Pulmonary Function of Age-group Swimmers

—Alveolar-capillary Gas Exchange—

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INTRODUTION

There has been a number of studies attempting to explain the physiological characteristics of young swimmers[1,3,10,14,25,32]. These studies suggest that swimming training accelerates both physical and functional development in propotion to the degree of training. Many physiological phenomena have been attributed to the swimmers as a result of his chronic intermittent exposure to work in an aquatic environment such as higher than normal values of resting pulmonary function, more efficient respiratory musculature supernormal exercise pulmonary diffusing capacity and pulmonary capillary blood volume, and a hyposensitivity of the respiratory center to CO_2. Except for the consistent finding of an elevated lung volume in swimmers, none of the other suggestions have been clearly demonstrated experimentally. Therefore, there is lack of evidence as to the specificity of swimming training and its influence on body stature and functional development in comparison to other forms of competitive training. The purpose of this investigation was to study whether long term swimming training had a effect on growth and its function.

METHODS

I. Subjects

The subjects consisted of twenty-nine competitive swimmers between the ages of 8–23 years. The subjects were related the Madison age-group swimming program and the University of Wisconsin Varsity Swimming Team. Among the subjects were included one World champion, two World class performers (by event time), six big ten Conference finalists and five State Junior Olympic champions. All except the 8 year old swimmers had at least two years of competitive training and experience.

II. Anthoropometry and pulmonary function measurements

Standing height and body weight were determined with a standard laboratory scale measuring height to the nearest 0.1 cm and body weight the nearest 0.1 kg. Spirometric measurements of VC, $FEV_{1.0}$ and MVV_{60} were determined using the technique of Kory et al.[19]. All determination were made with a low resistance spirometer. The residual volume (RV) was measured by helium dilution as a part of the determination of the breath holding pulmonary diffusing capacity for carbon monoxide (DLco) using Ogilve-Forster modification of the Krogh single breath-holding technique[26]. Pulmonary capillary blood volume (Vc) and membrane diffusing capacity were calculated from DLco measurements at two different oxygen tensions according to the procedure outlined by Roughton and Forster[31]. Total lung capacity (TLC) was calculated by adding the VC and RV.

RESULTS

The physical characteristics for the respective group were listed in Table 1. There was a significant increase in height (Ht) and weight (Wt) with age up through 15.9 years with no significant difference seen thereafter. The relationship of Ht and Wt to age in the present study are presented Fig. 1 and are compared to a longitudinal study of non-swimmers[1]. The characteristics of growth spurt afer 12 years and subsequent leveling off at approximately 16 years is apparent in each study. There is no apparent difference between the studies in the relationships between height, weight and age up through the age of 15 years. Thereafter, however, the difference in the mean values of height and weight between the present swimmers and non swimmers became apparent.

Static lung volume and ventilatory capacity (Table 1) increased with age up to 17 years with no further increase there after. When lung volume was adjusted for age and body stature

Table 1 Physical Characteristics, Lung Volume and Ventilatory Capacity

Group	N		Age (Yrs.)	Ht. (cm)	Wt. (kg)	VC (l)	Pred % (1)*	RV (l)	FRC (l)	TLC (l)
A (8.0–11.9)	8	$\bar{X}$	9.90	140.8	34.8	2.76	111.3	.732	1.539	3.49
		SD	1.31	10.8	6.10	.72	14.1	.182	.508	.86
B (12.0–15.9)	7	$\bar{X}$	13.3	165.3	55.1	4.38	111.0	1.243	2.372	5.56
		SD	.91	7.4	8.7	.81	17.1	.278	.667	.80
C (16.0–17.9)	5	$\bar{X}$	17.1	181.6	72.7	6.03	111.5	1.759	3.391	7.66
		SD	.67	6.75	8.98	.23	12.4	.486	.442	.70
D (18.0–23.0)	9	$\bar{X}$	20.0	181.1	74.1	6.03	113.8	1.753	3.773	7.79
		SD	2.10	5.10	5.10	.43	13.0	.282	.449	.65

Group	N		Pred % (2)*	FEV 1.0 (l/sec)	Pred % (3)*	MVV .60 (l/min)	Pred % (4)*	MMEF (l/min)	Pred % (5)*
A	8	$\bar{X}$	110.3	2.04	104.2	74.0	106.9	151.1	134.5
		SD	14.2	.62	20.9	17.3	16.9	53.3	30.3
B	7	$\bar{X}$	108.6	3.51	103.4	127.1	110.9	255.1	105.9
		SD	15.1	.59	18.5	31.4	29.5	55.7	18.7
C	5	$\bar{X}$	105.8	4.88	111.8	196.2	142.3	348.1	112.6
		SD	11.4	.47	12.2	26.8	14.9	26.8	9.0
D	9	$\bar{X}$	109.9	4.59	104.6	182.4	134.2	323.5	109.0
		SD	12.9	.60	16.3	19.7	18.4	26.3	11.9

* (1), (2), (4) Weng (34)
(3) Zapletal (35)
(5) Andrew (1)

by comparing the predicted values from age and height[34], both VC and TLC exceeded the normal predicted values by 9–14% at any age group. The relationship of lung volume to height was also compared with a group of non-swimmers[2]. The individual results and the linear regressions for the present study are shown and may be compared to the regression equation of the other studies. The actual regression equations are shown in Table 2 and indicate significant correlation coefficients for lung volume and body height (VC $r=0.943$, TLC $r=0.937$, RV $r=0.846$). The results indicate that for vital capacity up to a height of 170 cm, corresponding to an approximate age of 16 years, the swimmers were on or above the regression line for the non-swimmer groups (Fig. 2). However, above 170 cm 13 of 16 swimmers from this study exceeded one standard error of the normal regressions. As expected, a similar result

Table 2 Regression Equations for Lung Volume, Ventilatory Flow Rate and Alveolar-Capillary Gas Exchange in Swimmers
[Body Height (cm) is the Independent Variable]

Dependent Variable (Y)	Coef. of Indep. Vari. (a)	Constant (b)	Correlation (r)	S.E. of XY
VC (l)	.076	−7.92	.943	.516
RV (l)	.023	−2.67	.845	.153
FRC (l)	.052	−5.95	.888	.241
TLC (l)	.099	−10.59	.937	.25
$FFV_{1.)}$ (l/sec)	.061	−6,56	.912	.218
MMEF (l/min)	4.344	−463.09	.939	29.4
MVV_{60} (l/min)	2.397	−259.45	.859	14.1
DL_{CO} (ml/mmHg/min)	.492	−47.36	.882	4.96
DM (ml/mmHg/min)	.720	−56.56	.629	13.4
V_c (ml)	1.635	−171.36	.793	14.3

was obtained with obtained with total lung capacity. Residual volume (RV) was related to the height and compared to normal population (Fig. 2-2). The regression line for the both age group swimmers closely approximated normal population[20]. when RV was related to TLC, as RV/TLC there appeared to be a decrease with increasing age.

The group means and predicted values of forced expiratory volume in one second ($FEV_{1.0}$), maximum mid-expiratory flow (MMEF), and maximum voluntary ventilation (MVV) are presented in Table 1. Significant correlation coefficients for ventilatory flow rates and body height were obtained ($FEV_{1.0}$ $r=0.912$, MMEF $r=0.897$, MVV $r=0.859$). A comparison of the regression lines of the present study with a group of non-swimmers is shown in Fig. 2-3. The slope for the regressions for swimmers on $FEV_{1.0}$ was steeper than the non swimmers and crossed over at a height of approximately 150 cm. Above a height of 170 cm (corresponding to an age range of 16 years and above) the majority of the swimmers' values exceeded the regression lines for the non-swimmers. Wide individual variations in each group are observed for all flow rate measurements.

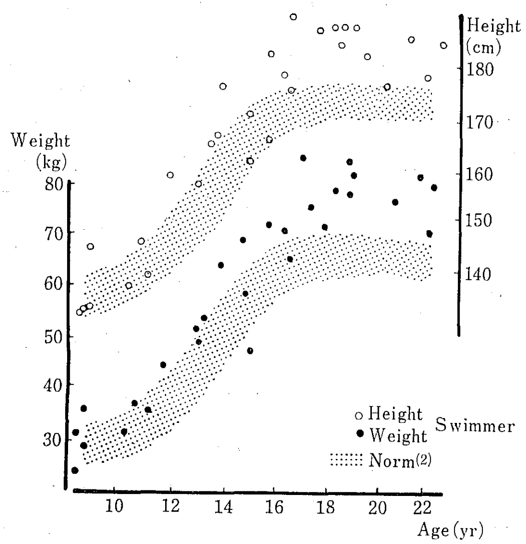
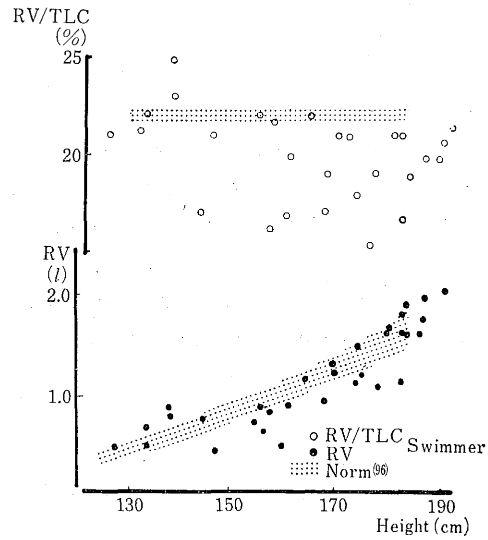


Fig. 1. Height and weight in relation to the age comparing non-swim population



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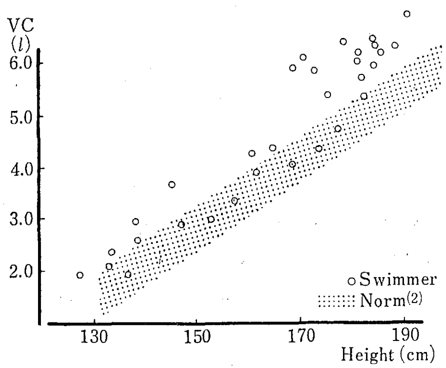

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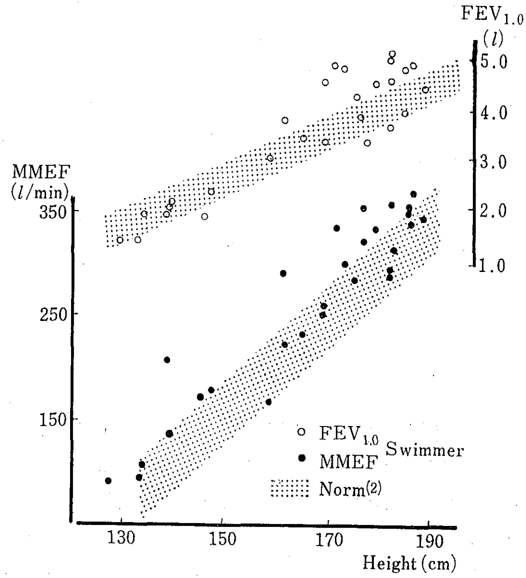

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Fig. 2. Lung volume (VC, RV, RV/TLC) and ventilatory flow rate (MMEF, $FEV_{1.0}$) in relation to the height comparing non- swim population

Resting diffusing capacity of the lung for carbon monoxide (DLco), pulmonary capillary blood volume (Vc), and membrane diffusing capacity (DM), measured by the single-breath method, are presented in Table 3. Absolute DLco increased with age (Fig. 3-1) and is shown to be a function of increasing BSA or body height. The increase in absolute DLco (single-breath method) with age appears greater than that obtained by Bucci[7] (also single-breath method) and in a mixed population of non-swim group in relation to height. However, when DLco was related to lung volume or effective lung surface area for diffusion, as DL/TLC, there appeared to be a decrease with age (6.69 to 5.70 ml/mmHg/min). Pulmonary capillary blood volume (Vc) increased up through a height of 170 cm or approximately the age of 16 years 56.5±17.5 to 138.0±14. ml). Above 16 years there was no further change in Vc with height or age (138.0±14.5 to 129.5±13.0 ml). Membrane diffusion (DM) also increased with increasing age (45.6±19.0 to 78.3±17.3 ml/mmHg/min, Fig. 3-2) but to a lesser degree than Vc. The Vc predicted from Ht[7] was

Table 3 Alveolar Capillary Gas Exchange at Rest

Group (yrs)	N		DLco Air (ml/mmHg/min)	Pred % (1)*	DL/TLC	DM (ml/mmHg/min)	Pred % (2)*	V_c (ml)	Pred % (3)*
A (8-11.9)	8	X̄	22.3	122.3	6.69	45.6	124.8	56.5	128.1
		SD	4.88	13.6	1.00	19.0	49.2	17.5	37.4
B (12-15.9)	6	X̄	32.9	130.8	6.00	54.9	95.5	87.0	137.1
		SD	7.67	18.0	.76	15.5	24.5	22.2	29.5
C (16-17.9)	4	X̄	48.3	147.3	5.93	77.8	97.2	137.8	162.9
		SD	3.8	10.2	.10	17.2	28.3	4.7	24.5
D (18-23)	8	X̄	41.5	128.9	5.36	78.3	98.9	128.9	156.1
		SD	4.9	10.9	.69	17.4	23.4	20.8	19.9

* (1), (2), (3) Bucci (7)

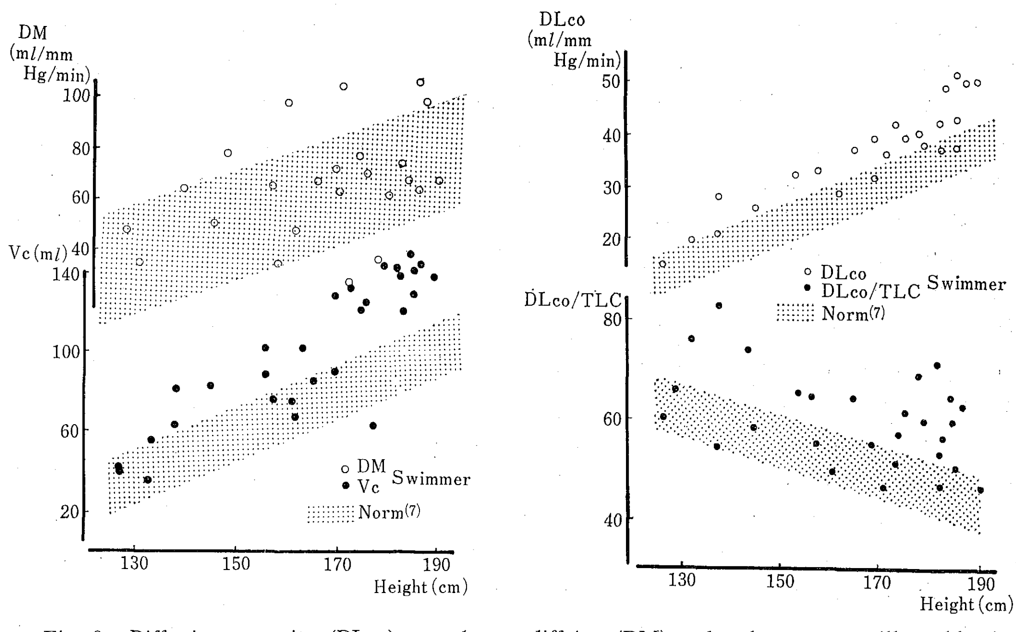

Fig. 3. Diffusing capacity (DLco), membrane diffsion (DM) and pulmonary capillary blood volume (Vc) in relation to the height comparing non-swim population

significantly greater at all ages. On the other hand, DM did not differ from the predicted value at any age level.

DISCUSSION

The results indicated there was no clear evidence of a significant alterlation from a normal growth pattern in the age-group competitive swimmers who had been training regularly for at least one or more years. Although no differrence in the overall pattern was found, study was in agreement with most studies that have reported the swimmer to be taller and heavier than the non-swimmer beyond the age of 16 years[1,4,33]. However, Åstrand et al.[3] in a cross-sectional study of girl swimmers, indicated and acceleration of height and weight up to 16 years. The authors attributed this numerical increase in the normal growth pattern to the swimming training. Andrew[1] in longitudinal study (over three years) has also suggested that swimming had a synergistic effect upon body stature. Erickson[15] re-examined the girl swimmer from Åstrand's study after they were fully grown. At the end of a 4-year period all of the girls were still significantly taller and heavier than the normal group. Although Erickson[16] confirmed Åstrand's earlier contension of accelerated growth in the swimmers, one can not conclude that intensive physical training had an additive effect on growth. In the present study the apparent acceleration of growth on the swimmer resembled the previous studies, but also failed to show an additive effect in growth. These data also correspond to the earlier studies of Ekblom[13] postulated that an increase in growth hormone might be a principal factor effecting the acceleration of growth. On the other hand Daniels and Oldridge[12] observed a group of boys (10–15 years) who were engaged in a running training program for 22 months and were unable to demonstrate any difference in growth rate between the training group and normal boys.

Static lung volume have been shown to be a function of body height and are highly correlated to body height in the present study. The increase in lung volume with age was related more to body height than chronological age. It was apparent that total lung capacity and its subdivision, vital capacity, were greater in the swimmers compared to normal regressions for age since their bodyheight were superior to the normal group. This is especially true in the taller (older) group. However, when lumg volume was corrected for body height using normal predicted values, the swimmers still demonstrated a larger VC (9–14%). This was true even in the younger group who had at most two years of training experience. Lung volumes comparable to the present study were obtained by Andrew[1] on age-group swimmers. His value in swimmers was significantly greater than a matched control group. Åstrand et al.[3] reported similar results in 30 girl swimmers. This finding was confirmed in a re-examination of the girls after a 4-year period[15]. It has been postulated that swimming training results in hypertrophy of the respiratory muscles[1,3], and larger lung volumes[1,3,8,26] in the younger athletes. However, it has not always been found in adult athletes[28]. A wide variation with normal value makes it difficult to establish a larger lung volume in any athletic group. In swimming traing, a greater volume of air has to be inhaled against the hydrostatic pressure of the water because of the limitation to the breathing pattern imposed by the arm stroke. It also seems reasonable with training, a significant advantage would be gained in that more air could be contained in the lung to maintain buoyancy and prolong inspiration with a greater flow rate. In the present study, it is hard to separate to the factors related to training and the constitution of the subjects. However, there is some evidence that swimming training modifies the growth pattern of lung volumes since most of the swimmers' values were greater than normal even lung volumes were corrected for body height. However, athletic training for sports other than swimming in youngsters has also demonstrated in increasing lung volumes[13]. This might suggest that the influence of an increased lung volume was not necessarily because of the specificity of swimming training Bechman[5] reported that RV decreased significantly with four months of swimming training. In the present study the swimmers had volumes same as normal values reported previously[6] However, when RV was related with TLC, the values decrease with increasing age while normal values stay unchanged with increasing age.

A considerable variation in ventilatory flow rates exists in the present study. By constrast to lung volues, the younger groups' values were not differrent from normal values. This may indicate that values were not different from normal values. This may indicate that even though the younger groups had larger stastic lung volume, its function is not developed enough. Higher $FEV_{1.0}$ (%) and MMEF found in the majority of subjects in the older groups are comparable to previous studies on swimmers[1,3].

The controversy exists as to wether ventilatry flow rates of athletes are superior to non-athletes or have a specific effect with training. In general, if the difference between athletes and non-athletes exists, it is slight. Cumming[9] reported that the score in this function was of little importance in the athletic performance of his subjects since maximal ventilation never exceeded the resting ventilatory flow rate (MVV). Olafson and Hyatt[27] have shown that flow limiting pressures are not reached even maximal treadmill exercise. However, in swimming with a limitation imposed upon the breathing pattern, flow limiting pressures might occure and it would seem advantageous to have a greater ventilatory flow rate. Another reason for the wide variability in results could be due to the fact that most of the ventilatory flow rates require cooperation and motivation of the subject, especially in the MVV. However, the MMEF is relatively independent of effort. The significantly higher correlation coefficient for DLco and body height observed is in agreement with that previously reported[6,34]. The higher DLco is apparent when compared to predicted normal values even in the youngest group (22–47% than normal). Additional data from other studies on college swimmers are shown for comparison[22,28]. The mean values in this study are comparable to those in previous studies. It has also been reported that greater DLco increase with an increase in alveolar volume[2,7,18,20]. A greater DLco would therefore be a reflection of the geater lung volume found in the swimmer. However, when DLco corrected for lung volume (TLC), the difference between swimmers' and normal values are still evident as when DLco was related to height. It has been suggested[11,18,21,24] that a larger Vc could be responsible for the higher DLco. In this study the significantly greater Vc observed in all age groups (28–63%) could be one of the main reasons for the geater DLco in swimmers. Åstrand et al.[3] reported that girl swimmers had greater blood volumes and heart volumes. Although this is possibility larger blood volumes have not been consistently reported in athletes[29]. However, greater heart volumes in trained youngsters has often been reported[3,33]. This study can not contribute to this factor since neither of these measures was obtained. No significant difference in DLco/TLC with increasing age in the swimmers was observed. The greater absolute DLco in the young swimmers compared to normal values persisted through the college level swimmers who had been in a training program for more than eight years. This constant increment in DLco with increasing height seems to indicate that alveolar capillary gas exchange had already been fixed at an early age and is ralated to lung size and not necessarily a result of training, i. e., the DLco did not increase more than expected during the growth period even though they had been in a strenuous swimming training program. DM increased slightly with age, however, considerable variability was observed. This is inherent in the measurement[17]. However, an increace in DM with age would be expected since it is a reflection of alveolar surface area which in turn increases with lung size. Any alteration in DM in the swimmer, who had a larger lung volume than normal, was not apparent.

SUMMARY

The effect of long term swimming training on body stature and pulmonary function was studied cross-sectionally in 29 trained swimmers (8–23 years) during their competitive season. The measurements consisted of physical anthropometry such as sanding height (Ht), body weight (Wt), static lung volumes including total lung capacity (TLC) and its subdivisions vital capacity (VC) and residual volume (RV), ventilatory flow rates including forced expiratory volume in one second ($FEV_{1.0}$), maximum mid-expiratory flow (MMEF) and maximum voluntary ventilation (MVV), and pulmonary diffusing capacity (DLco) and its components, pulmonary capillayy blood volume (Vc) and alveolar membrane diffusion (DM). Regression analysis was performed on all measurements utilizing body height, lung volume as the independent variable. There regressions were compared to similar regressions drawn on non-swimmers or other age-group swimmers of comparable age for comparison. Following results may be summarized:

1. The relationship of height and weight to age are similar to the relationship observed in an non-swimming population. The swimmers were taller and heavier at any age level.
2. A larger vital capacity and total lung capacity was seen in all age-group swimmers when when compared to a non swimming age group.
3. Although greater variability in the measured value within and between groups was evident, a higher than normal predicted value was observed in maximum voluntary ventilation and maximum mid-expiratory flow in all age-group swimmers. Forced expiratory volume was not consistently greater than normal predicted value in the swimmers.
4. A higher pulmonary diffusing capacity and pulmonary capillary blood volume were observed in all ages compared to a non-swimming population. There was no difference between the groups and a predicted membrane diffusion.

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エージグループ水泳選手の肺機能

—特に肺胞-肺毛細管ガス交換について—

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長期間水泳トレーニングが水泳選手の発育発達にどのような影響を及ぼしているかを特に肺機能について横断的に検討した。

被験者は米国人男子エージグループ水泳選手29名（8～23歳）であり，全員について身体形測：身長，体重，肺気量：肺活量（VC），残気量（RV），全肺気量（TLC），肺機能：強制呼吸1秒量（$FEV_{1.0}$），最大中間呼気流量（MMEF），最大換気量（MVV），肺拡散容量，（DL_{co}），膜拡散容量（DM），肺毛細管血量（Vc）を測定をした。その結果は以下の通りであった。

1．身長，体重の発育曲線は既報の水泳トレーニングを行っていないグループ（以後対照群という）の発育曲線と類似しているが水泳選手の方がどの年代においても対照群の値を上回っており，その差は年令の増大に伴い増した。
2．VC，TLC では対照群をすべての年令において，身長を考慮した値より9～14%上回った。残気量について若年グループ（8.0～11.9歳）では既報の標準値と差はなかったが，それ以後，年令の増大と共に標準値を下回る傾向にあった。特にTLCとの割合では年令の増大と共に減少の傾向を示した。
3．$FEV_{1.0}$，MVV，MMEF については各値とも比較的ばらつきが大きかったが，MVV と MMEF については各年代とも水泳選手の方が大きな値を示し（6.9～34.2%，5.9～34.5%），その差は年令の増大に従い大きくなった。$FEV_{1.0}$ については若年（8.0～11.9歳）で対照群との間に有意差はみられなかった。
4．DL_{co} では各年代とも高値（22～47%）を示し，Vc では 28～63%も標準値を上回った。DM については，そのばらつきが大きく標準値のと間に有意差はみられなかった。