THE EFFECT ON THE PRODUCTION OF BANTU, ENGAGED ON TRAM-SHOVELLING, OF DIFFERENT TEMPERATURE CONDITIONS

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SYNOPSIS

Heart rates, oral temperatures, shovels/min and number of ¾ ton cars/hour trammed over distances of up to 350 ft were measured in samples of 6-10 miners, engaged in tram-shovelling, at 76°, 84°, 86°, and 89°F wet bulb temperatures in stopes in a mine.

From the results it has been concluded that a man with an 'average' maximum oxygen intake capacity of about 2·8 litres/min should be able to work:

at 6 shovels/min, or 30 cars/shift per two men, at 76°-84°F;
at 5 shovels/min, or 27 cars/shift per two men, at 86°F; and
at 4 shovels/min, or 24 cars/shift per two men, at 89°F wet bulb air temperatures.

INTRODUCTION

A number of gold mines in South Africa still use tram-shovelling extensively. In this method of rock removal from the face of the stope, Bantu mine workers load rock into cars and tram the cars to a centre gulley where they are emptied. Previous studies from this Laboratory[3] have shown that tram-shovelling is one of the most arduous tasks underground. The rate of energy expenditure is relatively high, being an oxygen consumption of about 1·4 litres/min over a period of some hours.

In cool air conditions the upper limit to the rate of production of the well-motivated men employed on tram-shovelling has been shown[1] to depend upon their capacities for physical work of an endurance nature (as measured by their maximum oxygen intakes). However, in hot conditions the factors which set the upper limit to the rate of production are different. They are primarily the ability of the body to maintain a heat balance between the rate of heat production, due to physical work, and the hot atmosphere, so that the men do not develop excessively high body temperatures[8].

In order to give mine managers guidance on the 'optimum' rate of production of Bantu mine workers engaged upon tram-shovelling under different temperature conditions underground a study was carried out in a mine. The number of shovels per minute and cars per hour were recorded and heart rates and oral temperatures were measured throughout the duration of the shift on samples of 6-10 Bantu mine workers in different air conditions. The results of the study are recorded in this paper and conclusions are drawn as to the number of shovels per minute and cars per hour which Bantu mine workers of 'average' maximum oxygen intake capacity should be able to produce at wet bulb air temperatures of between 76° and 89°F without either excessive fatigue or danger of heat illness.

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METHOD

A total of 34 labourers were observed loading and tramming $\frac{3}{4}$-ton cars in different temperature conditions. The men worked in pairs on 17 different tracks as is the normal procedure in this particular mine. Observations were made each day on pairs of subjects simultaneously for the duration of a full shift. Three pairs of acclimatized labourers were observed while working at a wet-bulb air temperature of 76°F, four pairs were observed at 84°F and five pairs were observed while working at each of the wet-bulb temperatures 86 and 89°F. Wind velocities were between 80 and 120 ft/min.

Recording work rate. The shovelling rate per minute as well as the total number of shovels loaded by each subject into each car was recorded. The times taken to fill each car and to tram distances of up to 350 ft, empty and return the cars to the face were recorded. The number of cars loaded per hour and the total for the shift were noted. The lengths of the tracks were measured. Loading height varied according to working conditions but was generally in the range 24-32 in.

Energy expenditure measurements. Two samples of expired air were collected from each subject during loading. The samples were taken towards the middle of the shift. During the collection of the samples of expired air each subject was fitted with an Edwards face mask which was connected to a Max Planck spirometer by a 9 ft length of corrugated tubing. An aliquot sample of expired air was collected in butyl rubber bags and analyzed with a Haldane gas analysis apparatus.

Recording of heart rates. The heart rates were observed by means of a heart rate transmitter while the subjects were loading the cars and on a number of occasions while the men were tramming, and also immediately after the cars had been returned to the loading place.

Measuring oral temperatures. These were recorded before the subjects started work, two or more times during the shift, and at the end of the shift.

FINDINGS AND CONCLUSIONS

The information collected on the physiological responses and work output of the Bantu mine workers under various wet bulb air temperature conditions permits an assessment to be made of the physiological strain experienced by the men. It also allows for the setting of optimum production levels for these conditions, which are within the physiological capabilities of the 'average' Bantu mine worker.

Work rates and physiological responses under different wet bulb temperature conditions.

(i) *Cool conditions.*

In cool conditions a man's heart rate increases in direct relation to the increase in rate of oxygen consumption[4]. A measurement of heart rate during work can therefore be used to indicate the proportion of the man's maximum oxygen intake which he is using in the task in question. In general in cool conditions an average heart rate of between 120 and 130 beats/min in a normal man indicates that he is using about 50 per cent of his maximum oxygen intake. A level of work which results in a heart rate of 120 to 130 beats/min would be

considered to be safe for men working in cool conditions, for the period of a shift from day-to-day[2].

In Table I are given the oral temperatures, heart rates and shovels per minute of the six men observed over the period of a full shift at 76-77°F wet bulb. Three of the men (Nos. 3, 4 and 6) had heart rates of between 114 and 116 beats/min and they averaged 5·8 shovels per minute. This indicates that they were working at slightly below 50 per cent of their maximum oxygen intakes. By contrast, the others (Nos. 1, 2 and 5) had an average shovelling rate of 4·7 shovels per minute and a mean heart rate of 140 beats/min. These men were working at a lower or similar shovelling rate, but they had much higher heart rates than the others. From this result it can be concluded that subjects Nos. 1, 2 and 5 were working at a higher proportion of their maximum oxygen intakes and, as their mean work output was lower than that of Nos. 3, 4 and 6, it is reasonable to conclude that their maximum oxygen intakes were lower than those of the other three men.

TABLE I

WORK OUTPUT LEVELS, HEART RATES AND ORAL TEMPERATURES OF MEN WORKING AT 76°F W.B.

	W.B. temp. °F	Oral temperatures °F			Average heart rate beats/min	Shovels per min
		Initial	Average	Highest		
1	77	98·3	98·8	98·8	147	6·25
2		98·2	98·6	98·6	123	4·3
3	76·5	98·2	98·5	98·7	114	6·5
4		98·6	98·7	98·8	116	5·8
5	76·8	97·6	100·1	100·2	148	3·8
6		99·0	99·0	99·0	116	5·0
Av.	76·8	98·1	99·1	99·2	127	5·3

From a previous study[3] we know that the rate of oxygen consumption of men shovelling rock at 6 shovels per minute (a load of 15 lb on the shovel, thrown 15-16 ft) is about 1·4 litres/min. It is therefore reasonable to conclude that the three men shovelling rock at 5·8 shovels per minute, and with a mean heart rate of 115 beats/min, had a mean maximum oxygen intake of slightly in excess of 2·8 litres/min (i.e. twice 1·4 litres/min). As was shown by a previous study by this Laboratory[9] this is about the average for Bantu mine workers. The maximum oxygen intakes of the other three men (those with a mean heart rate of 140 beats/min) was well below the average and their physical working capacities were threfore *inadequate for the task of tram-shovelling.*

From these results it can be concluded that, provided Bantu mine labourers with maximum oxygen intakes of 2·8 litres/min and more are selected for tram-shovelling, they can be expected to shovel at a rate of 6 shovels per minute in cool air conditions for the entire shift. Furthermore, if men with maximum oxygen

intakes of 3·2 litres/min and more are selected, then a work output of 7 shovels/min would be reasonable.

(ii) *Warm conditions.*

When men work in warm and hot air conditions, the relationship between heart rate and oxygen consumption changes because of a reduction in stroke volume[5]. This results from the expansion effect of heat on the calibre of the peripheral blood-vessels and on the volume of blood in the vascular system. Under such air conditions a heart rate of 140 to 150 beats/min during work would not be regarded as excessive[6]. The more important consideration, however, is the risk of heat stroke and therefore the criterion which is used to set the limit for work in heat is an oral temperature of 101°F[8]. Studies (recorded in an internal report), have shown that with an oral temperature of 101°F there is a 1 in 20 probability of a rectal temperature of 104°F.

The oral temperatures, heart rates and work outputs of the men working at 84°F wet bulb are given in Table II. This shows that none of the Bantu mineworkers reached an oral temperature of 101°F. Three men (Nos. 8, 11 and 12) had a mean heart rate of 132 beats/min and an average rate of shovelling of 7 shovels per minute. However, the mean heart rate of the others (Nos. 7, 9, and 14) was 165 beats/min and their mean rate of shovelling was only 4·8 shovels per minute. As none of this latter group had oral temperatures in excess of 101°F, it can be concluded from their very high heart rates that their maximum oxygen intakes were too low for this task.

When the men worked at 86°F wet bulb the physiological reactions were more severe than at 84°F (Table III). Although the mean work output was not much higher, viz 6·1 compared with 5·6 shovels per minute at 84°F wet bulb, four workers had maximum oral temperatures above 101°F and there were no heart rates below 140 beats/min. One man (No. 21) had a very high heart rate of 181 beats/min while shovelling at 6·5 shovels/min. As his oral temperature was below 101°F the high heart rate must have been due to a lower than average physical working capacity rather than to an excessively high work rate. On these results it is clear that a shovelling rate of 6 shovels per minute is too high and it is recommended that at 86°F the optimum rate should be 5 shovels per minute. This would result in heart rates being reduced to below 150 beats/min in men with 'average' maximum oxygen intakes.

From these results it can be concluded that Bantu mineworkers with 'average' maximum oxygen intakes should be capable of working at 6 shovels per minute at 84°F wet bulb and at 5 shovels per minute at 86°F wet bulb for the full shift.

(iii) *Hot conditions.*

When the Bantu mine workers worked at 89°F wet bulb their mean rate of shovelling was 4·7 shovels per minute (Table IV). In spite of the fact that the work rate was much lower than in the cooler air conditions, as indicated by the shovel rate of 4·7 shovels per minute and the mean heart rate of 147 beats/min, the oral temperatures of all the men were above 101°F at some period of the shift and in four men it rose to above 102°F. This work rate should therefore be regarded as too high for 89°F wet bulb. A work rate of 4 shovels per minute is therefore proposed as the 'optimum' in order to bring the oral temperature responses to within acceptable limits.

TABLE II

WORK OUTPUT LEVELS, HEART RATES AND ORAL TEMPERATURES OF MEN WORKING AT 84°F W.B.

	W.B. temp. °F	Oral temperatures °F			Average heart rate beats/min	Shovels/ minute	Cars/ hour	Time to fill car	Shovels/ car
		Initial	Average	Highest					
7	83·6	98·4	99·3	99·4	166	5·2	4·0	8·4	88
8		98·3	100·3	100·3	139	6·2			
9	84·5	98·2	100·9	100·9	172	4·3	3·5	10·25	96
10		97·2	100·1	100·5	162	5·0			
11	84·7	98·0	100·4	100·6	141	9·2	4·8	7·34	108
12		96·7	98·7	98·8	117	5·5			
13	84·4	98·7	100·1	100·2	169	4·9	4·07	9·22	87
14		98·7	99·9	99·9	156	4·7			
Av.	89·3	98·1	99·9	100·1	153	5·6	4·16	8·8	95

TABLE III

WORK OUTPUT LEVELS, HEART RATES AND ORAL TEMPERATURES OF MEN WORKING AT 86°F W.B.

	W.B. temp. °F	Oral temperatures °F			Average heart rate beats/min	Shovels/ minute	Cars/ hour	Time to fill car	Shovels/ car
		Initial	Average	Highest					
15	87·5	98·9	100·8	100·8	152	6·5	4·63	9·1	115
16		99·4	100·3	100·3	149	6·4			
17	86·5	99·6	101·4	101·6	156	4·9	3·32	13·9	91
18		99·0	100·6	101·0	149	4·4			
19	85·9	99·0	100·9	101·0	164	6·5	4·60	8·1	92
20		98·5	100·5	100·8	156	4·3			
21	85·7	99·0	100·7	100·7	181	6·4	5·14	7·2	97
22		98·5	99·9	99·9	160	6·0			
23	85·5	98·6	100·6	101·0	161	8·0	5·45	6·5	104
24		99·0	100·3	100·3	149	8·0			
Av.	86·2	99·0	100·6	100·8	158	6·1	4·76	8·96	100

TABLE IV

WORK OUTPUT LEVELS, HEART RATES AND ORAL TEMPERATURES OF MEN WORKING AT 89°F W.B.

	W.B. temp. °F	Oral temperatures °F			Average heart rate beats/min	Shovels/ minute	Cars/ hour	Time to fill car	Shovels/ car
		Initial	Average	Highest					
25	88·6	98·6	101·3	101·4	150	5·09	4·50	10·34	88
26		98·6	101·0	101·0	152	3·84			
27	89·7	99·1	101·0	101·5	150	5·0	4·60	13·86	98
28		98·5	101·1	101·4	144	4·7			
29	89·4	98·4	102·0	102·2	136	4·96	3·88	13·56	105
30		98·6	100·9	101·2	130	3·7			
31	89·4	98·4	102·0	102·2	146	6·1	4·00	10·28	112
32		98·6	101·2	101·7	150	6·4			
33	90·0	98·6	101·4	103·0	157	3·9	3·71	13·30	100
34		99·0	101·9	102·7	158	3·8			
Av.	89·4	98·6	101·3	102·7	147	4·65	4·15	12·28	100

RATES OF PRODUCTION SUGGESTED FOR DIFFERENT TEMPERATURES

Provided that men selected for shovelling have 'average' work capacities they should be able to work at a shovelling rate of 6 shovels per minute *in cool and warm environmental conditions* (76-84°F wet bulb). At this shovelling rate (average shovel load of 15 lb) energy expenditure would be approximately 1·4 litres/min and a car would be filled (by two men working together) in eight minutes. This would give a production rate of approximately 5 cars per hour (because the average time taken to tram, empty and return cars over tramming distances ranging from 100 to 350 ft was three minutes). During a shift (effective six hours) a pair of labourers should produce 30 cars, or 22 tons of rock (Table V).

TABLE V

OPTIMUM PRODUCTION IN TRAM-SHOVELLING AT DIFFERENT W.B. TEMPERATURES

Air temperatures (°F W.B.)	Shovels/ min	Cars/hr (2 men)	Cars/shift (2 men)	Tons/shift (2 men)
*76-84°	6	5	30	22
86	5	4½	27	20
89	4	4	24	18

*(The production refers to men of 'average' work capacity; if men of better than average are selected, then 7 shovels/min, or 5½ cars/hr, or 33 cars/shift, could be expected.)

Judging from the average oral temperature (100·6°F) and heart rate response (158 beats/min) to an average shovelling rate of 6·1 shovels per minute it appears that the average acclimatized labourer would be able to work *at 86°F wet bulb at a shovelling rate of 5 shovels per minute* without strain (that is, a heart rate of approximately 150 beats/min or lower). At this shovelling rate two men could fill a ¾-ton car in 10 minutes and would be able to complete the cycle of operations in 13 minutes. The production rate should therefore be 4½ cars per hour (27 cars per 6-hour shift) which is 90 per cent of that attained in the cooler working conditions (Table V).

Considering the average oral temperature, heart rate and work rate of the men who were observed working in the 89°F wet bulb environment a shovelling rate of 4 shovels per minute (oxygen consumption of approximately 1·2 litres/min) would not be an excessive work rate for fully acclimatized labourers. At this shovelling rate a ¾-ton car can be loaded in 12 minutes and two men could produce four cars per hour. Two labourers would be able to load and tram 24 cars per 6-hour shift, which is 80 per cent of the output attained in the cool working conditions.

These proposed work output levels in heat compare well with the findings of a previous investigation[1] which showed that a rate of production in shovelling rock into mine cars at temperatures of 87 and 90°F wet bulb was 94 per cent and 83 per cent respectively of that attained at a wet bulb temperature of 81°F.

Rest pauses

On a number of occasions heart rates were measured while the men were tramming and emptying cars. It was generally found that while the men were tramming the

full car, their heart rates remained at the same levels as when they were loading, but that while they were emptying and returning the cars the pulse rates dropped by 10 to 40 beats per minute. This indicates that although the men were performing an essential element of their task, it provided in fact an opportunity for recuperation. Various muscle groups were used differently, allowing a certain degree of relaxation and recuperation of the muscle groups used while shovelling. This is probably the reason for the fact that very few labourers were observed taking rest pauses of longer than a few seconds. Under these working conditions the suggested shovelling rates allow sufficient time for recuperation and there appears to be no need to introduce additional rest periods.

CONCLUSION

This study, carried out on Bantu performing tram-shovelling in a mine, validates the conclusions reached in an earlier study.

These are:

(i) That up to 84°F wet bulb production should not be affected by heat.

(ii) That 'optimum' production at 86°F should be 90 per cent of that in cool conditions and at 89°F it should be 80 per cent.

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REFERENCES

1. COOKE, H. M., WYNDHAM, C. H., STRYDOM, N. B., MARITZ, J. S., BREDELL, G. A. G., KLEYN, V. W., MORRISON, J. F., PETER, J. and WILLIAMS, C. G. 'The effects of heat on the performance of work underground.' *Mine Ventilation Journal*, 177-196, October 1961.
2. MORRISON, J. F., BROWN, A. and WYNDHAM, C. H. 'A comparison of work study assessments and physiological measurements of men at work.' *Trans. S.Afr. Mech. Eng.*, 234-238, May, 1965.
3. MORRISON, J. F., WYNDHAM, C. H., MIENIE, B. and STRYDOM, N. B. 'Energy expenditure of mining tasks and the need for the selection of labourers.' *J. S.Afr. Inst. Min. Met.*, 69, 185-191, 1968.
4. WYNDHAM, C. H., STRYDOM, N. B., MORRISON, J. F., PETER, J. and POTGIETER, Z. U. 'Maximum oxygen intake and maximum heart rate during strenuous work.' *J. Appl. Physiol.*, 14, 927-936, 1959.
5. WILLIAMS, C. G., WYNDHAM, C. H., BREDELL, G. A. G., STRYDOM, N. B., MORRISON, J. F. and PETER, J. 'Circulatory and metabolic reactions to work in heat.' *J. Appl. Physiol.*, 17, 625-638, 1962.
6. WYNDHAM, C. H., STRYDOM, N. B., MORRISON, J. F., WILLIAMS, C. G., BREDELL, G. A. G. VON RAHDEN, M. J. E., HOLDSWORTH, L. D., VAN GRAAN, C. H., VAN RESNBURG, A. J. and MUNRO, A. 'Heat reactions for Caucasians and Bantu in South Africa.' *J. Appl. Physiol.*, 19, 607-612, 1964.
7. WYNDHAM, C. H. 'An operational study of the influence of human and other factors on industrial productivity.' *Trans. S.Afr. Mech. Eng.*, 239-251, May, 1965.
8. WYNDHAM, C. H. 'A survey of causal factors in heat stroke and of their prevention in the gold mining industry.' *J. S.Afr. Inst. Min. Met.*, 66, 125-155, 1965.
9. WYNDHAM, C. H. 'An examination of the methods of physical classification of African labourers for manual work.' *S.Afr. Med. J.*, 40, 275-278, 1966.