Int. Z. angew. Physiol. einschl. Arbeitsphysiol. 22, 311—316 (1966)

The Influence of Lubrication on the Energy Cost of Pushing a Mine Car

C. G. WILLIAMS, J. H. VILJOEN, C. H. VAN GRAAN, and A. MUNRO

Human Sciences Laboratory Transvaal and Orange Free State
Chamber of Mines, Johannesburg, South Africa

Received March 24, 1966

Introduction

Work output on a manual task depends on both psychological and physiological factors. Physiological factors include the maximum oxygen intake and endurance capacity of the individual, and the metabolic cost of the task. Information about these factors are, therefore, pre-requisites for putting a labourer in the right job when hard manual labour is concerned.

The maximum oxygen intake of the individual can be rapidly and accurately assessed [6]. CHRISTENSEN [4] and ASTRAND [1] reported that fit labourers under high incentives could not work for prolonged periods at a level of oxygen intake higher than 50% of their aerobic capacities. The figure of 55% reported by WYNDHAM *et al.* [9] was obtained on more objective evidence and has put this concept on a sound scientific basis.

The metabolic cost of industrial tasks depends among other factors on the worker's skill, economy of his movements and their smooth co-ordination. In pushing a mine car, however, the metabolic cost also depends on extraneous factors, such as the condition of the tracks and the lubrication of the axles of the mine car.

In order to evaluate the influence of dry and of partially lubricated axles of a mine car on the metabolic cost of pushing such a vehicle, a study was made on 16 Bantu mine recruits engaged in this type of work.

Method

16 Bantu mine labourers, with large variations in anthropometrical measurements, were studied. Their physical characteristics are given in Table 1 together with a mean figure of three estimates of their aerobic capacities. The men had all had 3 or more months experience on a mine.

The experiment was carried out on the surface at the experimental track used by the Human Sciences Laboratory. The track was specially constructed for studying this type of mining task. The group of subjects was divided into three sub-groups for ease of handling. The main study was made after 2—4 weeks of intense training.

Experiments were carried out while men pushed a mine car at a constant speed of 2 miles p. h. and with loads of 0, 1000, 1500 and 2000 lb added to the car. Attached to the mine car was a speedometer with a bell and buzzer which guided the labourer to keep the desired speed. At each load the car was lubricated, partially lubricated or well lubricated.

By using the Douglas bag method and an Edwards face mask, gas was sampled between the 6th and 9th min of work or between the 2nd and 3rd min where the

Table 1. *Physical characteristics of test subjects*

Subject No.	Weight (kg)	Height (cm)	Subject No.	Weight (kg)	Height (cm)
1	65.4	160	9	54.7	152
2	66.0	166	10	53.9	155
3	69.0	168	11	53.9	155
4	69.0	165.5	12	57.4	157
5	66.0	177.5	13	52.5	158
6	67.0	183	14	54.2	162.5
7	66.0	174	15	54.2	163
8	70.0	172.5	16	55.0	172

task was too strenuous to maintain for a longer period. By means of radio-telemetry, heart rates were measured directly before and following gas sampling. Expired gas samples were analysed for oxygen content in the Beckman oxygen analyzer (Model E2). The metabolic cost of work was calculated from the amount of oxygen consumed per minute.

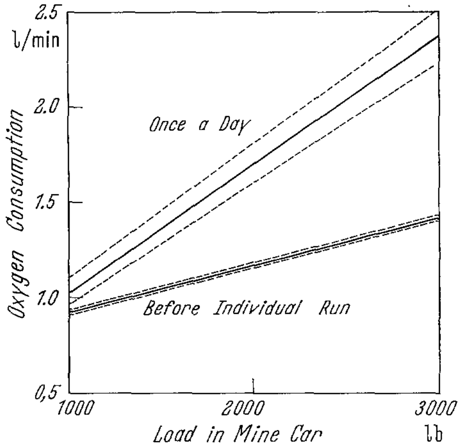
Results

Oxygen intake values, as related to the load pushed for the three types of lubricated axles, are shown in Fig. 1 a—c. The estimated curves are shown together with confidence intervals. Where the intervals do not overlap, a significant difference (at the 5% level) can be claimed between the mean oxygen intakes. Although oxygen intake increased linearly with load for all types of lubrication, the slopes of the three curves are markedly different. The curve relating oxygen intake of the men pushing a

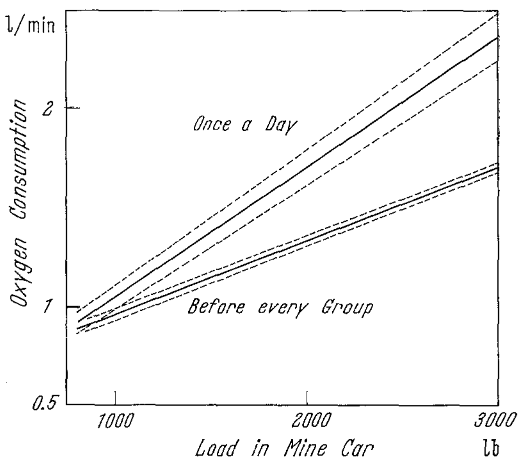
Table 2. *Oxygen consumption (l/min) required for different cars with different loads*

Axles	*Loads*			
	0 lb	*1000 lb*	*1500 lb*	*2000 lb*
Badly Lubricated	1.05	1.7	2.03	2.36
Partially Lubricated	0.95	1.33	1.53	1.70
Well Lubricated	0.93	1.17	1.28	1.40

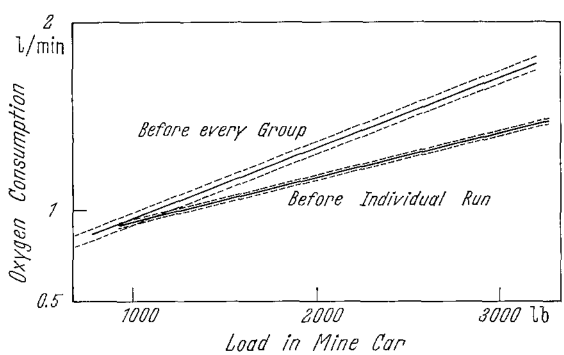
car with a dry axle, inclined steeply in contrast to the curve of oxygen intake of the men pushing the car with well lubricated axles. The curve of oxygen intake of the men pushing the car with partially lubricated axles occupies an intermediate position.



a



b



c

Fig. 1a—c. Effect of greasing

The increase in oxygen consumption per minute while pushing a car with different degrees of lubrication, and with different loads added to the car, is indicated in Table 2.

Discussion

The most striking feature of the present study was the highly significant differences found in the metabolic cost of pushing at a constant speed a mine car which has dry axles, compared with the same car with well lubricated axles. For the empty car lubrication had no appreciable effect on the oxygen intake, because differences found in oxygen intake were relatively small. Immediately the car was loaded, however, the oxygen intake of men, when they pushed cars with dry axles, increased significantly above values when pushing cars with well lubricated axles. As the curves relating oxygen intake with load have different slopes it is obvious that with increasing loads the differences in metabolic cost between the three different degrees of lubrication studied became more marked; at the highest load (total weight 3000 lb) there were highly significant differences in the oxygen intakes of the men while they pushed cars with dry, partially lubricated and well lubricated axles.

These results show that the task of pushing a fully loaded mine car of one ton capacity at a speed of 2 miles p. h. would require an oxygen intake of 1.40 l/min if the axles of the car are adequately lubricated. This is regarded as hard work following Christensen's work classification [4]. According to this classification, the task of pushing the mine car when the axles are badly lubricated (metabolic cost 2.36 l/min) would be very strenuous work.

A. V. Hill [5] claimed that for a man to be able to maintain prolonged work of several hours duration he should meet all the energy requirements aerobically. Observations by Christensen [4] and Wyndham *et al.* [9] indicated that aerobic work was possible when not more than 50 to 55% of an individual's maximum oxygen intake was involved. On this basis, therefore, labourers should have an aerobic capacity of at least 2.80 l/min to push a fully loaded mine car when the axles are adequately lubricated. The requirement when the axles of the car are partially lubricated is a maximum oxygen intake of 3.40 l/min, whereas when the axles are badly lubricated, the worker should have a capacity of 4.72 l/min.

These figures should be considered in relation to the maximum oxygen intake of 2.83 l/min of the average Bantu mine labourer [8]. It brings out the fact very clearly that unless the lubrication of the mine car is done thoroughly, few individuals would in fact qualify for this type of work.

As the pushing of mine cars is often an important mining operation and because ambient air temperatures are generally high in large areas of a mine, the labourer doing this type of work is at a double disadvantage.

Firstly, anaerobic metabolism occurs at lower levels of oxygen intake in heat compared with comfortable conditions [7]. This means that pushing the mine car at an oxygen intake of 1.40 l/min, when the required maximum oxygen intake is 3.0 l/min, would cause the worker to be partially on anaerobic metabolism when he works in heat. Secondly, the heat production at an oxygen intake rate of 1.40 l/min is 247 Cal/m^2 p.h. At this high rate of heat production the labourer might fail to maintain thermal equilibrium.

In the practical situation pushing loaded mine cars is usually followed by returning the empty mine car up grade to the working place. The time it takes to return the mine car to the working place may not be long enough to recover from the strain of pushing the loaded car, as recovery in heat is less rapid than recovery under normal conditions [2, 3].

Effective lubrication of axles will, however, reduce the time needed for recovery, and, under hot conditions, give added protection against disturbance of thermal equilibrium.

Summary

The oxygen intakes of 16 well-trained Bantu mine recruits were studied while they pushed a mine car at a constant speed of 2 miles p. h. The car had dry or partially lubricated axles and was pushed with loads of 0, 1000, 1500 and 2000 lb added to the car. When the car was empty the degree of lubrication had only a small effect on the mean oxygen intake of members of the group. With an increase in the load the differences in oxygen intake became greater and were all significant. For a maximum load of 2000 lb the oxygen intake values were 2.36, 1.70 and 1.40 l/min respectively for badly lubricated, partially lubricated and well lubricated axles. The average Bantu mine recruit with a maximum oxygen intake capacity of 2.80 l/min is well suited for pushing mine cars which are loaded to capacity and well lubricated. To push a badly lubricated car, when it is loaded to capacity, requires a labourer with a maximum oxygen intake capacity of 4.72 l/min. Few individuals would qualify for the task. In the practical situation, where ambient air temperatures are high, labourers engaged in pushing mine cars are at a double disadvantage. Anaerobic metabolism, and therefore fatigue, begins at lower levels of oxygen intake in heat than in comfortable conditions. To maintain the body in thermal equilibrium with its environment is also more difficult. Lubrication of mine cars, in addition to reducing work loads, therefore gives significant protection against disturbance of the thermal equilibrium of the body under hot working conditions.

Acknowledgement. This paper is published with the permission of the Transvaal and Orange Free State Chamber of Mines, Johannesburg, South Africa.

References

[1] Astrand, P. O.: Experimental studies of physical working capacity in relation to sex and age. Copenhagen: Munksgaard 1952.

[2] Brouha, L.: Fatigue, measuring and reducing it. Advanced Management, January 1954.

[3] — Protecting the worker in hot environments. 20th Ann. Meeting of Ind. Hyg. Foundation, November 1955.

[4] Christensen, E. H.: In: Symposium on Fatigue p. 93. London: Ergonomics Research Soc. 1953.

[5] Hill, A. V., and H. Lupton: Muscular exercise, lactic acid and the supply and utilization of oxygen. Quart. J. Med. **16**, 135—171 (1923).

[6] Maritz, J. S., J. F. Morrison, J. Peter, N. B. Strydom, and C. H. Wyndham: A practical method of estimating an individual's maximal oxygen intake. Ergonomics **4**, 97—122 (1961).

[7] Williams, C. G., G. A. G. Bredell, C. H. Wyndham, N. B. Strydom, J. F. Morrison, P. W. Fleming, and J. S. Ward: Circulatory and metabolic reactions to work in heat. J. Appl. physiol. **17**, 625—638 (1962).

[8] Wyndham, C. H., N. B. Strydom, J. F. Morrison, J. Peter, J. S. Maritz, and J. S. Ward: The influence of a stable diet and regular work on body weight and capacity for exercise of African mine recruits. Ergonomics **5**, 435—444 (1962).

[9] — — C. G. Williams, and M. von Rahden: A physiological basis for the optimum level of energy expenditure. Nature **195**, 1210—1212 (1962).

Dr. C. G. Williams
Human Sciences Laboratory
P. O. Box 809, Johannesburg, South Africa