Reply to Professor Macpherson's critique

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We are grateful to Professor Macpherson for his critique of our paper and particularly for his constructive criticism of our comments on the weighting given in the P4SR index to the effects of mean radiant temperature (M.R.T.).

However, before we deal in detail with Professor Macpherson's critique it is necessary to put into perspective the various aspects of our study because, in Professor Macpherson's opinion, one of our comments on the effects of radiation 'represents the major scientific finding described in the paper'. This is certainly not our view. We feel that because of the undue emphasis Professor Macpherson gives in his critique to this aspect of the paper he has lost sight of the main purposes of the study.

There were two main aims of the study in the mine at Mount Isa. The first was to determine which of three methods of assessing heat stress, the W.B., the C.E.T., or the P4SR, predicts most accurately the heat stress in the mine. The second aim was to try to set limits, based upon a rational physiological criterion, of heat stress at which the shift should be curtailed and at which work should be stopped. Professor Macpherson criticizes our attempt to achieve these aims by carrying out a study in the mine. We recognize his preference for hot room studies but the purposes for which the indices of heat stress were introduced was to be able to assess heat stress in industry. Academic exercises in hot rooms have their place but, finally, the accuracy of the indices of heat stress must be examined in industry if they are to be of any practical use.

When we plotted oral temperatures against P4SRs we found that the plots for high G.T.s fell well below the rest of the data. This result was quite unexpected but we regard it as an *incidental* finding. It does, however, raise some important issues with regard to the weighting given by P4SR to the effects of radiant heat and we would have been wrong to have ignored these issues.

Professor Macpherson advances two criticisms of

our interpretation of the anomalous finding with regard to oral temperatures at high G.T.s. In the first he disagrees with our division of the oral temperature/P4SR data into two class-intervals of differences between D.B. and G.T. This is a common statistical practice and we used a similar approach in examining the accuracy with which P4SR takes account of differences between D.B. and W.B. In his second criticism Professor Macpherson expresses surprise that the mathematical analysis of the relative weighting given to various heat stress parameters by P4SR shows that the effect of increasing D.B. decreases P4SR. A moment's reflection will enable the reader to appreciate that the net effect of an increase in D.B., *with all other environmental measurements held constant*, would be a lowering of the relative humidity, and, in the range of air conditions examined, this would have the effect of reducing the heat stress as expressed by P4SR.

Dealing with our comments on the effect of M.R.T. on P4SR, Professor Macpherson complains that we misquoted Ferres *et al.* (1954) by inserting in brackets the words 'as measured by G.T.' It would have been better if these words had appeared in italics to indicate that they were inserted by us and if anyone has been misled we apologize. We merely wished to draw attention to the fact that M.R.T. was determined from measurements of G.T., using Bedford's equation, and not by any other method such as a radiometer, for example. Professor Macpherson points out an error in our comments on the conclusion of Ferres *et al.* and we are grateful to him for doing so. The statement at the top of page 264 should be changed to read:

'The statement means that approximately the same effect on P4SR is seen from a change of 10°F. in D.B. as from a 30°F. change in G.T.'

However, our criticism of P4SR still stands. We show that a unit alteration in W.B., G.T., and D.B.

produces a change in P4SR of 0.20, 0.17, and -0.09 respectively. This indicates that in the specific range of air conditions examined a change of 1°F. in G.T. would have the same physiological effect as a 1°F. change in W.B. This deduction from the P4SR nomogram is at variance with the statement in the report by Ferres *et al.* and the conclusions of the only other research group who have carried out an intensive study of the physiological effects of M.R.T. Humphreys, Imalis and Gutberlet (1946) in a paper from ASHVE Laboratories, state that 'the effect of radiant heat on physiological reactions was much smaller than had been anticipated . . . this was particularly true of the higher E.T.s'. Figure 3 of their paper shows that at an E.T. of 90°F., the mean rectal temperature of men engaged on light work, in conditions where there was no difference between D.B. and M.R.T., was 99.8°F. and at the same E.T., but with M.R.T. 40°F. above D.B., the mean rectal temperature was only 100.1°F. In this regard it is important to recall that the weightings given to M.R.T. by P4SR in the original report (McArdle *et al.*, 1947) were based upon only eight experiments. It would be remarkable therefore if the P4SR nomogram was completely accurate in the weighting it gives to the effects of radiant heat.

Our conclusion that approximately the same effect on P4SR should be obtained from a 10°F. change in G.T. as a 3°F. change in D.B. was found by trying, empirically, various weightings of these two temperatures and ascertaining which of these weightings brought the anomalous oral temperatures closest to the regression line (a procedure not unlike that used in the development of the P4SR nomogram). We would be the first to concede that this procedure is not a satisfactory method, statistically, but we consider that our rather limited data on this point do not warrant any more extensive treatment. Our conclusion in this regard seems to be more in line with that of Humphreys *et al.* than with the weighting given to G.T. by the P4SR nomogram.

Professor Macpherson is apparently concerned about the F values quoted on page 260, columns 1 and 2. We should have included the relevant numbers of degrees of freedom applicable to the F values. In both cases the number of degrees of freedom associated with the greater estimate of the mean square was 57 and that associated with the lesser was 1. With these degrees of freedom the relevant F values are:

F 1%	6366
F 5%	250
F 10%	63

So the values quoted in the paper (11.71 and 15.02) indicate no significant difference in the slopes of the lines under discussion.

Professor Macpherson comments on the fact that

in Table 2, although P4SR values decreased over the first three hours, there was no significant difference in oral temperatures over the same period. It is not unusual for a trend to be shown in a stress parameter (which may or may not be significant) while at the same time no significant difference is shown in the strain one is measuring. Whether one shows a significant difference in a measurement depends upon both the magnitude of the variance and the size of the sample.

Professor Macpherson is concerned by the value of 34.81 in Table 1 in Appendix 2 (p. 271). We would agree that the value of 34.81 as the necessary increase in W.B. to give a unit rise in P4SR at various values of G.T. and D.B. at 80°F. W.B. appears absurd. However, it should be remembered that this table is based upon the partial derivatives of P4SR with respect to G.T., D.B., and W.B. The equation for the P4SR which was developed contains quadratic terms of the W.B. and the partial derivatives obtained from this equation are the *instantaneous* effects of a unit change in the variable being considered. The Table was included for illustrative purposes and it was not intended that the changes indicated in the table, if carried out, would have the effect of increasing P4SR by one unit. Clearly the effects of changes should be judged by determining the value of the partial derivatives as indicated on page 270, col. 2 of our paper.

Professor Macpherson also takes issue with our suggestion that, *for the conditions in the mine at Mount Isa*, the effect of mean radiant temperature can be determined with sufficient accuracy by means of the temperature of a mercury thermometer with a blackened bulb. We are aware of the theoretical objections raised by Professor Macpherson but in practice we found, from a comparison of 40 simultaneous measurements of G.T. and a thermometer with a blackened bulb, that only 1 in 20 of the pairs of measurements differed by more than 3.0°F. The Figure with the regression line and the 95% confidence limits was included in the paper submitted to the Journal but, for reasons of space, the Editor decided that the Figure should be excluded. We would be pleased to send a copy of this Figure to interested persons.

Professor Macpherson uses the term 'thermal athlete' to characterize a man with an oral temperature of 97.8°F. at a P4SR of 5.9. It should be noted that the conditions in this case were a G.T. of more than 10° higher than D.B., a condition at which we question the validity of the P4SR index. Even with most careful precautions oral temperature is a less accurate measure of core temperature than is rectal temperature (J. S. Haldane also emphasizes this point in his 1905 paper). Strydom, Morrison, Booyens, and Peter (1956), and Strydom *et al.* (1965) have shown that in conditions similar to those

in Mount Isa mine, oral temperature may be between 1.0 and 3.0°F. lower than rectal temperature. We were not unduly surprised, therefore, to find in our results an oral temperature of 97.8°F. at a P4SR of 5.9 in the particular circumstances we have referred to. We, as we stated in our paper, would have preferred to measure rectal temperatures but the management of the mine did not feel that this would be acceptable to the average miner. The great variability of oral temperature has the effect of increasing the variance in oral temperature about the regression line of oral temperature/P4SR. For this reason we did not expect the high order to correlation, say 0.90, that one gets between rectal temperatures and heat stress index values in hot room studies. Nonetheless it was encouraging to find, in spite of the greater variability in oral temperatures, a significant correlation of 0.75 between oral temperature and P4SR in the study in the mine at Mount Isa.

Professor Macpherson also notes, as we did, that nearly all the high P4SR values occurred in circumstances where G.T. was more than 10°F. higher than D.B. We consider this to be due to the 'excessive' weighting given to G.T. by the P4SR index. However, Professor Macpherson seeks to explain the anomalous oral temperatures in these conditions by the fact that the 'men did not work at the rate necessary for the prescribed P4SR values' and postulates that they withdrew to cool places 'for the good reason that they could not, without unacceptable distress, do otherwise'. We must challenge this contention. It implies that under all of the other 69 heat stress conditions, the assessments of work rate were correct but when the observers came to assess the work rates under conditions of high G.T. their observations were invalid.

Professor Macpherson takes us to task for stating that this is the first time such a study has been attempted in the industrial context and he quotes Haldane's paper (1905) and Caplan and Lindsay (1946) to refute our statement. However, Haldane measured rectal temperatures *only once on two miners*. All the other observations in the mine were made upon himself or on his scientific colleagues when they were climbing about in the mine. We doubt very much whether their rectal temperatures were representative of those of the miners carrying out their ordinary work in the mine. Caplan and Lindsay's experiment was artificial. The subjects of the experiment were selected because they 'were acclimatized to hot and humid conditions' up to 93°F. and the work consisted of *only three hours* of drilling by hand, under direct supervision, into granite blocks, imported into the mine for the

purposes of the experiment. The experiment bore little relationship to the conditions under which the men worked in the course of their everyday activities. Professor Macpherson also refers to the *innumerable* occasions on which the reactions of miners in their working conditions have been studied; we would be grateful for a list of references to such studies. The novelty of our approach is not that we made measurements of oral temperatures and of the four environmental parameters in working places in the mine at Mount Isa but that we used these measurements:

(1) to examine the accuracy, by statistical methods, with which three indices of heat stress can be used to predict oral temperatures of men at work in the mine at Mount Isa, and

(2) to set limits of heat stress for a six-hour shift and for stopping work.

We believe that our study is the first in which an examination has been made of the accuracy with which heat stress indices predict the physiological reactions of workmen in a mine when they are carrying out their ordinary work under different levels of heat stress. We make no claim that this approach does away with the need for hot room studies; rather we see it as a necessary supplement to hot room studies and as an essential step in the validation of conclusions drawn from such studies. We trust that Professor Macpherson's comments on page 75 of his critique '... in the interpretation of their results, they clearly hold their observations to be more trustworthy than those made in the laboratory by others' will be seen in the light of our last statement.

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