エージグループ水泳選手の最大酸素摂取量について

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Maximal Oxygen Uptake of Age Group Swimmers

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本研究は定期的に水泳トレーニングを積んでいる水泳選手の水泳時における最大酸素摂取量をトレッドミル運動時のそれと比較し、水泳トレーニングが両運動時における心肺機能にどのような影響をおよぼしているかを検討した。

被験者は米国人エージグループ水泳選手29名(8~21歳)であった。全員につき牽引負荷水泳法とBalke法によるトレッドミル運動を実施し、最大酸素摂取量を測定した。その結果は次のとおりである。

1. 最大酸素摂取量 (l/min) は水泳時、陸上運動時ともに年齢の増加にともない増大した。
2. 単位体重当たりの最大酸素摂取量 (ml/kg/min) では、水泳時、運動時ともにどの年齢群とも同じ値を示した。
3. 水泳時、陸上運動時ともに最大酸素摂取量については同じ値を示し、それはどの年齢群についても同様な傾向を示した。
4. 水泳選手と過去に報告された non-swim グループにおける最大酸素摂取量について、14歳まではnon-swim グループとの差はみられなかったが、14歳以降で水泳選手の方が有意に増大した。

Abstract

The effect of swimming training on cardio-pulmonary functions during tethered swimming and treadmill walking was studied crosssectionally in twenty-nine age group swimmers (8-21 years). All subjects underwent a progressive work test to the level of maximal volitional effort during treadmill walking and during tethered swimming.

The results may be summarized as follows :

1. Maximal oxygen uptake ($\dot{V}O_{2max}$, l/min) increased with age in both treadmill walking and tethered swimming.
2. No differences in $\dot{V}O_{2max}$ per unit of body weight ($\dot{V}O_{2max}$, ml/kg/min) with age during either treadmill walking or tethered swimming were observed.
3. No differences in $\dot{V}O_{2max}$ between swimming and treadmill walking were observed at any age level.
4. No significant differences were observed between age groups until approximately 14 years. Beyond this age $\dot{V}O_{2max}$ was higher in all of the trained swimmers compared to the non-swimming groups.

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Introduction

In the field of swimming, attention has been focussed on competitive swimming training programs for children since superior performances were often made by young athletes. To answer these questions a number of studies have been conducted on the physiological response to work in the water. The maximal oxygen uptake ($\dot{V}O_{2\max}$) of swimmers during running^{2,8,11,16}, cycling^{2,8,11}, and swimming^{2,3,8,11,12,16} has been reported. $\dot{V}O_{2\max}$ of swimmers while swimming reported by Åstrand⁸ was lower (10 to 20%) than their $\dot{V}O_{2\max}$ during running or cycling. Several reasons were suggested for the difference in $\dot{V}O_{2\max}$ in the three different types of exercise, including the difference in body position and the degree of muscle mass involved, the enhanced thermal exchange, a hampered breathing pattern, and increased respiratory resistance in the gas collection system during swimming.

A few investigators have reported no significant differences between the mean $\dot{V}O_{2\max}$ (l/min) during treadmill exercise and that during swimming^{8,15} in trained swimmers. The differences between the contrasting reports could be in the level of proficiency and degree of training of the swimmers used in the later studies. No study has been reported regarding $\dot{V}O_{2\max}$ during swimming compared to $\dot{V}O_{2\max}$ during treadmill exercise in younger age group swimmers. The purposes of this investigation were to investigate the $\dot{V}O_{2\max}$ during swimming and treadmill exercise and to see if their values change with age.

Methods

Twenty-nine highly trained American age-group swimmers between the ages of 8-21 years served as subjects. For purposes of comparison, the subjects were arbitrarily divided into three age groups; Group A=8.0-11.9 years; B=12.0-15.9 years; C=16.0-21.9 years. All tests were conducted during the subjects' competitive season (March-July, 1973) at the Biotron Research Center, University of Wisconsin in Madison. The anthropometric and physical data of these subjects appear in Table 1. Tethered swimming tests were performed in a swimming tank, 7m (length) $\times$ 4m (width) $\times$ 1.5m (depth) (Fig 1). The water

Table 1 Physical characteristics

Group	N	Age (Yrs)	Ht. (cm)	Wt. (kg)
A	8	$\bar{X}$ 9.90	140.8	34.8
		SD 1.31	10.8	6.1
B	7	$\bar{X}$ 14.3	165.3	55.1
		SD .91	7.4	8.7
C	14	$\bar{X}$ 18.9	181.2	73.6
		SD 2.11	5.1	6.19

Fig 1 Schematic view of tethered swimming

temperature was automatically set in a competitive situation (25-27°C). The front crawl style stroke was employed by all subjects.

After entering the water the swimmer inserted the mouthpiece of a two-way valve which was attached to a snorkel type head frame, and the noseclip. Then the subject was fitted to a gymnastic type canvas belt around his waist which was connected to a restraining line. The line was directed to rearward the subject over a ball-bearing pulley which was linked to the weight resistance apparatus.

Exercise protocol

- 1) Practice and warm up : One practice trial of a low work intensity was provided to familiarize each subject to tethered swimming.
- 2) Exercise : The testing work load was initially set at 1.1kg. The work load was increased at each level by 1.1kg increments until the subjects could no longer support the weight during the 4-6 min swimming.

The subjects were instructed to maintain the normal breathing pattern that they would use in a swimming situation. After three to four minutes from the start of exercise, expired gas was collected for $\dot{V}O_2$. After one level of work the subject was then instructed to stop by pulling the restraining line and to remain quiet while the recovery pulse was monitored (usually 3-4min). This procedure was repeated with increasing work load until maximal aerobic capacity was attained.

Treadmill test followed a modified Balke progressive test⁵⁾.

- 1) Practice and warm up : A practice trial was needed at low work intensity (2.5%, 3.8 mph) to familiarize the subject with the equipment and with the type of work required.
- 2) Exercise: The test started at a 2.5% grade at 3 mph and the grade was increased by 2.5% every two minutes except during the measurements of $\dot{V}O_2$, until the maximal voluntary work capacity was attained. $\dot{V}O_2$ was obtained at each 5% grade increment (5%, 10%, 15%, 20%, 25%). Expired gas was collected after three to four minutes of each work load. After one level of work, the subject continued to walk at work loads increasing progressively until the level of maximal volitional effort was attained.

Oxygen consumption was determined, utilizing an open circuit method and was analyzed by a Quintron gas chromatograph*. The analyzer was calibrated with gases of known concentration obtained volumetrically**.

Results

The mean and standard deviation of maximal values collected for the respective groups are listed in Table 2. $\dot{V}O_{2\max}$ was significantly greater with increasing age in both swimming and treadmill walking (Fig. 2). However, when $\dot{V}O_{2\max}$ was related to body size ($\dot{V}O_{2\max}$ ml/kg/min), no significant differences between ages were observed (Fig. 3). There was considerably more variation in $\dot{V}O_{2\max}$ per unit of body weight (ml/kg/

* Quintron Instrument Co., Inc., Model M-3.

** Gallen Kamp-Lloyd volumetric analysis (Instrumentation Assoc., Inc., New York, N. Y.).

Table 2 A comparison of oxygen consumption ($\dot{V}O_2$), pulmonary ventilation ($\dot{V}E$), breathing frequency (f), tidal volume (V_T), heart rate (HR), and lactate during maximal effort in swimming and treadmill walking

		Group A		Group B		Group C	
		mean	SD	mean	SD	mean	SD
$\dot{V}O_2$ (l/min)	Swim	1.70	.70	3.17	.69	4.35	.39
	Treadmill	1.86	.50	2.93	.79	4.20	.47
$\dot{V}O_2$ (ml/kg/min)	Swim	48.1	12.9	56.6	8.1	59.2	2.4
	Treadmill	49.6	7.1	55.6	5.3	57.0	5.0
$\dot{V}E$ (l/min)	Swim	43.1	14.8	70.2	11.1	97.0	15.7*
	Treadmill	45.8	11.3	75.9	23.1	107.9	16.3
(Breaths/min)	Swim	46.7	10.7	40.2	6.2	41.0	8.5
	Treadmill	57.6	8.8*	48.3	8.9	48.5	6.3**
V_T (l)	Swim	1.14	.35	2.19	.42	3.14	.55
	Treadmill	1.02	.29	2.12	.72	2.83	.38
HR (Beats/min)	Swim	178.5	13.6	181.7	7.3	181.9	6.5
	Treadmill	189.3	8.1*	188.6	7.5**	188.2	4.4***
Lactate (mg%)	Swim	54.6	16.6	67.5	13.8	101.6	27.4
	Treadmill	59.7	16.8	72.6	25.0	112.7	14.3

*** $P < 0.01$ ** $P < 0.02$ * $P < 0.05$ **Fig. 2** $\dot{V}O_{2\max}$ (l/min) in relation to the age compared to the other studies in swimmers and non-swimmers

min) within the youngest group of subject. Treadmill $\dot{V}O_2\text{max}$ was compared with other studies in the literature which included both non-swimmers^{4,12,16)} and age group swimmers⁷⁾. No differences were observed between these groups below approximately 14 years of age. Beyond this age level $\dot{V}O_2\text{max}$ was higher in all of the trained swimmers compared to the non-swimming groups (Fig. 2). There were no significant differences in $\dot{V}O_2\text{max}$ between swimming and treadmill walking in any age group (Fig. 4).

Fig. 3 $\dot{V}O_2\text{max}$ (ml/kg/min) in relation to the age compared to the other studies in swimmers and non-swimmers

Fig. 4 Comparison between maximal values for oxygen uptake, pulmonary ventilation, tidal volume, breathing rate, heart rate, blood lactate during swimming and treadmill walking

Fig. 4-2

Fig. 4-3

Fig. 4-4

Fig. 4-5

Fig. 4-6

$\dot{V}E_{max}$ and VT increased with age both in swimming and treadmill walking. A significantly higher $\dot{V}E$ was observed during treadmill walking than swimming in group C ($P < 0.05$). No significant differences in VT were observed between two types of exercise in any group. Maximal minute breathing rate ($\dot{f}$) appeared to decrease with age. Except in group B, significantly greater $\dot{f}$ was observed in treadmill walking compared to swimming ($P < 0.05$). Maximal HR did not differ with age during swimming or treadmill walking. However, when comparing the two forms of exercise, higher values were obtained during treadmill walking than in swimming in any group (Groups A, $P < 0.05$; B, $P > 0.02$; C, $P > 0.01$). Maximal lactates increased with age in both exercises, but there were no significant differences between swimming and treadmill walking in any group.

Discussion

Maximal oxygen uptake ($\dot{V}O_2\text{max}$) of trained swimmers has been reported to be approximately the same (5.0 l/min) as distance runners (4.8 l/min)¹⁰⁾. However, when expressed per unit of body weight (ml/kg/min), swimmers had much lower values because of their greater body weight. The cardio-pulmonary response to underwater work is different than land exercise^{9,11,16)}. Therefore, it was important to evaluate the swimmers' aerobic capacity during swimming. $\dot{V}O_2\text{max}$ of trained girl swimmers during swimming was 94% of their value in cycling²⁾. Holmer¹¹⁾ also reported that $\dot{V}O_2\text{max}$ did not reach the same level in most subjects in swimming as during running but closely approximated that found in cycling (N=9, $\bar{X}$ =89% of running $\dot{V}O_2\text{max}$, and $\bar{X}$ =97% of cycling). However, four of Holmer's subjects were not in the swimming training group. In fact, a re-calculation of his data in the five trained swimmers showed that they could attain almost the same maximal value in swimming as during running ($\bar{X}$ =97% of the running). Magel¹⁵⁾ and Dixon⁸⁾ have also reported that there was no significant difference in $\dot{V}O_2\text{max}$ during swimming ($\bar{X}$ =4.26 l/min), ($\bar{X}$ =4.05 l/min), and treadmill running ($\bar{X}$ =4.20 l/min), ($\bar{X}$ =4.26 l/min) in college swimmers.

The maximal oxygen consumption measured during both exercise in the present study may not represent the subjects' actual values since repeated testing was not performed on all subjects. However, seven of the college swimmers and two of the younger swimmers were retested in both treadmill and tethered swimming. The results showed that the $\dot{V}O_2\text{max}$ in both exercises was almost identical. The lower $\dot{V}E$ during swimming compared to land exercise has been observed previously^{2,8,11,15)}. The authors explained that the decrease in both $\dot{V}E$ and VT was a result of the limited number of strokes per minute since all swimmers observed a one breath to one stroke ratio. The effect of hydrostatic pressure on the thorax¹⁰⁾ might account for a lower VT. The maximal heart rates may also be considered a good estimation of whether the subjects attained a maximal aerobic capacity or not. The heart rate at exhaustion in the present study was similar to maximal values reported by others both in swimming^{8,15,16)}, and treadmill exercise^{8,15,16)}. In this study, even the younger swimmers, who were less experienced attained the same maximal aerobic capacity during swimming as in walking and this was similar to that reported in well trained college swimmers^{8,15)}. This result was not consistent with other studies which indicated that untrained^{8,11)} or recreational swimmers¹⁴⁾ attained significantly lower $\dot{V}O_2\text{max}$ (20-25%) during swimming than that during land exercise. The finding that no significant differences were obtained in $\dot{V}O_2\text{max}$ between swimming and treadmill walking at any age level in this study suggests that the adaptation of the younger swimmers during swimming was similar to that of the older swimmers. In addition, the younger swimmers were apparently not restricted as were the untrained swimmers and therefore, were able to attain their maximal values during swimming.

The maximal blood lactates reported in younger children indicated a greater variability than that observed in older children and adults^{4,7,17,18)}. One possible reason for this variability could be the criteria used in the younger subjects. The younger subjects were reported

unwilling to strain themselves⁴⁾. The sampling technique might also account for the difference observed. In the present study maximal lactate of group A ($\bar{X}=59.7\pm16.8\text{mg}\%$) and B ($\bar{X}=72.6\pm25.0\text{mg}\%$) were lower than Åstrand's values (10-11 years, $\bar{X}=84.0\pm6.9\text{mg}\%$; 14-15 years, $\bar{X}=90.4\pm4.8\text{mg}\%$)⁴⁾ and considerably lower than Cunningham's (10 years, $\bar{X}=81.0\pm21.7\text{mg}\%$; 14.9 years, $\bar{X}=108.6\pm17.7\text{mg}\%$)⁷⁾ but higher than Morse, et al. (10-17 years, $\bar{X}=68\text{mg}\%$)¹⁷⁾. A lactate value of approximately 90mg% has been suggested as a criterion for maximal exercise⁴⁾. From this criterion the present younger groups (A and B) might not have pushed themselves to exhaustion. However, Erikson⁹⁾ has reported that the lower values (less than 50% of adult values) for PFK in children might be one explanation of the children's low maximal lactate values. His finding might explain the reason why the present younger group had lower maximal lactate values.

The maximal blood lactate for the older group (C, $\bar{X}=112.0\pm14.3\text{mg}\%$) was comparable to that reported previously^{4,7,11)}. Although no study has been found reporting maximal blood lactates in age group swimmers comparing land exercise and swimming, the present study of maximal blood lactates during swimming was not significantly different from treadmill walking because of greater variability in both exercises. However, treadmill exercise has a tendency to show higher values than swimming at all ages. Holmer¹¹⁾ reported that in adult subjects, there was not significant difference in maximal blood lactate comparing swimming, running, or cycling exercise. These results might indicate that maximal swimming exercise is strenuous enough to yield maximal or nearly maximal aerobic and anaerobic energy producing processes.

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