AN ERGOMETRIC ANALYSIS OF AGE GROUP SWIMMERS

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ABSTRACT

Thirteen male competitive swimmers (mean age 14.7 years) were studied during maximal exercise on a treadmill, cycle ergometer and biokinetic swim bench. The mean maximal oxygen uptake values elicited (treadmill = 66.5 ml.kg.1 min.1; cycle ergometer = 61.0 ml.kg.1 min.1; biokinetic swim bench = 44.5 ml.kg.1 min.1) were higher than those reported elsewhere for children not engaged in intensive training and even when compared with other groups of similarly aged swimmers the values exhibited were some of the highest recorded. The results were directionally similar to those of other studies comparing treadmill and cycle ergometer exercise with the mean maximal oxygen uptake on the cycle ergometer 9% lower than that on the treadmill. There is no other study with which to compare swim bench values but the majority of maximal values were consistently and significantly lower than those achieved on the other ergometers. The swimmers rank within the group was minimally affected by the type of ergometer on which the measurement was made.

Key Words: Ergometry : Swimmers : Children : Maximal Cardiorespiratory Parameters

INTRODUCTION

During prolonged physical work the individual’s performance capacity depends largely upon his ability to deliver oxygen to the working muscles. Consequently, it is widely accepted that the adequacy of the circulatory and metabolic responses to exercise in man is best described by the determination of maximal oxygen consumption and associated parameters (Åstrand, 1952; Rowell, 1974). Highly conditioned adult endurance athletes have been extensively studied and reported to possess large aerobic capacities (Åstrand and Rodahl, 1977). Several studies have reported the maximal oxygen consumption of children engaged in competitive sports training, particularly running (Daniels and Oldridge, 1971; Daniels, Oldridge et al, 1978) and swimming (Seliger, 1968; Sobolova, Seliger et al, 1971; Cunningham and Enyon, 1973) but none are specific to this country. The present study was designed to ascertain the maximal aerobic capacity and associated cardiorespiratory parameters of a group of well trained young competitive swimmers, and to compare the relative merits of the cycle ergometer, treadmill and biokinetic swim bench in eliciting these maximal measures.

METHOD

Thirteen male swimmers from the Salford Triple S Club volunteered as subjects, their physical characteristics are displayed in Table I. The subjects were habituated to the experimental procedures prior to the testing sessions. Pilot studies established that the highest “maximal” or peak oxygen uptakes were achieved using a discontinuous protocol. Exercise mode and subject order were randomised so that each subject exercised on one ergometer per day and completed the tests over three consecutive days.

<table>
<thead>
<tr>
<th>Age</th>
<th>Height</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>yrs</td>
<td>cm</td>
<td>kg</td>
</tr>
<tr>
<td>11.8 – 18.7</td>
<td>154.3 – 181.6</td>
<td>39.2 – 80.5</td>
</tr>
<tr>
<td>14.7 ± 2.0</td>
<td>168.4 ± 8.7</td>
<td>55.5 ± 13.4</td>
</tr>
</tbody>
</table>

Values are mean ± S.D. : n = 13
A discontinuous cycle test was administered using a friction loaded Monark ergometer and a constant pedal rate of 60 revs. min.\(^{-1}\). Following a five minute warm-up at an intensity of 120W, the test commenced at an intensity of 150W with incremental increases of 30W every three minutes and a one minute rest between stages. The test was terminated by voluntary exhaustion.

The running test was performed on a motorised treadmill. Following a five minute warm-up at 12 Km hr.\(^{-1}\) and 0% grade the test was undertaken at a speed of 14 Km hr.\(^{-1}\) with the incline increased 2\(\%\) every three minutes. A one minute rest was allowed between stages and the test continued until the subject was exhausted.

The protocol on the biokinetic swim bench (Isokinetics Inc.) consisted of a discontinuous simulated swim test with the exercise intensity incrementally increased, using isokinetic resistance. Following a three minute warm-up, exercise bouts of three minutes duration were interspersed with ten minute rest periods. Each swimmer simulated his principal competitive stroke and the isokinetic resistance was progressively increased until the subject voluntarily terminated the exercise.

RESULTS

The ergometric data for maximal cardiorespiratory measures are summarised in Table II.

### TABLE II

<table>
<thead>
<tr>
<th>Measure</th>
<th>Treadmill</th>
<th>Cycle Ergometer</th>
<th>Biokinetic Swim Bench</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\dot{V}O_2), STPD, l.min(^{-1})</td>
<td>3.69 ± 0.94</td>
<td>3.36 ± 0.72</td>
<td>2.49 ± 0.77</td>
</tr>
<tr>
<td>(\dot{V}O_2)/W, ml.kg(^{-1}) min(^{-1})</td>
<td>66.5 ± 4.0</td>
<td>61.0 ± 4.6</td>
<td>44.5 ± 4.6</td>
</tr>
<tr>
<td>VE, BTPS, l.min(^{-1})</td>
<td>119.8 ± 25.4</td>
<td>115.3 ± 22.5</td>
<td>91.2 ± 27.0</td>
</tr>
<tr>
<td>RF, breaths min(^{-1})</td>
<td>58 ± 9</td>
<td>57 ± 12</td>
<td>67 ± 17</td>
</tr>
<tr>
<td>T.V., BTPS, l</td>
<td>2.16 ± 0.68</td>
<td>2.19 ± 0.80</td>
<td>1.51 ± 0.66</td>
</tr>
<tr>
<td>Vent. Equiv., l.100ml(^{-1})</td>
<td>2.7 ± 0.3</td>
<td>2.9 ± 0.3</td>
<td>3.1 ± 0.4</td>
</tr>
<tr>
<td>R</td>
<td>0.98 ± 0.10</td>
<td>0.97 ± 0.10</td>
<td>0.98 ± 0.05</td>
</tr>
<tr>
<td>H.R., beats min(^{-1})</td>
<td>198 ± 7</td>
<td>189 ± 9</td>
<td>176 ± 12</td>
</tr>
<tr>
<td>(O_2) pulse, ml.beat(^{-1})</td>
<td>18.7 ± 4.9</td>
<td>17.8 ± 4.2</td>
<td>12.8 ± 7.4</td>
</tr>
</tbody>
</table>

Values are means ± S.D.; n = 13

Several subjects did not exhibit an oxygen plateau at maximal values but in children this is a well documented phenomenon on both the treadmill (Åstrand,
1952) and cycle ergometer (Cumming and Friesen, 1967). Cunningham, McFarlane et al (1977) found no significant differences in VO\textsubscript{2} maximum of ten year old children attaining and not attaining a plateau. Since each subject worked to exhaustion the peak VO\textsubscript{2} values were taken as the VO\textsubscript{2} maximum regardless of whether a VO\textsubscript{2} plateau had been established.

The data associated with maximal exercise were analysed using a paired t-test and the results are illustrated in Table III. The mean absolute and relative VO\textsubscript{2} maximum during cycling were significantly lower than those during running (\( P < 0.05 \)). Three subjects attained a higher VO\textsubscript{2} maximum cycling but the mean value was 9% lower than running although individual cycling values ranged from 6% higher to 20% lower than those elicited whilst running. The mean values of absolute and relative VO\textsubscript{2} maximum during both cycling and running were higher than those achieved on the biokinetic swim bench (\( P < 0.001 \)). All values on the swim bench were lower than those on the treadmill (range from 14% to 48%, mean 35%). One subject exhibited a higher VO\textsubscript{2} maximum on the swim bench than on the cycle ergometer. The mean swim bench VO\textsubscript{2} maximum was 26% lower than the mean cycling value and individual values ranged from 1% higher to 43% lower than cycling values. Maximal heart rate was significantly higher during running than cycling (\( P < 0.05 \)) or simulated swimming (\( P < 0.001 \)) and significantly higher during cycling than simulated swimming (\( P < 0.01 \)). No further significant differences (\( P > 0.05 \)) were found between treadmill running and cycling values. Pulmonary ventilation was significantly higher during both running (\( P < 0.001 \)) and cycling (\( P < 0.01 \)) than simulated swimming. Tidal volume was significantly higher during running (\( P < 0.01 \)) and cycling (\( P < 0.001 \)) than simulated swimming. Ventilatory equivalent was higher during running than simulated swimming (\( P < 0.01 \)) but there was no significant difference between the mean cycling and swim bench values (\( P > 0.05 \)). No significant differences between the mean respiratory frequencies or respiratory quotients were demonstrated on any of the ergometers (\( P > 0.05 \)). Oxygen pulse was significantly higher during both running (\( P < 0.001 \)) and cycling (\( P < 0.001 \)) when compared with simulated swimming.

Spearman rank correlation coefficients were computed for the maximal oxygen uptake data on each ergometer and the results are illustrated in Table IV. All correlations were highly significant (\( P < 0.001 \)).

### Table IV
Correlational analysis of maximal oxygen uptake data

<table>
<thead>
<tr>
<th>T.M. vs. C.E.</th>
<th>T.M. vs. B.S.B.</th>
<th>C.E. vs. B.S.B.</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.89</td>
<td>0.86</td>
<td>0.88</td>
</tr>
</tbody>
</table>

All values highly significant (\( P < 0.001 \))

### DISCUSSION

The swimmers studied are actively engaged in frequent prolonged periods of strenuous training. They participate in seven training sessions per week, swimming at least 7000 metres per session. One would expect aerobic capacity in these swimmers to be highly developed and this seems to be the case. The maximal oxygen uptakes (VO\textsubscript{2} maximum) of children not engaged in long term heavy physical training are well documented. Shephard (1971) has summarised the mean values for those studies conducted prior to 1970 with Nagle, Hagberg et al (1977) and Gilliam, Katch et al (1977) providing more recent data. The reported values for this age group vary from fourteen year old boys whose mean VO\textsubscript{2} maximum, elicited on a cycle ergometer, was 31.9 ml.kg\textsuperscript{-1}.min\textsuperscript{-1} to fifteen year olds whose mean treadmill VO\textsubscript{2} maximum was 56.3 ml.kg\textsuperscript{-1}.min\textsuperscript{-1}. The highest of these values is less than 85% of the mean (66.5 ml.kg\textsuperscript{-1}.min\textsuperscript{-1}) reported in the present study. Whether this large difference in VO\textsubscript{2} maximum is solely due to training can only be answered by the collection of data on a longitudinal basis and we are currently engaged in a study of this type.
Table V illustrates data concerning male age group swimmers as reported by other writers. The oxygen uptake values, measured at exhaustion on the cycle ergometer, in the present study are in close agreement with those of Caffrey (1974) but are somewhat higher than other reported data. Caffrey's (1974) subjects were heavier than the present sample resulting in a lower mean value when \( V'02 \) maximum was related to bodyweight. Unlike runners, however, swimmers do not have to carry their whole bodyweight during swimming and it seems more logical to express \( V'02 \) maximum in litres per minute rather than relate it to bodyweight. Pulmonary ventilation at \( V'02 \) maximum was in close agreement with Caffrey's (1974) sample and considerably higher than that reported by other writers. Mean maximal heart rates in the present study were within the range reported by others. The mean \( V'02 \) maximum elicited on the treadmill in the present study is higher than the \( V'02 \) maximum elicited by either Newble and Homan (1978) or Nomura (1979) but somewhat lower than that achieved by the older subjects of Eriksson et al (1974). Pulmonary ventilation follows a similar trend but the mean maximal heart rate of our subjects is very close to that of the eighteen year old subjects of Eriksson et al (1974). Other maximal cardiorespiratory parameters are inconsistently reported but from the data available the maximal tidal volumes and respiratory rates reported here are within the range reported by others.

The maximal oxygen pulse achieved by our swimmers is considerably higher than those reported by Cunningham and Enyon (1973), Wirth, Trager et al (1978) and Seliger (1968) indicating either a larger stroke volume, a greater arterio-venous oxygen difference or both. The ventilatory equivalent at \( V'02 \) maximum in our subjects is similar to that reported by Seliger (1968) but considerably lower than those reported by Eriksson and his associates (Eriksson, Berg et al, 1978; Eriksson, Holmer et al, 1974). As the mean respiratory quotient elicited was also relatively low and several subjects failed to exhibit an "oxygen uptake plateau", it is possible that the \( V'02 \) measured at exhaustion may not represent a true \( V'02 \) maximum for these young athletes. They are accustomed to maximal exercise as swimmers and were highly motivated to exhaustive exercise, but their lower body musculature may have fatigued early due to swimming training which places greater demands upon arm and shoulder muscles. This may limit the applicability of treadmill and cycle ergometer in the assessment of swimmers and it is interesting to note that none of the studies cited report a mean respiratory quotient of 1.15 or higher which has been suggested as a criterion of \( V'02 \) maximum in adults by Issekutz, Birkhead et al (1962).

In studies on adults a mean difference between the \( V'02 \) maximum elicited on a treadmill and on a cycle ergometer is a common finding and treadmill values are reported to exceed cycle ergometer values by 5 to 15% (Hermansen, Ekblom et al, 1970; Åstrand and Saltin, 1961; Miyamura and Honda, 1972). Several explanations have been offered for this phenomenon. Higher cardiac outputs due to greater stroke volumes have been reported during treadmill running (Miyamura, Kitamura...
et al, 1978; Hermansen, Ekblom et al, 1970) and it has been suggested that as running is a much more ballistic movement with a shorter contraction phase than cycling, venous return will be facilitated (Miyamura, Kitamura et al, 1978). Extremely high intramuscular pressures may occur during maximal cycling, restricting the blood flow to the working muscles (Hermansen, Ekblom et al, 1970). Miyamura, Kitamura et al (1978) reported a higher arterio-venous oxygen difference on the treadmill but other studies do not confirm this finding (Hermansen, Ekblom et al, 1970; Shephard, Allen et al, 1968). The muscle mass utilised during treadmill running is probably greater than that used for cycling and it has been demonstrated that the VO₂ maximum of swimmers can be increased approximately 8% by increasing the total working muscle mass (Jensen, Butts et al, 1980). Hockey (1980) elicited a 4% increase in the VO₂ maximum of his subjects by adding arm work to cycling but their VO₂ maximum was still 6% lower than that achieved on a treadmill.

The only previous study we can find which compares treadmill and cycle ergometer measures on the same children is that of Boileau, Bonen et al (1977). They found a difference of 7.9% between treadmill and cycle ergometer measures of VO₂ maximum which is of similar magnitude to our 9% difference. Boileau, Bonen et al (1977) and the present study found the treadmill maximal heart rates and absolute and relative maximal aerobic power significantly higher. Boileau, Bonen et al's (1977) data demonstrated that significantly higher maximal respiratory rates and maximal oxygen pulse were achieved on the treadmill. We cannot confirm these findings. When the data in the present study was compared to that of Boileau, Bonen et al (1977) the respiratory rates were similar but the subjects in the present study achieved a mean oxygen pulse approximately 50% greater on both the treadmill and cycle ergometer. This is not an unexpected finding in the light of the training programme undertaken by the Salford swimmers. Boileau and his associates (1977) observed a significantly higher respiratory quotient during cycling, thus suggesting a higher proportion of anaerobic work, but they did not report individual aerobic performance on the cycle or treadmill. The present investigators found no significant differences in respiratory quotient across the ergometers but three subjects achieved their highest VO₂ maximum on the cycle ergometer. Similar findings have been reported by Mc Ardle and Magel (1970) and both studies suggest a specificity of training in that all the subjects attaining VO₂ maximum scores on the cycle were regular cyclists. This has been confirmed in our laboratory with international cyclists recording scores ranging from 78 ml.kg⁻¹.min⁻¹ to 80 ml.kg⁻¹.min⁻¹ during cycling.

Tables II and III illustrate that the majority of maximal values achieved on the biokinetic swim bench were consistently and significantly lower than those achieved on either the treadmill or cycle ergometer. There is no other study with which to directly compare the results of the present study but lower VO₂ maximum, VE maximum and HR maximum are common findings when arm cranking is compared with either treadmill running or cycling (Davis, Vodak et al, 1976; Oldridge, Heigenhauser et al, 1979). Asmussen and Hermingsen (1958) demonstrated a lower oxygen pulse during arm cranking compared to leg work. With a group of female speed swimmers Oldridge, Heigenhauser et al (1979) demonstrated at 33% decrease in VO₂ maximum when arm cranking was compared with treadmill running and this percentage decrement is in close agreement with that exhibited by the swimmers in the present study. The reason for the lower VO₂ maximum during simulated swimming is probably the result of a smaller working muscle mass. The significantly lower maximal heart rates and maximal oxygen pulses reflect a lower cardiac output and/or arterio-venous oxygen difference. A heart rate significantly lower during maximal swimming than during cycling or running is a well documented phenomenon (Holmer, 1972; Mc Ardle, Glaser et al, 1971). In the simulated swimming exercise the stroke volume may also be reduced. The prone body position should aid venous return but the small ineffective muscle pump provided by the arms in conjunction with a substantial degree of isometric forearm contraction probably limits venous return and decreases the potential adjustment of stroke volume.

**CONCLUSION**

The VO₂ maximum values reported here are considerably higher than those reported elsewhere for children not engaged in long term, heavy physical training and even when compared with other groups of similarly aged swimmers the Salford swimmers exhibit some of the highest values recorded.

The results are directionally similar to values reported in other studies comparing treadmill and cycle ergometer exercise and we were unable to elicit as high a VO₂ maximum using a simulated swimming exercise as on the more popular ergometers. It seems that, although the biokinetic swim bench is an excellent dryland training facility, it is not an appropriate means of obtaining a swimmer's VO₂ maximum, as it only exercises the upper limbs. Nevertheless, despite the differences in the VO₂ maximum exhibited on the three ergometers, the high significant correlations shown in Table IV indicate that the swimmer's rank within the group is minimally affected by the type of ergometer on which the measurement is made. Therefore, for purposes of monitoring relative fitness between individuals throughout the season, similar results can be expected from VO₂ maximum measurements on any of the ergometers used in this study.
ACKNOWLEDGEMENTS
We are grateful to John Mulhall for his technical assistance in collecting the data and to Bruce Lawrie, Senior Local Government Officer, for allowing us to use his highly talented and enthusiastic swimming squad.

REFERENCES


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