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⑥ Perception of Effort during Constant Work to Self-Imposed Exhaustion

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⑪ 22 Dec 77

⑫ 26p.

⑯ 3E161102BS08

Mail Proofs to:

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Running Title: RPE during work to exhaustion

⑭ USARIEM-M-14/78

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER: M 10/78
2. GOVT ACCESSION NO.:
3. RECIPIENT'S CATALOG NUMBER:
4. TITLE (and Subtitle): Perception of Effort during Constant Work to Self-Imposed Exhaustion
5. TYPE OF REPORT & PERIOD COVERED:
6. PERFORMING ORG. REPORT NUMBER:
7. AUTHOR(s):
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8. CONTRACT OR GRANT NUMBER(s):
9. PERFORMING ORGANIZATION NAME AND ADDRESS:
US Army Research Institute of Environmental Medicine, Natick, MA 01760
10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS:
6.11.02.A Defense Research
Army 3E161102BS08 84182005
11. CONTROLLING OFFICE NAME AND ADDRESS:
US Army Medical Research & Development Command
Washington, DC 20314
12. REPORT DATE: 22 Dec. 1977
13. NUMBER OF PAGES: 22
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office): Same
15. SECURITY CLASS. (of this report): Unclassified
15a. DECLASSIFICATION/DOWNGRADING SCHEDULE:
16. DISTRIBUTION STATEMENT (of this Report): Distribution of this document is unlimited
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report): NA
18. SUPPLEMENTARY NOTES: NA
19. KEY WORDS (Continue on reverse side if necessary and identify by block number):
perceived exertion, exhaustion, RPE

V(E), V(E)/VO2, V(E)/CO2

[illegible]

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The purpose of this study was to describe the pattern of change in effort sense and the value of this pattern in predicting work end point at relatively high work intensity (80% $\dot{V}O_2$ max). ~~The~~ patterns of change of various physiological functions were also observed. Two modes of work (walking and running) were compared to ascertain generalizability of results. ~~Twenty-six~~ healthy male volunteers, served as subjects. Time to exhaustion (ET) did not differ between walking and running. As work continued during both tasks, significant increases of $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}_{CO_2}$ and HR and a significant decrease

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of ET_{CO_2} were observed; while $\dot{V}O_2$ and R remained fairly constant. $\dot{V}O_2$ and $\dot{V}_E$ during the run were about 5% greater than during the walk; there were no differences in other measures. Ratings of perceived exertion (RPE) from the Borg Scale were identical for both conditions, increasing in a near linear fashion from a value of 12.9 at 25% of total work time to 18.9 at exhaustion. RPE obtained at 25 and 50% ET were extrapolated to time of exhaustion; the point of intercept corresponded to RPE for maximal work. At exhaustion, Ss rated perception of respiratory exertion for the walk as less than that for the run; perception of leg exertion was not different for the ~~two~~ conditions. Plasma lactate, epinephrine and norepinephrine concentrations following exercise did not differ between the two conditions. The findings for the walking experiment were essentially replicated in a second investigation involving another 28 Ss. It is concluded that, with the exception of $\dot{V}O_2$ and some ventilatory parameters, walking and running at the same relative work intensity resulted in comparable perceptual and physiological responses. Psychophysical judgments made early during work were found to be reasonably accurate predictors of exhaustion time.

Abstract

The purpose of this study was to describe the pattern of change in effort sense and the value of this pattern in predicting work end point at relatively high work intensity (80% $\dot{V}O_2$ max). The patterns of change of various physiological functions were also observed. Two modes of work (walking and running) were compared to ascertain generalizability of results. Twenty-six healthy male volunteers served as subjects. Time to exhaustion (ET) did not differ between walking and running. As work continued during both tasks, significant increases of $\dot{V}_E$, $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}_{CO_2}$ and HR and a significant decrease of ET_{CO_2} were observed; while $\dot{V}O_2$ and R remained fairly constant. $\dot{V}O_2$ and $\dot{V}_E$ during the run were about 5% greater than during the walk; there were no differences in other measures. Ratings of perceived exertion (RPE) from the Borg Scale were identical for both conditions, increasing in a near linear fashion from a value of 12.9 at 25% of total work time to 18.9 at exhaustion. RPE obtained at 25 and 50% ET were extrapolated to time of exhaustion; the point of intercept corresponded to RPE for maximal work. At exhaustion, Ss rated perception of respiratory exertion for the walk as less than that for the run; perception of leg exertion was not different for the two conditions. Plasma lactate, epinephrine and norepinephrine concentrations following exercise did not differ between the two conditions. The findings for the walking experiment were essentially replicated in a second investigation involving another 28 Ss. It is concluded that, with the exception of $\dot{V}O_2$ and some ventilatory parameters, walking and running at the same relative work intensity resulted in comparable perceptual and physiological responses. Psychophysical judgments made early during work were found to be reasonably accurate predictors of exhaustion time.

Key Words: perceived exertion, exhaustion, RPE

Perception of Effort during Constant Work to Self-Imposed Exhaustion

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It has been demonstrated that rating of perceived exertion (RPE), from the psychophysical category scale developed by Borg (1973), is a linear function of work intensity (Borg and Noble, 1974; Frankenhaeuser et al., 1969; Morgan and Borg, 1976; Skinner et al., 1973). Within the context of increasing work intensity, RPE, both as a separate entity and in conjunction with other variables, has also been shown to be a good predictor of the point at which an individual will discontinue work (Morgan and Borg, 1976). However, these previous findings are not surprising in that one would expect the perception of the degree of work difficulty to increase as the intensity of work increases from light to heavy. Further, since many physiological measures (eg., oxygen consumption, heart rate, minute ventilation) also increase as a function of increasing work intensity, the fact that RPE increases as a function of these physiological measures (Borg and Linderholm, 1967; Borg and Noble, 1974; Edwards et al., 1972; Ekblom and Goldharg, 1971) is also not surprising.

Transient increases in RPE during prolonged work at a constant work intensity have been previously observed (Kamon et al., 1974; Noble et al., 1973; Pandolf et al., 1972); however, work was performed at a relatively low intensity and was discontinued at a time specified a priori. The decision to discontinue hard physical work has, no doubt, a complex basis. One's perception of exertion must play a primary role and is probably representative of the summation and/or interaction of other factors which contribute to the decision to discontinue work. The intent of this study was to describe the pattern of change of effort sense and the value of this pattern in predicting work end point, during work of relatively high intensity (80% $\dot{V}O_2$ max) to self-imposed exhaustion, i.e., the point at which the subject decided to discontinue work. The patterns of change of various physiological functions were also observed. Two modes of work were compared, walking and running, to ascertain the generalizability of results obtained and the study was repeated in a separate group of subjects, with minor modifications, in the walking mode, to ascertain reproducibility of the results obtained.

Methods

Twenty-six healthy male volunteers served as subjects for this study (Group I). The mean age, height and weight was 22.3 yrs (s.e. = 0.42), 178.1 cm (s.e. = 1.2) and 75.1 kg (s.e. = 1.3), respectively. Each volunteer was informed of all procedures to be used and signed a statement of informed consent in the presence of a physician who was not involved in the actual investigation.

Prior to experimental testing, subjects were trained to walk and run on a motor driven treadmill and familiarized with the testing procedures. Upon his arrival at the laboratory for experimental testing, the subject completed a questionnaire pertaining to events of the previous 24 hours. Questions dealt with physical activity, diet, sleep, alcohol and drug consumption, and sense of well being. If the questionnaire revealed any factor thought to influence experimental results, the subject was not tested at that time. Paper electrodes were affixed to his upper torso for the monitoring of EKG. All exercise tests were performed on the treadmill with the subject attired in loose fitting shorts, socks, and running shoes. Tests were performed between 0830 and 1600 hours; the laboratory temperature was maintained at 22°C (s.d. = 1.0). Each subject performed four exercise tests on separate days: $\dot{V}O_2$ max in the walking mode (Max W), $\dot{V}O_2$ max in the running mode (Max R), walk to self-imposed exhaustion at 80% $\dot{V}O_2$ Max W (80W), and run to self-imposed exhaustion at 80% $\dot{V}O_2$ Max R (80R). Max W and Max R were performed on consecutive days, while at least two days rest from testing was allowed prior to 80W and 80R. The order for walking or running tests was randomly assigned.

Max W and Max R were determined in continuous tests. For Max W the subject walked at a rate of 3.5 mph at 0% grade during the initial 2 min; the grade was then increased 2.5% at 2 min intervals until the subject was no longer able to continue. Heart rate (HR) and ratings of perceived exertion (RPE) were obtained during the last 10 sec of each two minute period. End tidal CO_2 (ET_{CO_2}) was measured and timed collection of expired air obtained during the last 30 seconds of walking at 5%, 10%, and all grades thereafter. For Max R the subject ran at a rate of 6.5 mph at 0% grade during the initial 2 min. The grade was then increased 2.0% at 2 min intervals until the subject was no longer able to continue. For each 2 min period, HR and RPE were obtained during the last 10 sec, while ET_{CO_2} was measured and a timed collection of expired air was obtained during the last 30 seconds of running at all grades.

From the submaximal results of the tests for Max W and Max R, treadmill grades of incline corresponding to 80% Max W (mean = 3.5 mph, 16.7% grade) and 80% Max R (mean = 6.5 mph, 4.4% grade) were ascertained. Prior to each endurance test, subjects were instructed to continue to walk or run until they could no longer continue; at this point they so informed the test moderator.

Effort was made to provide a constant and equal testing environment. Extraneous sensory input was kept to a minimum. The experimental setting was presumably bland; no interaction between the subject and investigative team, other than that related to the experiment, was allowed. Investigators often employ a variety of incentives in an attempt to motivate subjects to perform maximally. Since these incentives are non-systematic and differentially adopted across subjects, the net result is that variability rather than uniformity is created. For this reason no attempt to "motivate" subjects to continue work was made in the present investigation. Presumably, the decision to terminate work was governed by "intrinsic" factors as opposed to "extrinsic" reward systems. It is our view that such an approach is preferred in an investigation of the type described here. Heart rate, RPE, and ET_{CO_2} were measured and timed collections of expired air obtained during the latter 30 sec of 5 min intervals and at the completion of the test. Only at the completion of each of the endurance tests the subjects were also asked to rate (on the Borg scale) the degree of exertion specifically perceived for the legs (RPEL) and for respiration (RPER). Endurance time was taken as the time at which the subject informed the test moderator he could no longer continue the test. Four minutes following the completion of each endurance test anticubital venous blood samples (25 ml) were obtained for the determination of blood lactate, plasma epinephrine, and plasma norepinephrine concentrations.

Heart rate was measured from standard EKG tracings and ratings of perceived exertion, according to the revised Borg Scale (Borg, 1973), were simultaneously obtained. To determine ET_{CO_2}, 10 consecutive breaths were continuously sampled for CO_2 at the mouth using a Beckman LB-2 infra-red CO_2 analyzer. For each breath, peak CO_2 was determined and the mean of the 10 determinations taken as ET_{CO_2}. Expired air was collected via a Collins Triple-J valve into vinyl Douglas bags and analyzed for fraction of O_2 with a Beckman OM-11, polarigraphic oxygen analyzer and for fraction of CO_2 with a Beckman LB-2 infra-red CO_2 analyzer. Expired air volume was ascertained by withdrawing the contents of each Douglas bag into a calibrated tissot spirometer. Minute ventilation ($\dot{V}_E$), corrected to BTPS, was calculated. Oxygen consumption, corrected to STPD, was calculated by the Haldane method. Other calculated parameters included respiratory exchange ratio (R), ventilatory equivalent for oxygen consumption ($\dot{V}_E/\dot{V}O_2$), and ventilatory equivalent for carbon dioxide production ($\dot{V}_E/\dot{V}_{CO_2}$). Blood lactate concentration was determined by a standard enzymatic technique. Plasma epinephrine and norepinephrine concentrations were assayed by the trihydroxyindole method of Griffiths et al. (1970) using an Aminco-Bowman spectrophotoflourometer equipped with an ellipsoid condensing system.

Max W and 80W (mean = 3.5 mph, 14.6% grade) were repeated in a separate group of 28 subjects (Group II) with physical characteristics similar to those of the previous subjects. The mean age, height and weight was 20.1 yrs (s.e. = 0.51), 176 cm (s.e. = 1.07) and 74.9 kg (s.e. = 1.9), respectively. During this 80W, however, data were only obtained at 5 min and at the completion of the test. This modification was used because of our concern that repeated interaction between subject and experimentor, involved in sampling data at 5 min intervals, had the potential to influence results obtained.

Results

Table 1 lists maximal values obtained for Group I (Max W and Max R) and Group II (Max W). $\dot{V}O_2$ max and $\dot{V}_E$ max were 5.5 and 6.2%, respectively, greater during Max R than during Max W. No other differences were apparent between the two tests. While not statistically different, $\dot{V}O_2$ max for Group II was less than that for Group I. Although $\dot{V}_E$ max for Group II was not different from that of Group I, $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}_{CO_2}$ for Group II were significantly greater, 2.7 and 2.1, respectively, and ET_{CO_2} was significantly smaller, 1.7 torr, than those of Group I.

(Insert Table 1 about here)

Figure 1 depicts the means (± s.e.) of serially measured parameters, as a function of percent endurance time, for Group I, 80W and 80R, and for Group II, 80W. Oxygen consumption was relatively stable throughout all of the tests, and in each case was equal to 80% $\dot{V}O_2$ max. Due to differences in $\dot{V}O_2$ max for the three conditions, actual $\dot{V}O_2$ was greater for Group I:80R (44.8 ml/kg•min) than for Group I:80W (42.6 ml/kg•min) which in turn was greater than Group II:80W (40.1 ml/kg•min). During both 80W and 80R for Group I, $\dot{V}_E$ exhibited a linear increase ($0.8\ L/m^2 \cdot min \cdot min^{-1}$) as a function of time. In both cases, the initial measure of $\dot{V}_E$ (at about 25% ET) was 72% $\dot{V}_E$ max, while the final measure of $\dot{V}_E$ (at the end of the test) was 89% $\dot{V}_E$ max. Minute ventilation for 80R was maintained about 5% greater than that for 80W; $\dot{V}_E$ for Group II:80W was similar to that of Group I:80W. Progressive increases of $\dot{V}_E/\dot{V}O_2$ (0.4/min) and $\dot{V}_E/\dot{V}_{CO_2}$ (0.4/min) and a progressive decline of ET_{CO_2} (0.3 torr/min) occurred for Group I during both 80W and 80R. There were no differences in these variables between 80W and 80R, and responses for Group II:80W were similar to those for Group I:80W. Measures of R were relatively constant throughout all of the tests and not significantly different among the experimental conditions. Heart rate also exhibited transient increases (about 1 bpm/min) as a function of time during both 80W and 80R for Group I. In both cases, HR at 25% ET was 88% of HR max, while at the completion of the test HR was 96% of HR max. There were no differences in HR between 80W and 80R for Group I, and HR for Group II:80W was similar to that for Group I:80W.

(Insert Figure 1 about here)

Perception of effort during 80W and 80R were identical for Group I. Neither were there differences between Groups I and II for effort sense during 80W. Perception of effort exhibited a linear increase of about 0.4/min during the initial 75% ET (about 13 min). In all cases ratings were about 66% of RPE_{max} at 25% ET, and were in excess of 95% of RPE_{max} at the completion of all tests.

Table 2 lists values for variables measured only upon completion of each test. It will be noted that there was no difference in ET between 80R and 80W for Group I, while for Group II:80W, ET was significantly less than that of Group I. There were no differences in the degree of exertion specifically perceived for the legs (RPEL) between 80R and 80W for Group I, nor did RPEL for Group II:80W differ from that for Group I. For Group I, the degree of exertion specifically perceived for respiration (RPER) was significently less for 80W than that for 80R. There were no differences in lactate epinephrine or norepinephrine between 80R and 80W for Group I, nor did these parameters for Group II:80W differ from those for Group I. Lactate increased seven to nine fold over the mean resting value of 1.1mM. Norepinephrine increased about four fold over the mean resting value of 0.29 ug/L, while epinephrine increased about three fold over the mean resting value of 0.03 ug/L.

(Insert Table 2 about here)

Discussion

Prior to treating the data related to the major objective of this study, i.e., perceptual and physiological changes during prolonged work to self-imposed exhaustion at a constant intensity, it appears appropriate to first comment on a related topic, maximal work. Maximal aerobic power was significantly greater (5%) for running than that for walking; this increase is essentually what one would expect from additional active muscle mass involved in running as opposed to walking. This same observation has been previously reported (McArdle *et al.*, 1973). The 6.2% greater $\dot{V}_E$ max observed during running was appropriate for both the $\dot{V}O_2$ max and $\dot{V}_{CO_2}$ max, as indicated by maximal values of $\dot{V}_E/\dot{V}O_2$, $\dot{V}_E/\dot{V}_{CO_2}$, and ET_{CO_2} which were not different between walking and running. With the expected exceptions of $\dot{V}O_2$ max and $\dot{V}_E$ max, maximal values for the various physiological parameters measured were comparable between walking and running. This indicates that, under conditions of maximal work, near equal physical stress, as sensed from these physiological factors, was experienced under conditions of both walking and running. Therefore, to the extent that these factors affected the perception of the degree of difficulty of maximal work, physiological input provided while running was similar to that while walking. This is perhaps reflected in the near equal values obtained for perception of effort under both conditions of maximal work.

When Max W was repeated in a separate group of subjects (Group II) the results were similar to those obtained in the first investigation (Group I). A difference of 2.8 ml/kg·min for $\dot{V}O_2$ max, as observed between the two groups, could be meaningful if testing the effects of experimental intervention in a single group of subjects. However, a difference of this magnitude observed between two volunteer groups of subjects is not necessarily indicative of different physical fitness levels and is probably not of physiological significance. Likewise, the slightly greater degree of hyperventilation indicated for Group II when compared to Group I, as evidenced by greater $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}_{CO_2}$ and lesser ET_{CO_2}, was hardly of physiological significance. Again, differences of this small magnitude could be expected between groups of volunteer or randomly selected subjects.

At first glance, the endurance times to exhaustion observed in this study appear low. Certainly others (Gleser and Vogel, 1971; Gleser and Vogel, 1973; Hermansen et al., 1967) have observed longer endurance times at 80% $\dot{V}O_2$ max. However, the intent of these earlier studies was to obtain a work end-point which was brought about by some physiological limitation, e.g., depletion of muscle glycogen. As such, procedures designed to extend work performance to the fullest (e.g., rest periods, motivation) were employed. Our primary interest was to obtain a work end-point resulting from a conscious decision that the work, as an entity unto itself, had become too difficult, independent of extraneous stimuli. As such, in our testing procedure we consciously attempted to eliminate extraneous stimuli which may have influenced the subject's performance. When we repeated the walk to exhaustion in a separate group of subjects, we sampled data only at five minutes and at the end of the test. Endurance time for this group of subjects was less than for our first group. It is possible that for the first group of subjects the procedures involved in sampling data at five minute intervals were sufficient to distract from attention to stimuli provided by the work, thereby allowing an increase in endurance time. It is of interest to note that when Michael and Eckardt (1972) asked subjects to select a work load which would exhaust them in fifteen minutes, they chose a work load corresponding to about 85% $\dot{V}O_2$ max. Weiser et al. (1973) found a mean endurance time of 36 minutes when subjects cycled at 56% $\dot{V}O_2$ max under experimental conditions which were also relatively void of extraneous sensory input.

As previously stated, one's perception of exertion must play a primary role in the decision to discontinue work. Therefore, it is not surprising that at exhaustion, subjects rated work about 19 on the Borg scale (verbal description: very, very hard). However, it is notable that RPE exhibited near linear patterns of increase throughout the initial 75% of the endurance tests. Further, when extrapolated to 100% ET from RPE obtained during the initial 75% of the endurance tests, the point of intercept corresponded to RPE obtained during maximal work. Because the increase was linear, this was true if extrapolation was performed from ratings obtained even at 25 and 50% ET. This indicated that the early pattern of change of RPE during prolonged work can be used as a sensitive predictor of the point of self-imposed exhaustion, and this has also been demonstrated for maximal exercise involving progressively increasing work loads (Morgan and Borg, 1976).

Others (Kamon et al.,1974; Pandolf et al., 1972) have found RPE to be a curvelinear function of time during 30 minutes of work at a constant intensity. In these studies work was performed at a lower relative intensity and at the test's completion subjects were under less stress (e.g., heart rates were less than 160 bpm and perception of effort was less than 16 on the Borg Scale). One common factor between these previous studies and ours is that the response pattern of RPE was similar to the pattern of physiological responses. While their plots for physiological responses were remarkably curvelinear, the present findings tended more toward linearity.

There is every indication that progressive hyperventilation occurred throughout the endurance tests as evidenced not only by the progressive increase of $\dot{V}_E$, but more so by progressive increases of $\dot{V}_E/\dot{V}O_2$ and $\dot{V}_E/\dot{V}_{CO_2}$ and a progressive decline of ET_{CO_2}. This hyperventilation was probably stimulated by a decrease in arterial pH. That the work in these tests resulted in significant metabolic acidosis is indicated by the high concentration of blood lactate observed at exhaustion. Aside from the obvious similarity between the linear pattern of increase of RPE with that of $\dot{V}_E$, the question remains as to whether $\dot{V}_E$ affected RPE. Noble et al. (1973) observed that ventilatory parameters accounted for the greatest amount of RPE variance among subjects performing prolonged work under both neutral and heated conditions. Bakers and Tenney (1970) have shown that subjects were capable of accurately perceiving differences in ventilatory sensations associated with differences in ventilatory volume and rate. Modification of perceived exertion by means of hypnotic suggestion, has consistently been associated with changes in ventilatory minute volume (Morgan et al., 1973; Morgan et al., 1976). Like $\dot{V}_E$ max, $\dot{V}_E$ for running was about 5% greater than that for walking at 80% $\dot{V}O_2$ max. This greater ventilation was appropriate for the 5% greater $\dot{V}O_2$ required for the running test, as evidenced by measures of $\dot{V}_E/\dot{V}_{O_2}$, $\dot{V}_E/\dot{V}_{CO_2}$ and ET_{CO_2} which were not different between the two conditions. However, at exhaustion, when asked to rate the degree of exertion specifically perceived for respiration, subjects gave significantly higher ratings for running than for walking, corresponding to the ventilatory differences between the two conditions. Additionally, at exhaustion under both conditions, subjects perceived breathing as being hard to very hard. These data suggest that perception of difficulties in breathing did contribute to the decision to discontinue work.

The relative constancy of R throughout all tests suggests these measures were probably representative of metabolic respiratory quotient (RQ), free from ventilatory influences. That RQ was above 0.90 in all instances indicates preferential utilization of carbohydrate as substrate for metabolism during the work. A preferential utilization of carbohydrate is further suggested by the high levels of blood lactate observed at exhaustion.

The response of heart rate, as a function of % ET was linear during the initial 75% of the endurance tests. The relative lack of increase of heart rate during the latter 25% of the test is explainable. At this time, heart rate was in excess of 95% of maximal heart rate, leaving very little room for further increase. In the previous studies of 30 minutes of continuous work (Kamon et al., 1974; Pandolf et al., 1972), the response curves for RPE and heart rate over time described a positively decelerating power function despite the fact that these measures were well below maximal values. There was only a slight increase in heart rate after the initial 5-10 minutes of work. It is possible that the greater increase in heart rate found in the present study reflected increased sympathetic stimulation. Both plasma epinephrine and norepinephrine concentrations were increased, and the plasma norepinephrine levels to the extent which cardioacceleration could be expected. It is unlikely that plasma catecholamines were increased in the previous studies. Haggendul et al. (1970) have indicated significant increases in plasma norepinephrine occurred only when the relative intensity of work was in excess of 75% $\dot{V}O_2$ max. Relative work intensities in the previous studies ranged between 40 and 68% $\dot{V}O_2$ max. Whether the high heart rates observed in the present study directly influenced perceptual responses and the decision to discontinue work, or simply mirrored the physical stress subjectively experienced during prolonged work cannot be stated. The latter explanation has been used by others (Ekblom and Goldbarg, 1971) including Borg (1973), to account for the observed interrelationship between heart rate and RPE as functions of differences in work intensity.

There is little doubt that the perception of local fatigue in the legs contributed to the decision to discontinue work in the present study. At the completion of all endurance tests, subjects rated the work of the legs to be in excess of 17 (verbal description: very hard) on the Borg scale.

With the few previously noted exceptions, when work at 80% $\dot{V}O_2$ max was performed to exhaustion, physiological and perceptual responses obtained while running were remarkably similar to those obtained while walking. Results obtained when the walk at 80% $\dot{V}O_2$ max was repeated in a separate group of subjects were also similar to those obtained for the initial group. Others have observed that when work of different modes was performed at equal oxygen consumption, RPE was greater for the work which involved the smaller muscle mass. For example, at equal oxygen consumption, RPE was greater for cycling vs. treadmill work (Skinner <u>et al</u>., 1973) and for arm vs. leg work (Gamberle, 1972). Again, differences in $\dot{V}O_2$ max with different work modes are related to differences in working muscle mass, work with the greater mass results in a higher $\dot{V}O_2$ max. Therefore, when expressed as a function of relative intensity (i.e., % $\dot{V}O_2$ max), RPE was found to be equal across work modes (Ekblom and Goldbarg, 1971; Sargent and Davies, 1973). In the present study work was equated on a relative basis and for RPE the response curve while running was superimposable upon that while walking. Prior to our study it was not clear as to whether the relationship between RPE and relative work intensity would hold for walking vs. running. Two previous studies (Noble and Borg, 1971; Noble et al., 1973) compared RPE as a function of treadmill speed while walking to that while running. When RPE was plotted as a function of heart rate, RPE was significantly greater for walking than that for running at a given heart rate. Since heart rate is also a function of relative work intensity, these data suggested that the functional relationship between RPE and relative work intensity for running might be different from that for walking. Moreover, plotting RPE as a function of relative work intensity with data from an earlier study (Noble and Borg, 1971), reveals the percent $\dot{V}O_2$ max at which a given RPE occurred was about 20% greater for running than for walking. The authors do not state in which work mode $\dot{V}O_2$ max was measured. Regardless, the largest expected difference due to work mode would have been about 5%. Additionally, several authors (Pandolf and Noble, 1973; Stamford and Noble, 1974) have reported that for cycling at equal relative work intensities, RPE was greater for work performed at lower (<40 rpm) than for higher pedal rates (>60 rpm). These authors speculated that intense local muscular discomfort associated with work at the lower pedal rates was responsible for the increased RPE. The present study permitted a test of whether the same would be true for walking on an incline. Of course, the present data support the contention that RPE is a function of relative work intensity independent of mode of work and other factors.

In summary, our present results indicate that during work of relatively high intensity to exhaustion, the perception of exertion increases in a linear fashion as a function of time. The rating of perceived exertion was near maximal at exhaustion. Some physiological parameters (e.g., $\dot{V}_E$ and HR) had similar patterns of response. Changes in perception of exertion occurring early during work were a sensitive predictor of exhaustion time. With the exception of some ventilatory parameters, results obtained while walking were essentially the same as those obtained while running, indicating a certain generalizability of these results. Finally, the results obtained were replicated in a separate group of subjects.

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Table 1. Means and standard errors from Max R and Max W for Group I and from Max W for Group II.

	Group I (n=26)		Group II (n=28)
Variable	Max R	Max W	Max W
$\dot{V}O_2$ (ml/kg·min)	56.0 (1.2)	52.9 (1.0)*	50.1 (1.1)
$\dot{V}_E$ (L/m^{2}BSA·min)	70.8 (1.3)	66.4 (1.3)*	67.1 (1.4)
$\dot{V}_E/\dot{V}O_2$	32.4 (0.9)	32.2 (0.8)	34.9 (0.8)$^+$
$\dot{V}_E/\dot{V}_{CO_2}$	33.8 (0.7)	33.2 (0.8)	35.3 (0.6)$^+$
R	0.96(0.02)	0.97(0.01)	0.99(0.02)
ET_{CO_2} (torr)	36.1 (0.8)	36.7 (0.6)	35.0 (0.6)$^+$
HR (bpm)	196 (2)	196 (2)	194 (3)
RPE	19.2 (0.4)	19.4 (0.2)	19.0 (0.3)

* Significantly (P <05) lower than Max R.

$^+$ Significantly (P<.05) different from Group I, Max W.

Table 2. Means and standard errors for endurance time and selected perceptual and biochemical variables for Group I (80R and 80W) and Group II (80W).

	Group I (n=26)		Group II (n=28)
Variable	80R	80W	80W
Endurance Time (min)	22.8 (2.1)	24.1 (2.2)	18.0 (1.8)+
RPE (Legs)	17.5 (0.5)	17.9 (0.5)	17.0 (0.6)
RPE (Respiration)	17.7 (0.4)	16.6 (0.4)*	15.0 (0.4)#
Lactate (mM)	9.2 (0.8)	8.8 (0.8)	7.3 (0.6)
Epinephrine (ug/L)	0.07(0.01)	0.08(0.02)	0.09(0.02)
Norepinephrine (ug/L	1.20(0.17)	1.34(0.17)	1.13(0.11)

* Significantly ($P<.05$) lower than 80 Run (Group I).

+ Significantly ($P<.05$) lower than 80 Walk (Group I).

Significantly ($P<.05$) lower than 80 Run (Group I).

Figure Caption

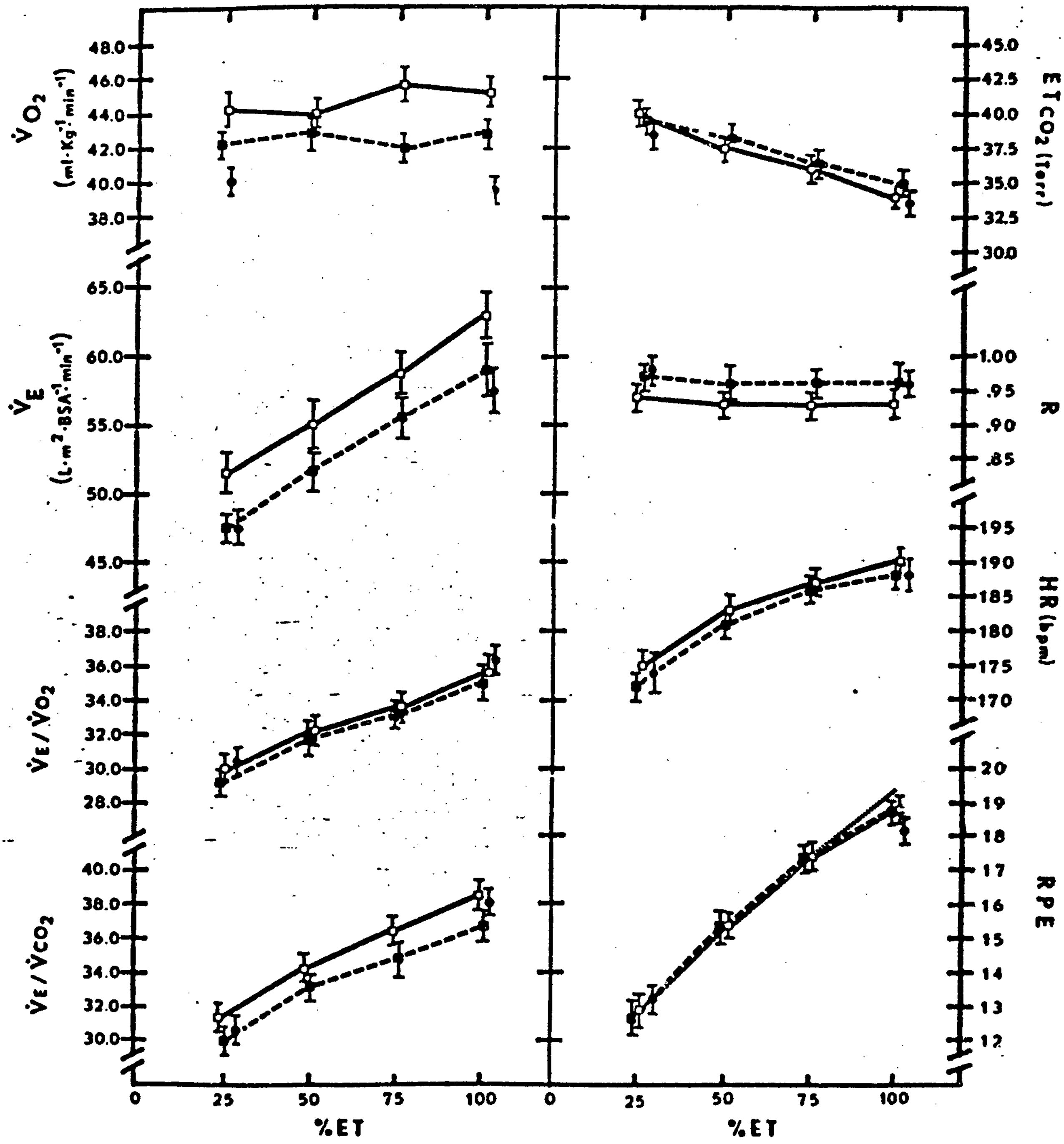
Figure 1. Means (± s.e.) of serially measured parameters as a function of percent endurance time for Group I: 80 Run (□—□), Group I: 80 Walk (□━□) and Group II: 80 Walk (○). The dotted line for RPE represents extrapolation to 100% Endurance Time from ratings at 25, 50, and 75% of total performance times.

The views of the author do not purport to reflect the positions of the Department of the Army or the Department of Defense.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

The authors are indebted to Damon Burton, Domenic Castignetti, Dan Ebert, Vincent Forte and Adrian Lussier for their excellent technical assistance.

This work was presented, in part, at the Annual Meeting of the American College of Sports Medicine, New Orleans, LA, Spring 1975. (Abstract: Med. Sci. in Sports 7:81, 1975).



$\dot{V}O_2$ (ml·Kg⁻¹·min⁻¹)
48.0
46.0
44.0
42.0
40.0
38.0
$\dot{V}_E$ (L·m²·BSA⁻¹·min⁻¹)
65.0
60.0
55.0
50.0
45.0
$\dot{V}_E/\dot{V}O_2$
38.0
36.0
34.0
32.0
30.0
28.0
$\dot{V}_E/\dot{V}CO_2$
40.0
38.0
36.0
34.0
32.0
30.0
0
25
50
75
100
%ET
ETCO₂ (torr)
45.0
42.5
40.0
37.5
35.0
32.5
30.0
R
1.00
.95
.90
.85
HR (bpm)
195
190
185
180
175
170
RPE
20
19
18
17
16
15
14
13
12
0
25
50
75
100
%ET