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lowest 5s PO divided by time). Absolute PP and MP for both UB and LB did not differ between groups. A comparison of PO's made relative to BW showed B to have higher values than C: 11.25 vs 10.25 W/kg for LB PP ($p < .01$) and 9.21 vs 7.96 W/kg for LB MP ($p < .001$). Similar PO relationships were found for the UB where PP and MP values were higher for B than C: 7.61 vs 6.76 W/kg ($p < .01$) and 6.07 vs 4.95 W/kg ($p < .001$), respectively. Concomitantly, PD was lower in B than C for both the UB ($p < .01$) and LB ($p < .001$). These data show that significant differences exist in the anaerobic performance of aerobically trained athletes compared to subjects who are not highly trained and that these differences are reflected in the musculature of the UB as well as the legs.

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Upper and Lower Body Anaerobic Power:
Comparison between Biathletes
and Control Subjects

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Abstract

This study compared power outputs (PO) from both the upper body (UB) and lower body (LB) Wingate tests of anaerobic power between biathletes and control subjects. Ten biathletes (B) selected by the British Ski Federation for potential assignment to the British team and 13 control (C) subjects cranked or pedalled the same Bodyguard ergometer at maximal RPM's for 30s against resistances of 2.94 and 4.41 joules/rev/kg body weight (BW), respectively. PO's were calculated in watts (W) and expressed as peak power (PP, highest 5s interval), mean power (MP, the mean for 30s), and power decrease (PD, difference between PP and lowest 5s PO divided by time). Absolute PP and MP for both UB and LB did not differ between groups. A comparison of PO's made relative to BW showed B to have higher values than C: 11.25 vs 10.25 W/kg for LB PP ($p < .01$) and 9.21 vs 7.96 W/kg for LB MP ($p < .001$). Similar PO relationships were found for the UB where PP and MP values were higher for B than C: 7.61 vs 6.76 W/kg ($p < .01$) and 6.07 vs 4.95 W/kg ($p < .001$), respectively. Concomitantly, PD was lower in B than C for both the UB ($p < .01$) and LB ($p < .001$). These data show that significant differences exist in the anaerobic performance of aerobically trained athletes compared to subjects who are not highly trained and that these differences are reflected in the musculature of the UB as well as the legs.

Introduction

The energy sources available for muscular contraction can be divided into aerobic and anaerobic components. Many studies have examined the aerobic component where the measurement of maximal aerobic power has been used as the criterion of performance capacity. This measurement has been applied to various populations so that normal values are available for sedentary individuals as well as for athletes from various disciplines (1).

The role of anaerobic metabolism during exercise has been extensively studied in man but chiefly in terms of the oxygen debt mechanism and patterns of oxygen uptake (16,17) with little emphasis on complete exhaustion and, therefore, capacity for anaerobic energy release (19). Furthermore, only in recent years has attention been given to the investigation of anaerobic capacity and power in skeletal muscles of different athletic groups (5,15). Well-trained or elite athletes, however, form a unique population in which to study the physiologic responses to maximal exercise and to assess the human limits of physical performance, endurance, and power.

Among endurance athletes, cross-country skiers have generally been reported to possess the highest capacity for the transport of oxygen (23). Indeed, cardiorespiratory fitness has been shown to be a significant factor in the racing success of skiers (22). The biathlon is an athletic event which combines cross-country (Nordic) skiing with target shooting. Thus, the successful biathlete must possess the high aerobic capacity of the Nordic skier in addition to shooting ability.

In response to a request from the Director of the British Biathlon Team, British Ski Federation, The Army Personnel Research Establishment (APRE)

conducted assessments of aerobic power on members of the all-military team. The opportunity arose, therefore, to also determine the anaerobic power of such individuals since few investigations have examined this energy component in elite athletic groups. In addition, since cross-country skiing is an event in which the upper body is utilized to nearly as great an extent as the legs, power outputs were also determined during high-intensity, upper body (arm crank) exercise. Such assessments may provide useful information on the physiologic limits of the anaerobic energy system in various muscle groups and provide a more complete profile of the well-trained, elite athlete.

Methods

The subjects employed in this study were 10 male military personnel who had been selected by the British Ski Federation for potential assignment to the British Biathlon Team. In addition, for comparative purposes, measurements were made on 13 healthy soldiers from the APRE Trials Section who had not participated in regular training for top class competitive sport. Anthropometric measurements included height, weight, and percent body fat. The latter was determined from the sum of skinfold thicknesses at the subscapular, triceps, biceps and suprailiac sites using the equations of Durnin and Womersley (7). The assessments of aerobic and anaerobic power were made on separate days. These measurements were performed between 0900-1200 hours with the subjects in the post-absorptive state. Aerobic power was determined by the direct measurement of maximal oxygen uptake ($\dot{V}O_{2\max}$) using a motor-driven treadmill (Woodway) as the mode of exercise. A discontinuous protocol as originally described by Taylor et al (27) and

modified by Mitchell et al, (21) was utilized. The Douglas bag technique was used to measure expired air volumes and gas composition. The establishment of a plateau in oxygen uptake (less than 0.15l/min) with an increase in exercise intensity (2% increase in grade) was the criterion for the attainment of $\dot{V}O_{2max}$.

Anaerobic power was determined for both the upper and lower body using a procedure developed at the Wingate Institute, Israel (3). The Wingate test (WT) utilizes a cycle ergometer which is pedalled or cranked at maximal velocity for 30s against a resistance determined according to the body weight of the subject. A Bodyguard 990 ergometer (Ogloend, Norway) was modified (Dr. W. I. Hopkinson, APRE) to permit the instantaneous application of resistance to the flywheel. A counter-balanced lever arm to which a weight is attached that can be moved to obtain resistances between 0 and 80 Newtons replaced the standard device for applying resistance. Pedal revolutions were measured by optical sensor at the flywheel and monitored with a recorder. The resistance applied was 4.41 joules/pedal revolution/kg BW for leg pedalling and 2.95 joules/pedal revolution/kg BW for arm cranking. The power output (PO) was calculated in watts (W) for each second of the test and then averaged over 5 second intervals. Three indices of anaerobic power were then calculated for both the upper and lower body: peak power (PP), the highest PO during any 5 second period (usually the first); mean power (MP), the average PO generated during the 30s; and power decrease (PD), the difference between PP and the lowest 5s PO expressed in watts/s.

Independent t-tests were used to compare the biathlete and control groups. Correlation coefficients were calculated to assess the degree of association between aerobic and anaerobic performance and also upper and

lower body anaerobic performance. Each correlation coefficient was tested for a significant difference from zero.

Results

Data on age, anthropometry and $\dot{V}O_2$ max for the two groups of subjects are summarized in Table 1. The biathletes had a significantly lower body weight and % body fat and a significantly greater aerobic power than the control subjects.

The PO values expressed in both absolute terms and relative to body weight for the upper and lower body WT are presented in Table 2. There was no difference between groups in PP or MP for either the upper or lower body when values were expressed in absolute terms. However, expressed per kg body weight PP and MP were significantly greater in the biathletes for both the upper and lower body. PD was significantly lower in the biathletes compared to the control subjects for both the upper and lower body.

The relationship between indices of PO from the WT and $\dot{V}O_2$ max for all subjects is presented in Figures 1 and 2 for the upper body and lower body, respectively. In Figure 1, a strong correlation is seen between MP from the upper body WT and $\dot{V}O_2$ max ($r=0.80$, $p<.001$). A significant positive relationship is also seen with PP ($r=0.50$, $p<.05$). A significant negative correlation, however, occurred between PD and $\dot{V}O_2$ max ($r=-0.65$, $p<.001$). Similar relationships were also seen for the lower body (Figure 2). Again the strongest correlation was between MP and aerobic power ($r=0.86$, $p<.001$) with significant relationships also evident between $\dot{V}O_2$ max and PP ($r=0.61$, $p<.001$) and PD ($r=-0.67$, $p<.001$).

The relationship between power output values obtained from the upper body and lower body WT's is shown for all subjects in Figure 3. Significant correlations were found for all three indices: PP, $r=0.66$, $p<.001$; MP, $r=0.77$, $p<.001$; PD, $r=0.59$, $p<.01$.

Discussion

While the role of anaerobic metabolism during exercise has been extensively studied in man, little attention has been given to the assessment of anaerobic capacity and power production in skeletal muscles of different athletic populations. One of the major findings of the present study is that biathletes who have a high aerobic capacity also possess a greater capacity for anaerobic exercise in both the upper and lower body compared to control subjects when power outputs are expressed relative to body weight. These data appear, however, to contradict studies which have found either a negative correlation between $\dot{V}O_2$ max and anaerobic performance (2,5,13) or a positive correlation between % fast twitch (FT) fiber composition of the leg muscles and power outputs from anaerobic tests (4,13). It has thus been concluded in athletes that there is a specific distribution in aerobic and anaerobic power which presumably reflects the histological and biochemical structures of muscles and that such specificity is not found among untrained, non-athletic groups (2,5,14).

However, the interpretation of the above data is largely dependent upon the selection of groups used to make the comparisons. Surprisingly few data exist where an athletic or well-trained group is compared to a group which is not participating in regular training for competitive sport. In closer scrutiny of the data presented by Crielaard and Pirnay (5), it becomes evident that if marathoners were compared to the control group a strong

negative correlation would be found between $\dot{V}O_2$ max and anaerobic power; however, if the same comparison was made between the sprint group and controls, a positive relation would be found since the sprinters not only had a greater anaerobic capacity, as expected, but also possessed a higher $\dot{V}O_2$ max.

With respect to available data on skiers, Komi et al (15), on the other hand, reported no differences in anaerobic power (as measured by the Margaria test) or isometric muscular force of leg extensors between cross-country skiers and a control group of subjects. More recently, Haymes and Dickinson (9), however, in a study profiling the physical capacities of elite ski racers reported values of 21 W/kg for anaerobic power measured by the Margaria test. While no control subjects were used for comparison, these values are as high or higher than values reported by other workers (6,18,30) suggesting that endurance trained athletes also possess high anaerobic capacities. Finally, a recent report by Stray-Gundersen et al (26) is of considerable interest regarding the relationship between aerobic and anaerobic capacities in elite skiers. These authors found that cross-country skiers not only possessed a high $\dot{V}O_2$ max and a high aerobic capacity as determined by oxidative muscle enzyme levels (rectus femoris and triceps) but also had a predominance of fast twitch fibers (64% and 59%, respectively) in these muscles.

Power decrease values derived from the WT are purported to serve as an index of muscular fatigue (2) and have been used to relate muscle morphology to anaerobic performance where a positive correlation has been shown with % FT fiber composition (4,10). Similar results have also been reported for the relationship of %FT to peak torque decline on an anaerobic isokinetic fatigue

test (10,29). In agreement with previous studies using cycle ergometer (20) and isokinetic (11) tests, negative correlations were found between $\dot{V}O_2$ max and power decrease during the WT. Also significant differences occurred in PD values for both the upper and lower body between the biathletes and untrained subjects. The data suggest, therefore, that the biathletes possess a greater aerobic potential in arm and leg muscles and thus are more resistant to fatigue than the control subjects. These data, however, appear somewhat paradoxical in view of the higher power output values found in the biathletes suggestive of a higher % FT fiber composition of the muscles. However, as stated by Gollnick and Matoba (8) it is important to emphasize that FT fibers can be highly oxidative and with endurance training the oxidative potential can be increased to a point where it approximates that of ST fibers of untrained individuals. The recent data of Stray-Gundersen et al (26) as previously referred to also support this concept and largely explain the greater fatigue resistance but higher power outputs of the biathletes.

Another major finding of this study was that the power output response to supramaximal exercise involving the upper body is similar to that of the legs when biathletes are compared to control subjects. Furthermore, significant correlations ranging from 0.59 to 0.77 were found for indices of power output when comparing the upper and lower body Wingate tests among all subjects. This relationship leads to the assumption that there is some generality in the anaerobic capacity of individuals. In other words, performance in the leg test may give an indication of the performance in the arm test and vice-versa. These data support similar results for aerobic capacity where Sawka et al (25) found that aerobic power for cycle exercise was the most important determinant of upper body (arm cranking) aerobic performance. An explanation

for these similarities between the upper and lower body may reside in the composition of the muscles. While there is a large inter-individual variation in muscle fiber composition, postmortem studies indicate that a certain relationship exists in the fiber composition in different muscles of the same subject. The vastus lateralis, rectus femoris and gastrocnemius muscles of the lower extremity and the deltoid and bicep muscles of the upper extremity contain approximately 50% ST and 50% FT fibers for untrained subjects (24). In highly endurance trained subjects (orienteers), Jansson and Kaijser (12) have reported a close congruity between the fiber composition (68% ST) of the muscles of the upper (deltoid) and lower (vastus lateralis and gastrocnemius) extremities. More recently, Tesch and Karlsson (28) reported that the fiber type distribution of the vastus lateralis and deltoideus does not appear to be different in physically active but nonspecifically trained men.

In conclusion, the data suggest that biathletes possess a greater capacity for anaerobic exercise and a greater resistance to muscular fatigue as measured on the Wingate test in both the upper and lower body compared to control subjects when power outputs are expressed relative to body weight. Also a generality in the anaerobic capacity of individuals appears to exist as evidenced by the significant correlations between power output values from the upper and lower body.

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This study was conducted while J. F. Patton served as an exchange scientist from the US Army Research Institute of Environmental Medicine, Natick, MA. 01760-5007, USA

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TABLE 1. Physical characteristics of subjects (Mean \pm SD)

| | <u>Controls</u> (n = 13) | <u>Biathletes</u> (n = 10) |
|-------------------------------|-----------------------------|-------------------------------|
| Age, yrs | 25.3 \pm 4.6 | 22.2 \pm 2.0 |
| Height, cm | 174.0 \pm 6.9 | 176.1 \pm 5.9 |
| Weight, kg | 78.3 \pm 6.4 | 70.6 \pm 6.7* |
| % Body Fat | 17.5 \pm 4.3 | 12.3 \pm 2.5** |
| $\dot{V}O_{2max}$, ml/kg/min | 49.8 \pm 5.4 | 67.9 \pm 3.4*** |

* p<.05; ** p<.01; *** p<.001

TABLE 2. Upper and lower body power outputs from Wingate test (Mean \pm SD).

| | Controls (n = 13) | Biathletes (n = 10) |
|---------------------|----------------------|------------------------|
| <u>Upper Body</u> | | |
| Peak Power, W | 530 \pm 57 | 538 \pm 73 |
| W/kg | 6.76 \pm 0.53 | 7.61 \pm 0.62** |
| Mean Power, W | 390 \pm 40 | 429 \pm 52 |
| W/kg | 4.98 \pm 0.43 | 6.07 \pm 0.37*** |
| Power Decrease, W/s | 10.64 \pm 2.62 | 8.28 \pm 2.21* |
| <u>Lower Body</u> | | |
| Peak Power, W | 800 \pm 73 | 782 \pm 50 |
| W/kg | 10.25 \pm 0.91 | 11.25 \pm 0.82* |
| Mean Power, W | 622 \pm 53 | 651 \pm 74 |
| W/kg | 7.96 \pm 0.69 | 9.21 \pm 0.33*** |
| Power Decrease, W/s | 13.15 \pm 2.94 | 9.85 \pm 1.78** |

* p<.05; ** p<.01; *** p<.001

Figure 1. Relationship between $\dot{V}O_{2\max}$ and indices of power output from the upper body Wingate test.

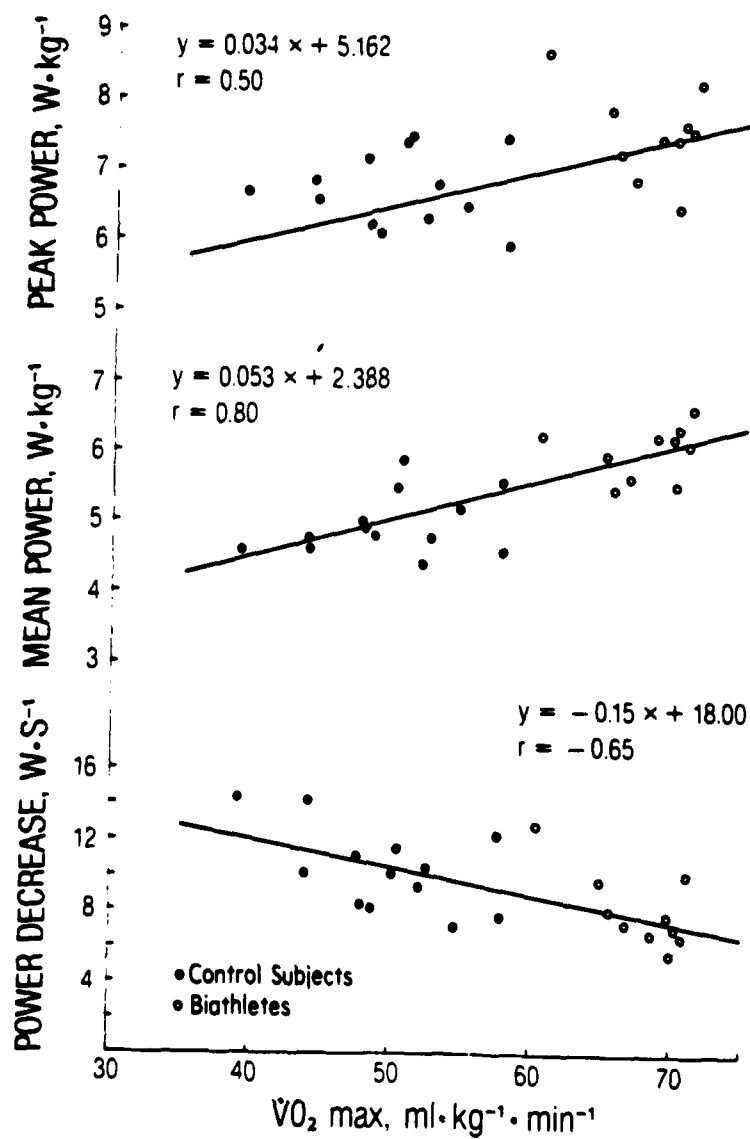


Figure 2. Relationship between $\dot{V}O_{2\max}$ and indices of power output from the lower body Wingate test.

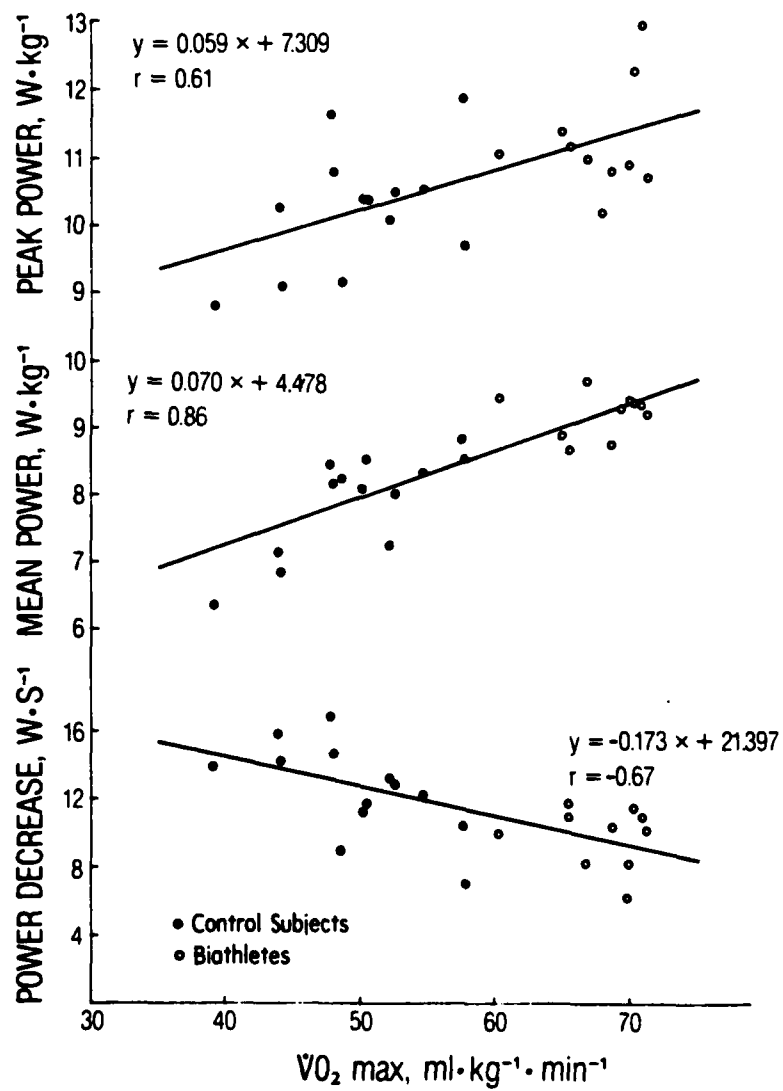
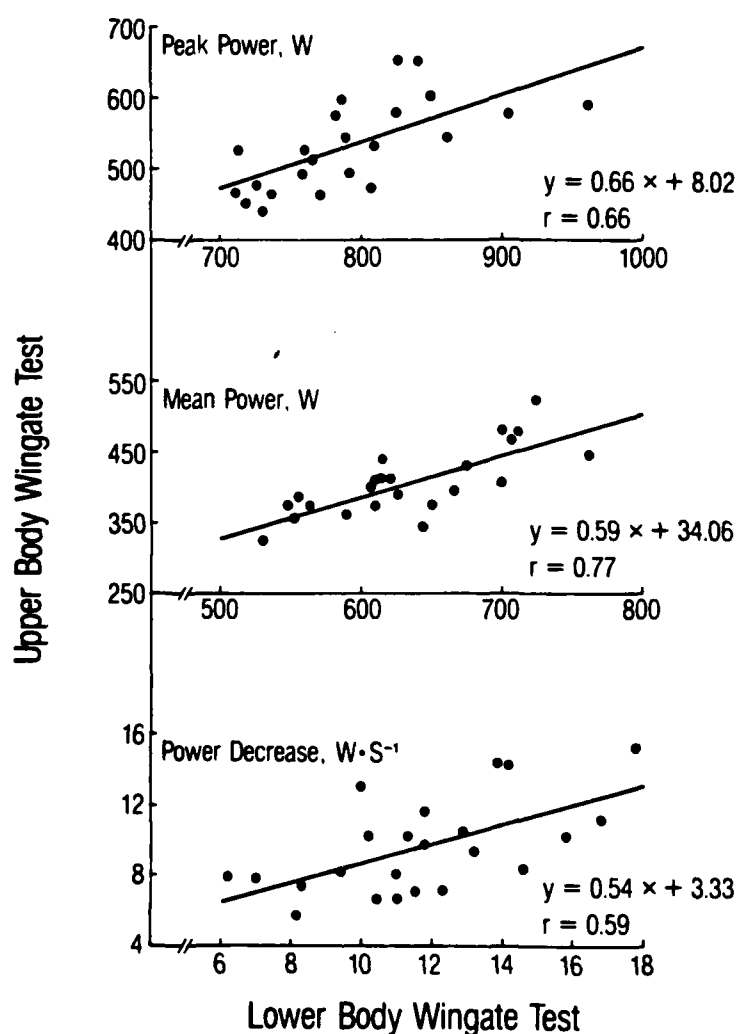


Figure 3. Relationship between upper and lower body power output values from the Wingate test.



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