines, and secondary data for illustration, are used.

ASSESSMENT OF 'FITNESS'

The health and safety risks associated with physically-demanding work, especially when complicated by hot environments,[4,5] are:

- premature fatigue and collapse;
- a variety of heat disorders, notably heat stroke, an affliction which leads to irreversible organ and tissue damage, as well as high mortality rates;
- aggravation of pre-existing (albeit undetected) irregularities, especially of the heart and circulation; and
- cognitive dysfunction, which leads to inappropriate decision-making, accidents, injuries and even fatalities.

In addition to factors such as age, anthropometric profiles and gender, the underlying origins associated with the above events are:

- an inadequate inherent (substantially genetic) capacity to undertake physically demanding work and tasks, a feature deemed as essential for elite-level athletic prowess[6];

- poor endurance fitness, a consequence of an inactive lifestyle[6];
- inherent heat intolerance[5]; and
- poor health.[4,5]

The array of tests currently applied in the South African mining industry to address 'fitness' as an integral part of medical surveillance consists of physical (PWC) and functional (FWC) work capacity assessments, as well as heat tolerance screening (HTS). The latter assessment is well-established in the South African mining industry and requires no further reference. However, it shares the same underlying philosophy of PWC and FWC assessments, i.e., *inter alia*, to identify the 'high-risk' individual. At present PWC and FWC assessments using test batteries developed as an AngloGold (now AngloGold Ashanti) and Anglo Platinum initiative of some 10 years ago, are conducted at 17 Rehabilitation and Functional Assessment (RFA) centres representing in excess of 260 000 employees from a variety of mines.

PWC assessments

The main purpose of PWC assessments is to ensure that prospective and in-service employees are fundamentally capable, from a cardiorespiratory point of view, of undertaking physical work without undue risk. Obesity *per se* does not influence the outcome.

Conventional assessments of work capacity (maximal aerobic capacity or VO_2 max) and endurance fitness are cost prohibitive within the context of routinely evaluating at least 50 to 100 prospective and in-service employees per day at numerous mines' occupational health centres. Therefore, for the purpose of field studies or industrial screening, derived methods are commonplace. Of historic interest is the indirect Astrand-Rhyming test, as endorsed by the International Olympic Committee and the International Federation of Sports Medicine.[7] The International Organization for Standardization (ISO) specifies different methods for the determination of work (metabolic) rate in the assessment of work practices, among others the use of heart rate as a proxy for calorimetry, spirometry and haematology (ISO 8996[8]). The ISO method exploits the linear relationship between heart rate and work rate, and this well-established precedent also forms the basis of PWC assessments.

In the South African mining industry PWC is assessed at a work rate corresponding to concurrent oxygen consumption level of about 1,0 to 1,2 l/min, i.e. about 340-400 W, depending on mechanical efficiency. This work rate could be regarded as 'moderate' and is representative of the majority of job categories on hard-rock mines.[5]

The PWC assessment used in the RFA centres is based on and incorporates two important principles. Firstly, it takes

Work simulation

Physical work capacity assessment

into account that candidates may not have had any form of endurance training prior to taking the test and it is therefore conducted at a submaximal work load. There are consequently no special physical attributes necessary to pass the test except reasonable health and the absence of overt cardiorespiratory limitations, as well as the inherent capacity to work to avoid premature fatigue. Secondly, the assessment is based on Astrand and Rodahl's[9] well-established 'gold standard', namely that in any industrial setting '... a work load taxing of 30–40% of the individual's maximal oxygen uptake is a reasonable upper limit for physical work performed over an 8-hour day'. In practice this means that 'self-pacing' is a recommended norm provided that work output remains productive. The respective categories used to interpret the responses (Table 1) are based on heart rates that can be equated to self-pacing (≤ 120 beats/min) and those heralding the onset of undue effort, i.e. in excess of 150 beats/min.[5,9,10]

A Category C rating implies that the candidate is incapable of sustaining physical effort at a level that is not even 'sedentary'. Apart from the distinct likelihood that such employees are unproductive, there is the risk of premature fatigue, collapse and even serious heat disorders. Under such circumstances the risk is not restricted to the individual but extends to team members and co-workers.

The risk associated with an inadequate physical work capacity, as outlined earlier, is a reality of underground gold mining. PWC assessments can, to a large extent, identify such a risk and, in conjunction with other forms of assessment, also provide the means to monitor physical conditioning programmes in a meaningful and objective manner. This augurs well for gainful employment without compromising health and safety.

A final comment in respect of the choice of heart rate, as opposed to oxygen consumption, is rather relevant in an industrial context: heart rate is a more appropriate measure of overall stress and the discrepancy between oxygen consumption and heart rate in classifying workloads could be substantial, with oxygen consumption consistently underestimating overall physical stress.[11]

Table 1. Interpretation of PWC heart rate responses

Category	Heart rate (beats/min)	Interpretation
A	≤120	Fit for any form of physical work
B	120 – 150	Acceptable; Occupational Medical Practitioner discretion for 'strenuous' work
C	>150	Unfit for full-shift physical work; review needed for job placement

FWC assessments

The purpose of FWC assessments is to match the prospective or in-service employee's task-specific abilities with the requirements of the occupation. The design of the test battery enables job allocation and/or re-allocation and, most notably, facilitates rehabilitation following injury or illness.[10,12] The retention of skills and experience stand to benefit employer and employee alike.

Whereas PWC assessments are designed to rate cardiorespiratory fitness, FWC assessments are task-specific. The basic requirement is that the range of representative tasks that constitute the test battery, with the exception of dexterity assessments, must be able to be executed 'productively', i.e. without having to incur exertion levels in excess of self-pacing.[10,12] As with PWC assessments, the parameter of choice is heart rate and the task-specific nature of FWC assessments also enjoys recognition in ISO 8996.[11]

According to Velozo[13] 'limitations of most traditional approaches to work evaluations are their **lack of focus on the actual work environment …'** (Author's emphasis). To counter this, the FWC test battery used in the RFA centres therefore consists of a variety of elements representative of key occupations and tasks. The simulations are realistic in all respects and their development and design were guided and endorsed by mine management.[10]

UNDERGROUND WORK DEMANDS

Over the period September-October 2009 a survey was conducted by AngloGold Ashanti, Ltd. and published in internal reports, to evaluate the possible health and safety risks associated with physically-demanding tasks, as required in terms of Section 11 of the MHS Act.[1] To this end, full-shift heart rate profiles (Polar heart rate monitors; accuracy ±1%, i.e. ±1 beat/min) of a production stope team of 16 experienced (employment ≥ one year) were recorded over a total of 118 man-shifts. Surveys of this nature are conducted under the direct supervision of mine management and with endorsement of the mine's Health and Safety Committee. Members of designated production teams also participate on the basis of formal informed consent. Production schedules remain unaltered. Secondary data from the survey are presented in this paper to illustrate the physical demands of underground work in terms of heart rate responses.

The mean heart rate was 89 ±11.8 beats/min (mean ± SD), the shift duration being 9.42 ±1.29 decimal hours (mean ± SD).

The general impression is that self-pacing is a significant feature of underground work or that the work demands are essentially sedentary. Figure 1 represents a full-shift heart rate profile of one of the participants: despite a mean heart rate of only 82 beats/min, peaks of 120 beats/min and more, the highest being 148 beats/min, were evident over extended periods. This is rather typical of all recorded data, as would be evident from the summary below.

- Number of employees (n) 16
- Work rates in excess of 120 beats/min
  % of shift time (mean ± SD) 9.4 ± 7.9
- Exposure time in decimal hours (mean ± SD) 1.75 ± 1.47
- Heart rate >120 beats/min (mean ± SD) 149 ± 16
- Peak heart rates recorded (mean ± SD) 169 ± 16

Heart rates of above 120 beats/min exceed self-pacing and represent exertion levels consonant with 'heavy' to 'very heavy' work,[4] possibly also complicated by substantial environmental heat loads. In fact, work rates of this nature were recorded in 89% of shifts worked and, with one exception, in all of the volunteer employees.

Where overall exertion levels exceed 120 beats/min in hot environments for periods of one to two hours or more, there are, at least potentially, decided health and safety risks, notably with regard to the development of heat disorders such as heat exhaustion and heat stroke.[5] Predisposing factors, among others, are poor work capacity, functional limitations that add to overall stress levels and a lack of endurance fitness, while secondary factors such as age, gender and anthropometric contra-indications cannot be discounted.[4]

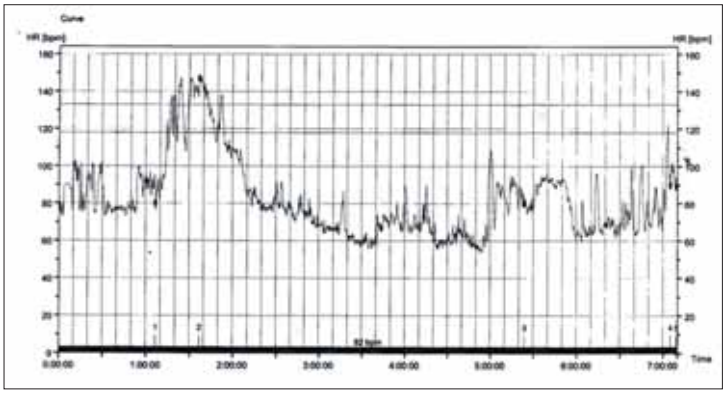

Figure 1. A typical full-shift heart rate profile

In any industrial setting where high heart rates are typical of certain occupations or even tasks, the cause could be related to either excessive task demands (e.g. poor ergonomics) and/or limitations with respect to the individual's work capacity (e.g. cardiorespiratory insufficiency).

To obtain further perspective, the AngloGold Ashanti survey was extended to VO_2 max determinations, conducted by the

Department of Physiology, Nutrition and Consumer Science at the Potchefstroom Campus of the North West University (Ethical Clearance Certificate NWU-0074-08-A1). The concurrent maximal heart rates recorded for the available employees (n=13) averaged 183 ± 15 beats/min (mean ± SD) and it should therefore be evident that at a work peak of 169 ± 16 beats/min (mean ± SD), superimposed on heart rates already in excess of 120 beats/min, as shown above, overt levels of exertion and the onset of fatigue cannot be ruled out in the normal course of underground production routines.

'FITNESS FOR WORK' BASED ON PHYSICAL AND FUNCTIONAL WORK CAPACITY ASSESSMENTS

Whereas the development of PWC and FWC assessments is based on recognised scientific principles and established norms,[4,8,14] the extent to which these assessments can be used to predict the prospective or even in-service employee's ability to cope with underground work demands, is uncertain. The basic reason is that the underground workloads, unlike controlled simulations, reflect the outcome of numerous, often conflicting, factors and day to day variations could be considerable. To expect consistently clear-cut correlations would be unrealistic.

From the 2009 survey it was evident that the PWC heart rate was poorly correlated with the mean working heart rate (r = +0,33). However, the correlation between the PWC heart rate response and higher work demands, as expressed in terms of the mean heart rate in excess of 120 beats/min, improved to +0.63, and to +0.65 with respect to peak heart rates. At face value these findings suggest that high PWC heart rates are predictive of progressively higher stress levels when individuals with work capacity limitations are confronted with more challenging demands.

The FWC test score reflects 'physiological economy', i.e. the physiological cost measured in heart beats to perform a given task. As a consequence, the ability to cope with the demands of underground work, an inverse relationship between FWC scores and working heart rates is expected.

Table 2. Anthropometric and cardiorespiratory features of volunteer subjects (mine employees) and reference populations[15]

Parameter[a]	Group		
	SA mining industry[b]	Trained males[c,d]	Inactive males[c]
Age: years	36.0 ± 9.4	25.8 ± 10.7	43.3 ± 13.0
Height: cm	171 ± 6.8	179.6 ± 6.2	174.9 ± 6.3
Mass: kg	68.3 ± 7.0	75.1 ± 8,8	76.8 ± 9.8
MAC: ml/min	2404 ± 43	3663 ± 571	2718 ± 568
MAC: ml/kg/min	34.5 ± 6.5	48.9 ± 6.8	35.8 ± 8.3
Oxygen pulse	12.4 ± 4.3	20.6 ± 3.1	16.6 ± 2.5

[a] All data expressed as means ± SD
[b] n = 13
[c] n > 200
[d] Not world class
[e] Index of cardiorespiratory efficiency: VO_2 max (maximal aerobic capacity, MAC in ml/min) expressed in terms of the concurrent heart rate maximum i.e. ml/beat.

With respect to mean working heart rates, the correlation amounted to a rather indifferent -0.43 which, as in the case of PWC correlations, improved to -0.58 when 'mean heart rate in excess of 120 beats/min' was substituted.

In the above survey the heart rate profiles recorded were primarily related to work demands and, although body temperature elevations and indications of dehydration were recorded, these were not regarded as significant. Despite the limitation that the data was drawn from a small sample, the general conclusion, therefore, is that although PWC and FWC are poor or indifferent predictors of mean responses to underground work, they appear to be meaningful, if not indispensable, as criteria of the ability of individuals to cope with more demanding levels of work which may, in fact, constitute decided health and safety risks.

WORK CAPACITY VIS-À-VIS WORK DEMANDS

In pursuing 'reversed ergonomics' as a strategic option to compensate for ergonomic constraints and limitations, the fundamental question that needs to be resolved is whether or not the 'physical fitness of the worker' provides an adequate alternative to achieve the desired levels of productivity. Where productivity levels still fall short of the desired targets, a number of distinct scenarios require examination. Firstly, the work output target may be unrealistic because it exceeds reasonable work capacity expectations, notably where work rates consistently exceed the '30 – 40% of maximal oxygen uptake' (VO_2 max) criterion irrespective of the ability of the employee. In such a scenario it follows that an extensive revision of work practices is indicated. However, a scenario also exists wherein work capacity falls short of 'reasonable expectations' as a result of, for example, underlying poor health, inherent work capacity limitations and even an undisciplined lifestyle, or any combination of such and possibly other limitations. In this scenario the emphasis shifts to the fitness and ability of the employee.

The current group of volunteer employees is poorly endowed with respect to maximal work capacity, in both absolute and relative terms, and notably with respect to indicators of cardiorespiratory efficiency (Table 2). This means that the effort required to work at rates normally regarded as 'self-paced' would be relatively high, the potential consequence being premature fatigue. For example, equating the PWC oxygen consumption of 1.0 – 1.2 l/min to a representative work load, the current group would on average be working at about 42 to 50% of maximal aerobic capacity. Even the crucial comparison, which compensates for low body mass, i.e. maximal aerobic capacity (VO_2max) expressed in terms of body mass (ml/kg/min), suggests that the local population can be likened to a sedentary (inactive) group of males generally some 10 years older. The oxygen pulse, a measure of cardiorespiratory efficiency, is also significantly lower than the untrained/inactive reference group, a finding which once again questions the work capacity of the local labour force. Moreover, it clearly underlines the importance of assessments of this nature.

The notion that PWC and FWC standards are set at levels that are too high, and accordingly unfair and discriminatory,

is devoid of substance: the elementary fact that the current group of employees was deemed 'fit for work' on the basis of PWC and FWC assessments is a clear vindication of the norms applied to achieve desired safety margins for full-shift physically demanding work without placing unnecessary restrictions on employment opportunities.

An equally compelling observation is that the discontinuation of cardiorespiratory fitness assessments for trainee firefighters in the United Kingdom was associated with adverse health and employment outcomes.[16] It remains to point out that the basis of these assessments is a step-test essentially similar to the PWC test, except that the minimum requirement equates to a maximal aerobic capacity of 42 ml/kg/min. On the basis of this standard, the data presented in Table 2 suggest that hardly any of the current group of mine employees would have qualified as firefighters.

CONCLUSIONS AND RECOMMENDATIONS

Despite the universally recognised principle of good ergonomics, i.e. 'fitting the task to the man', a phrase first coined by Etienne Granjean,[14] technological and economic constraints often dictate a converse approach, i.e. 'fitting the man to the task', a concept referred to as 'reversed ergonomics'. According to Hodgdon and Jackson[17] '… the missing component in ergonomics … (is) … the physical fitness of the worker', a perspective that is most certainly relevant to the entire South African mining industry. Therefore, under well-defined circumstances, at least in principle, there appears to be ample justification for the application of 'reversed ergonomics', the obvious proviso being that the health, safety and the general quality of life of employees is not jeopardised as a result.

Any initiative to enhance productivity on the basis of 'reversed ergonomics' introduces formidable challenges. Therefore, in occupational settings as complex as the South African mining industry, tripartism (government, industry and organised labour) is an essential ingredient. Unfortunately, however, the *status quo* is less than satisfactory, and conflict and dispute remain current realities.

- The MHS Act[1] provides an admirable framework with respect to risk assessment and management which, in the present context, addresses the health and safety consequences of strenuous work in adverse environments and, in a general sense, 'fitness for work'. By contrast, the relevant DMR guideline[3] on fitness for work, specifically Section 8.3.11, is too superficial to be relevant or to provide guidance. A comprehensive revision is proposed.
- The current physical and functional work capacity test battery, an AngloGold (now AngloGold Ashanti) and Anglo Platinum initiative has become part and parcel of medical surveillance programmes at numerous South African mines. It should be apparent that the mining industry has taken the lead in this respect and, with an ever-increasing number of mines adopting these assessments, it seems as if the current test battery is destined to become a mining industry norm. The challenge is to ensure that the test battery is applied in a consistent manner at all RFA centres.

• There is no doubt that organised labour is well capable of making significantly meaningful contributions to an initiative that, fundamentally, was designed to promote and advance health and safety, as well as continued employment opportunities. Co-operative participation in health and safety programmes appears to be a key ingredient.

The perceptions presented above suggest that a comprehensive tripartite review may have considerable merit.

The challenge of underground work in South African deep-level mines leaves no doubt that levels of physical and functional fitness consistent with the demands of the occupation are prerequisites to sustain health, safety and career opportunities. The following extracts provide an Australian perspective.[18]

• 'A recent survey of a cross-section of OHS officers working in Queensland and New South Wales mines - - - indicated that **lack of fitness, stamina and skill rank highest … as contributors to injury'** (This author's emphasis).
• '… a broader view of this concept ('fit for work') should consider the interaction between a worker's capacities and the demands of the job, and how much they do, or do not, match.' It should also **take a long-term view** of - - - health and fitness … **over a career … and cumulative effects of work demands'** (This author's emphasis).
• ' … the expectation that **all members of the general workforce could perform all mining work-tasks,** and that they can do so **with no risk of injury, may be increasingly unrealistic'** (This author's emphasis).
• '… **physical activity and fitness levels have arguably declined,** and levels of overweight and obesity have clearly increased …' (This author's emphasis).

It is suggested that the Australian experience and perspectives, as outlined above, are equally relevant to the South African mining industry.

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LESSONS LEARNED

1. Assessments of 'fitness for work' must be realistic simulations of the dominant tasks typical of given occupations, as well as the expected work output.
2. It is fundamental to ensure that there is no mismatch between employees' work capacity, work practices and production targets.
3. Full shift heart rate profiles are indispensable in the evaluation of the health and safety risks typical of deep-level mining. Mean heart rate tends to underestimate the actual risk.
4. The challenge of underground work in South African deep-level mines leaves no doubt that levels of physical and functional fitness consistent with the demands of the occupation are prerequisites to sustain health, safety and career opportunities.

Measurement equipment

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