Gender, Age and Event Differences of Hong Kong Elite Swimmers' Pulmonary Functions
香港精英游泳選手的肺活量在性別、年齡和項目上之分別

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Abstract

The purpose of this study was to investigate the general pulmonary functions among the Hong Kong elite swimmers. Forty swimmers were randomly tested. Two prediction equations were computed based on the regression analysis of the data. It is hoped that the present information concerning the pulmonary functions of local elite athletes will be useful for the Hong Kong coaches as well as sport scientists.

摘要

香港的運動生理學正在起飛階段，各項運動的教練在訓練上注入這個元素，令運動員之演出大有進步，全運會自行車金牌選手黃金寶便是最佳例子。四十個精英泳手被隨機抽樣調查。運動員被劃分爲1） 長/短距離，2） 性別，3） 少年組/高級組，他們的肺活量被測試，調查員還推算兩條方程式，希望可供本港教練和運動員參考。

Introduction

Recently, sports physiology plays an important role in monitoring and improving sports performance. The purpose of the study was to understand the gender, age and swim event differences in pulmonary functions of Hong Kong elite swimmers.

It is substantial to have better knowledge of the physiological conditions of athletes. Fu (1989) declared that the advances in the sports science as well as the availability of better facilities and coaching had enabled us to push human performance toward new horizons.

Some athletes had good performance in various international events, Ms Lee Lai Shan, wind-surfer, and Mr Wong Kam Po, cyclist, are the best examples.

The determinants of these performances are established by the features of the activity, and by the physical and physiological characteristics of the swimmer. Therefore, the swimmer has to develop physiologically to meet the physical requirements at world class competition.

There were some recent evidences indicating that a large vital capacity offered some competitive advantages to long distance swimmers, since it increased thoracic buoyancy (Shephard, 1987). Simth, McMurray and Symanski (1984) claimed that competitive swimmers should be classified as endurance athletes, regardless of their corresponding events, due to the training volumes of swimming.

On the other hand, Lakhera, Kain and Bandopadhyay (1994) suggested that the development of the lung during adolescence under nutritional and health conditions was governed by the process of growth with no or inconsequential additional effects of physical activity. Chen and Kuo (1989) also discovered that there was gender and age differences existing in pulmonary functions.

Based on the above mentioned, if the vital capacity was really overwhelmed by endurance training, then long distance swimmers had a higher pulmonary functions than the sprinters as the training programs for long distance swimmers were tended to be more laps and concentrated more on endurance.

However, if the vital capacity was governed by the process of growth and not by the physical activities, then other factors, such as gender and age might play an considerable role in predicting the pulmonary functions.

In order to resolve the above arguments, this study was to see whether there was any lung functions difference between gender, age and swim event. It was hoped to find out the true factors affecting the pulmonary functions. Since the process of growth related to body structure, measures of heights and weights were also tested against the lung functions.

Estimation of Pulmonary Functions

The prediction equations, in liters, for FVC and FEV1 were as follows (Rosentswieg, et al. 1986):

FVC = Sitting Height in cm 0.1968 - 3.3070

FEV1 = Sitting Height in cm 0.1543 - 2.1950

The standard error of the estimate was 0.54 and 0.41 for FVC and FEV1 respectively.

Forced Vital Capacity

Singh, Singh & Sirisinghe (1992) revealed that forced vital capacity had small changed with age. FVC only had significant negative correlations with age, with FVC of aged 40-49 being about 11% lower than that in aged 13-19.

McArdle et al. (1994) stated that FVC varied considerably with body size and body position during the measurement, standard values were customarily 4 to 5 liters in healthy young men and 3 to 4 liters in healthy young women. FVCs of 6 to 7 liters were not extraordinary for tall individuals, and a value of 7.6 liters had been reported for a professional football player and 8.1 liters for an Olympic gold medallist in cross-country skiing. The large lung volumes of some athletes probably reflected genetic influences because static lung volumes did not change appreciably with exercise.

Forced Expiratory Volume

It was more common to appraise respiratory function in terms of the maximum volume that could be expelled in the first second of a single breath following a maximal inspiration (Forced expiratory volume, or FEV1). Shephard (1987) said that in a young and healthy adult, this volume amounted to 81 to 85 percent of the vital capacity, but in a 60-year old, the ratio of FEV1 to vital capacity drops to about 70 percent.

The percentage of the vital capacity expired in the first second was reduced by exposure to irritant vapors such as ozone and finely suspended particulate such as tobacco smoke or industrial dusts.

Studies related to swimming

In a cross-sectional study with 30 girl swimmers, Engstorm, Erikson, Karleg, Saltin and Thoren (1971) found that 12-16 years old girls could be trained to an exceptionally high functional capacity. In other longitudinal study with 29 female swimmers over a period of 8 years, Engstorm, Erikson, Karleg, Saltin, and Thoren (1971) found significant increased in static lung volumes and vital capacity. Magel et al. (1975) indicated that trained swimmers had significantly higher lung functions than non-athletes.

Competitive swimming, like running, comprised a variety of events ranging from pure sprint to endurance swims. Houston (1978) claimed that competitive swimmers have been classified as endurance athletes, regardless of their respective events, due to their high training volumes (Smith et al.,1984). This classification had justified by the high metabolic capacities and cardiac outputs similar to other endurance athletes. While swimmers were endurance-trained athletes, the majority of competitive swim events tended to be sprint-oriented, lasting less than 2 minutes. Lakhera et al. (1994) detected that swimmers were to have higher vital capacity and forced expiratory volume than all other athletes studied.

Method

Subjects

The subjects in this study were 40 elite swimmers randomly selected from a pool of 204 Hong Kong top level swimmers. Twenty of them were males while the rest were females. Males aged 16 or above and females aged 14 above were categorized as senior. Meanwhile, male swimmers who were 15 or under and female swimmers aged 13 or under fell into the junior class. Age classification of males and females was based on the principle that females had earlier maturation (physically), earlier retirement due to high school pressure and reached their optimal level around 14. The nature and purposes of this study were explained to each subject prior to the experience.

Procedures

A conventional closed circuit spirometry was used in the study. All subjects were required not to have exercise within 6 hours prior to the testing, since FVC had been shown to be temporarily reduced following acute exercise (Cordain et al., 1990). All volumes were ATPS. In order to achieve a steady rate of oxygen consumption, the subjects were enlightened to sit quietly, until their heart rate was back to normal, that was, 60-80 beats per minute, prior to the testing. All measurements were made while the subjects seated comfortably and wearing nose clips. Three trials were taken at each time period, and the highest value was employed for data analysis.

Data Analysis

All the data were analyzed by using the Statistical Package for Social Science (SPSSx User Guide, 1988). Descriptive statistics, including the standard deviations and means, were obtained. A 2 x 2 x 2 factorial MANOVA design was used to investigate the effects of gender (male and female), age (junior and senior) and swimming event (sprinter and endurance) on pulmonary functions.

Results

The descriptive statistics of each measure by independent variables were observed in the following paragraphs and is presented in Table 1.

The average height of 20 male swimmers was 170.5cm and mean weight was 59.95kg. They had an average of 4. 37L in FVC and 3.64L in FEV1. The mean FEV1/FVC% was 83.61%. For the female swimmers, the average height was 158.75cm and 47.95kg respectively. Their average FVC was 2.95L and their mean FEV1 was 2.60L with an average of 87.81% in FEV1/FVC%.

Twenty junior swimmers had an average height 161.7cm and mean weight was 49.15kg. They had an average of 3. 15L in FVC and 2.66L in FEV1. The mean FEV1/FVC% was 84.49%.

Meanwhile, the average height and weight of 20 senior swimmers were 167.55cm and 58.75kg respectively. Their average FVC was 4.16L and their mean FEV1 was 3.58L with an average of 86.92% in FEV1/FVC%.

Among 20 sprinters, their average height was 168.05cm and mean weight was 56.35kg. They had an average of 3. 68L in FVC and 3.22L in FEV1. The mean FEV1/FVC% was 87.66%.

The average height and weight of 20 endurance swimmers were 161.2cm and 51.55kg respectively. Their average FVC was 3.64L and their mean FEV1 was 3.02L with an average of 83.75% in FEV1/FVC%.

McArdle et al. (1994) stated that FVC for males was 4. 8 liters and 3.2 liters for females. In addition, the FEV1/FVC% was about 85% for normal individuals for both sex

Table 1. Descriptive Data of the Sample (N=40)

Source	N	FVC	FEV1	FEV1/FVC%	Ht	Wt
GENDER						
Male	20	4.37	3.64	83.61	170.50	59.95
Female	20	2.95	2.60	87.81	158.75	47.95
AGE						
Junior	20	3.15	2.66	84.49	161.70	49.15
Senior	20	4.16	3.58	86.92	167.55	58.75
SWIM EVENT						
Sprinter	20	3.68	3.22	87.66	168.05	56.35
Endurance	20	3.64	3.02	83.75	161.20	51.55

Note. FVC= Forced Vital Capacity; FEV1 = Forced Expiratory Volume 1; Ht = Height; Wt = Weight; The values for FVC and FEV1 mean in liter; Height measured in cm; Weight measured in kg; Junior was 15 or under for male and 13 or under for female; Senior was 16 or above foe male and 14 or above for female; Sprinter referred to swimmers who participated in 50 or 100 meters in any of the four strokes; Endurance referred to swimmers who participated in 400, 800 or 1,500 meters freestyle event, 200 meters butterfly, 200 meters backstroke or 200 meters breastroke event.

Physiological Characteristics

The pulmonary functions, including FVC, FEV1 and FEV1/ FVC% of the samples are presented in Table 2:

For the FVC measures, the minimum was 2.03L; the maximum FVC was 5.97L while the mean value was 3.66L. For the FEV1, the minimum, maximum and mean values were 1.70L, 5.01L and 3.12L respectively. Meanwhile, the minimum, maximum and mean values of FEV1/FVC% were 60.4%, 95% and 85. 71% respectively. The minimum height of the subjects was 138cm, the maximum was 187cm and the mean height was 164.63cm. The weight of the subjects was also measured and the minimum weight was 28kg, the maximum was 76kg and the mean weight was 53.95kg.

Table 2. Overall Physiological Characteristics (N=40)

Variable	N	Min	Max	Mean	SD
FVC	40	2.03	5.97	3.66	1.08
FEV1	40	1.70	5.01	3.12	.90
FEV1/FVC%	40	60.40	95.00	85.71	7.34
Height	40	138.00	187.00	164.63	10.02
Weight	40	28.00	76.00	53.95	11.04

Note. FVC = Forced Vital Capacity; FEV1 = Forced Expiratory Volume 1; Ht = Height; Wt = Weight; The values for FVC and FEV1 mean liter; Height measured in cm; Weight measured in kg.

1) FVC of the Subjects

Forced Vital Capacity of senior swimmers were significantly higher than the FVC of junior swimmers $F(1,38) = 26.83$, $P<.05$. Moreover, male subjects had a significantly higher FVC than female subjects $F(1,38) = 52.26$, $P<.05$. However, no significant difference in FVC was found between sprinters and endurance swimmers. There were no significant mean differences for all interaction effects (see Table 3).

Table 3. MANOVA Results of FVC (N=40)

Source of Variance	SS	df	MS	F
Age	10.27	1	10.27	26.83*
Gender	20.01	1	20.01	52.26*
Swim Event	.02	1	.02	.52
Age x Gender	1.54	1	1.54	4.02
Age x Swim Event	.02	1	.02	.54
Gender x Swim Event	1.08	1	1.08	2.82
Age x Gender x Swim Event	.38	1	.38	.99
Residual	12.25	32		
Total	45.57	39		

Note. Age=Male or Female; Swim Event=Sprinter Swimmers or Endurance Swimmers.
**P < .05*

2) FEV1 of Subjects

Senior swimmers' FEV1 were significantly higher than the FEV1 of junior swimmers $F(1,38) = 28.68$, $P<.05$. Male swimmers had a significant larger FEV1 than female swimmers $F(1,38) = 36.43$, $P<.05$.

No significant difference in FEV1 was found between sprinters and endurance swimmers. There were also no significant mean differences for all interaction effects (see Table 4).

Table 4. MANOVA Results of FEV1 (N=40)

Source of Variance	SS	df	MS	F
Age	8.65	1	8.65	28.68*
Gender	10.99	1	10.99	36.43*
Swim Event	.42	1	.42	1.38
Age x Gender	.79	1	.79	2.60
Age x Swim Event	.23	1	.23	.77
Gender x Swim Event	.20	1	.20	.65
Age x Gender x Swim Event	.41	1	.41	1.35
Residual	9.65	32		
Total	31.34	39		

Note. Age = Junior or Senior; Gender = Male or Female; Swim Event = Sprinter Swimmers or Endurance Swimmers.

**P < .05*

3) FEV1/FVC% of the Subjects

There was no significant mean difference in all the independent variables (age, gender and swim event).

No significant mean difference was found for all interaction effects (refer to Table 5).

Table 5. MANOVA Results of FEV1/FVC% (N=40)

Source of Variance	SS	df	MS	F
Age	58.98	1	58.98	1.32
Gender	176.36	1	176.36	3.94
Swim Event	152.69	1	152.69	3.41
Age x Gender	12.96	1	12.96	.29
Age x Swim Event	146.65	1	146.65	3.27
Gender x Swim Event	111.72	1	111.72	2.49
Age x Gender x Swim Event	7.79	1	7.79	.17
Residual	1433.41	32		
Total	2100.56	39		

Note. Age = Junior or Senior; Gender = Male or Female; Swim Event = Sprinter Swimmers or Endurance Swimmers.

Correlational Analysis

The correlations between FVC and height was significant ($r^2 = .74$), it meant that there was a strong positive relationship between FVC and the height. FVC also had a strongly positive relationship with the weight ($r^2 = .81$).

Meanwhile, the findings indicated a significant positive association of FEV1 with height and weight ($r^2 = .71$ and $r^2 = .8$ respectively).

However, there was no significant correlations between FEV1/FVC% and height ($r^2 = -.15$). The weight was also not significantly correlated with FEV1/FVC% ($r^2 = -.1$).

Table 6. Correlations between Pulmonary Functions and Height, Weight of Subjects (N=40)

Variables	Ht	Wt
FVC	.74*	.81*
FEV1	.71*	.80*
FEV1/FVC%	-.15	-.10

Note. Ht = Height; Wt = Weight; FVC = Forced Vital Capacity; FEV1 = Forced Expiratory Volume 1; The values for Height measured in cm; Weight measured in kg; FVC and FEV1 mean liter.
**P < .05*

Multiple Regression Analysis

A stepwise regression analysis was carried out on FVC and FEV1. It was found that the regression model of FVC had an adjusted R square of .76 and the adjusted R square of FEV1 was .72. Height was dropped out eventually from regression analysis, as there was no significant effect of height on predicting pulmonary functions. From the regression analysis, the following formulas were obtained and please refer to Tables 7, 8, 9 and 10.

FVC = .0456(Weight) - .867(Gender) + .576 (Age) + 1.635

FEV1 = .03858(Weight) + .56(Age) - .585(Gender) + 1.077

Weight = kg

Gender: 1 = Male, 2 = Female

Age: 1 = Junior, 2 = Senior

Adjusted R = .76

Table 7. Multiple Regression Model for FVC (N=40)

Model	Coefficients	t
(Constant)	1.64	2.24
Weight (kg)	.046	4.16*
Gender	-.87	-4.05*
Age	.58	2.89*

**P < .05*
Adjusted R2 = .72

Table 8. MANOVA Analysis (FVC) for Weight (kg), Gender and Age (N=40)

	SS	df	MS	F
Regression	35.25	3	11.75	40.97*
Residual	10.36	36	.29	
Total	45.61	39		

**P < .05*

Table 9. Multiple Regression Model for FEV1 (N=40)

Model	Coefficients	t
(Constant)	1.08	1.66
Weight (kg)	.039	3.97*
Gender	-.59	-3.08*
Age	.56	3.16*

Adjusted R^2 = .72
**P < .05*

Table 10. MANOVA Analysis (FEV1) for Weight (kg), Gender and Age (N=40)

	SS	df	MS	F
Regression	23.19	3	7.73	34.22*
Residual	8.13	36	.23	
Total	31.32	39		

Adjusted R^2 = .72
**P < .05*

Student-Newman-Keuls Analysis of FVC

For the FVC, significant mean difference were found between Gp1 and Gp4 (M = -1.69, P<.05), Gp2 and Gp4 (M = -1.65, P<.05) (see Table 11).

More significant mean differences were found between Gp3 and the other groups. Gp3 and Gp5 (M = 2.05, P<.05), Gp3 and Gp6 (M = 2.28, P<.05), Gp3 and Gp7 (M = 1.28, P<.05), and Gp3 and Gp8 (M = 1.81, P<.05).

There were 4 sets of significant mean difference found in Gp4. The related groups were Gp5 (M = 2.59, P<.05), Gp6 (M = 2.80, P<.05), Gp7 (M = 1.81, P<.05), and Gp8 (M = 2.33, P<.05).

Table 11. Student-Newman-Keuls Analysis of FVC of Subjects (N=40)

	Gp1	Gp2	Gp3	Gp4	Gp5	Gp6	Gp7
Gp2	-.04						
Gp3	-1.17	-1.12					
Gp4	-1.69*	-1.65*	-.52				
Gp5	.89	.93	2.05*	2.59*			
Gp6	1.11	1.17	2.28*	2.80*	.22		
Gp7	.12	.16	1.28*	1.81*	-.77	-.99	
Gp8	.64	.68	1.81*	2.33*	-.25	-.47	.52

Note. Gp1 = Male/Junior/Sprinter;
Gp2 = Male/Junior/Endurance;
Gp3 = Male/Senior/Sprinter;
Gp4 = Male/Senior/Endurance;
Gp5 = Female/Junior/Sprinter;
Gp6 = Female/Junior/Endurance;
Gp7 = Female/Senior/Sprinter;
Gp8 = Female/Senior/Endurance.

*P < .05

Student-Newman-Keuls Analysis of FEV1

The results of the Student-Newman-Keuls analysis are presented in Table 12. There was significant mean difference found in Gp1 (Male/Junior/Sprinter Swimmers) and Gp4 (Male/Senior/Endurance Swimmers, M = -1.15, P<.05). In Gp2, significant mean difference was found with Gp3 (M = -1.27, P<.05) and Gp4 (M = -.56, P<.05).

Three groups had significant mean difference with Gp3 (Male/Senior/Sprinter Swimmers); the first was Gp5 (M = 1.69, P<.05). The second one was Gp6 (M = 1.98, P<.05) and the last one was Gp8 (M = 1.38, P<.05).

There were 4 sets of significant mean difference with Gp4 (Male/Senior/Endurance Swimmers), they were Gp5 (M = 1.98, P<.05), Gp6 (M = 2.27, P<.05), Gp7 (M = 1.28, P<.05) and Gp8 (M = 1.67, P<.05).

Table 12. Student-Newman-Keuls Analysis of FEV1 of Subjects (N=40)

	Gp1	Gp2	Gp3	Gp4	Gp5	Gp6	Gp7
Gp2	.42						
Gp3	-.86	-1.27*					
Gp4	-1.15*	-1.56*	-.29				
Gp5	.83	.41	1.69*	1.98*			
Gp6	1.12	.71	1.98*	2.27*	.29		
Gp7	.13	-.29	.99	1.28*	-.70	-.99	
Gp8	.52	.11	1.38*	1.67*	-.31	-.60	.39

Note.
Gp1 = *Male/Junior/Sprinter;*
Gp2 = *Male/Junior/Endurance;*
Gp3 = *Male/Senior/Sprinter;*
Gp4 = *Male/Senior/Endurance;*
Gp5 = *Female/Junior/Sprinter;*
Gp6 = *Female/Junior/Endurance;*
Gp7 = *Female/Senior/Sprinter;*
Gp8 = *Female/Senior/Endurance.*

*P < .05

Student-Newman-Keuls Analysis of FEV1/FVC% of Student

There was a significant mean difference between Male/Junior/Endurance swimmers and Female/Senior/Endurance swimmers (M = -13.80, P<.05), see Table 13.

Table 13. Student-Newman-Keuls Analysis of FEV1/FVC% of Subjects (N=40)

	Gp1	Gp2	Gp3	Gp4	Gp5	Gp6	Gp7
Gp2	11.96						
Gp3	3.42	-8.54					
Gp4	5.96	-6.00	2.54				
Gp5	1.16	-10.80	-2.26	-4.80			
Gp6	4.68	-7.29	1.25	-1.28	3.51		
Gp7	.54	-11.42	-2.88	-5.42	-.62	-4.13	
Gp8	-1.84	-13.80*	-5.26	-7.80	-3.00	-6.51	-2.38

Note.
Gp1 = *Male/Junior/Sprinter;*
Gp2 = *Male/Junior/Endurance;*
Gp3 = *Male/Senior/Sprinter;*
Gp4 = *Male/Senior/Endurance;*
Gp5 = *Female/Junior/Sprinter;*
Gp6 = *Female/Junior/Endurance;*
Gp7 = *Female/Senior/Sprinter;*
Gp8 = *Female/Senior/Endurance.*
*P < .05

Discussions

Sprinter and Endurance Swimmers

Smith et al. (1984) and Van-Handel et al. (1991) both suggested that endurance athletes had significantly larger lung volume measures than sprinters. However, this research had different results. The findings indicated that there was no significant difference in lung functions between the long and short distance swimmers in Hong Kong.

This finding showed a resembling decoration with some other former studies. The research findings supported Price et al. (1983) who suggested that the unique patterns and demands of breathing in swimming might affect the pulmonary functions of short and long distance subjects in like fashion. It was also consistent with Farrell (1981) suggestion that FVC, TLC and RV were not different when sprinters and endurance athletes were compared.

Lakhera et al. (1994) revealed that both sprinters and endurance swimmers had the same level of resistance to air movement in the lungs. The results of the present study were also in agreement with Inbar et al. (1990) who suggested that no mean differences were observed between the endurance athletes and short distance athletes.

Male and Female Swimmers

The result of the present study showed that there was difference between male and female swimmers in their pulmonary functions. The results showed that male swimmers had greater pulmonary functions than female swimmers, which were in agreement with Shephard (1987) who revealed that lung functions were comparatively higher in male than female. Chen and Kuo (1989) also suggested that men had greater pulmonary functions than women did by doing a measurement of lung functional tests and respiratory muscle endurance tests.

This phenomenon could be explained by Miles & Durbin (1985) research, which suggested that the small airways might close early due to airway constriction or smaller diameter of the airway in the girls. This might explain why the present study showed that female had lower pulmonary functions than male. There was a possibility that this divergence was due to differences in position, age or gender of the subjects (Gibbons et al. 1985).

Junior and Senior Swimmers

The result indicated that senior swimmers had greater pulmonary functions than junior swimmers. The findings were in agreement with Hartung et al. (1982) who suggested that senior athlete was competent to discharge at a greater percentage of their lung capacities than younger athlete. Lakhera et al. (1994) also retrieved that mature athletes had larger lung volumes and capacities than adolescence athletes by using conventional closed circuit spirometry and giving two trails for each subject. However, the present outcome did not support Cordain et al. (1990) who suggested that young subjects were able to quickly expire to their vital capacities and reached volumes near RV than senior subjects.

Height and Weight of Swimmers

Body structure actually varies according to the sex and it will be built up as a swimmer gets older. Therefore, male swimmers should be taller and heavier than female swimmers. Senior swimmers should be taller and heavier than junior swimmers. These ideas were supported by the present investigation.

In the present research, male swimmers were taller and heavier than female swimmers (170.5cm Vs 158.75cm and 59. 95kg Vs 47.95 respectively, see Table 1). Senior swimmers were taller than junior (167.55cm Vs 161.70cm, see Table 1) and senior swimmers were also heavier than that of junior (58. 75kg Vs 49.15kg, see Table 1).

The results demonstrated that there were strong relationships in lung capacities between height and weight. It showed that the taller the subject, the larger the pulmonary functions the subject had. And the findings was in agreement with the previous researches conducted by investigators like Shephard (1987), Cordain et al. (1990) & McArdle et al. (1994) who indicated that pulmonary functions related to height and weight.

Model of Predicting Pulmonary Functions

The formula predicted by Rosentswieg et al. (1986), who estimated the pulmonary functions by using one independent variable only, which was sitting height (cm) of the subjects.

However, it was encountered in the present research that age, gender and weight were good predictors to pulmonary functions. Age, gender and weight had very high predictable power to FVC. They explained 76% (Adjusted R^2) of the regression model. For the FEV1, 72% (Adjusted R^2) of predictable power was found.

Comparing to the prediction equations obtained by Rosentswieg et al. (1986) with standard errors of .54 and .41, the present equations had higher predictive power on estimating pulmonary functions.

Summary and Conclusion

Pulmonary Functions of Subjects

Generally, male swimmers had a larger FVC and FEV1 than female swimmers. Similar to the gender of swimmers, senior subjects had higher lung capacities than junior subjects. However, there was no significance difference between sprinter and endurance swimmers. There was no significant difference for all interaction effects on the pulmonary functions.

There was a strong positive relationship between FVC and FEV1 with height (cm), and weight (kg) of the subjects.

The results yielded the following formulas:

$$FVC = .0456(Weight) - .867(gender) + .576\ (Age) + 1.635$$

$$FEV1 = .03858(Weight) + .56(Age) - .585(Gender) + 1.077$$

In the multiple regression analysis, four independent variables (age and gender, weight and height) were selected as the predictors.

This investigation revealed that the lung functions of elite swimmers were not governed by the swim events they entered. The pulmonary functions were actually affected by the age, gender and the growth process of swimmers. Male swimmers had greater lung capacities than female swimmers, and senior had larger pulmonary functions than junior did. There was no interaction effects found between swimming event, age and gender.

From this study, the investigator also found that not only age and gender had effect on lung functions, but weight and height also played an important role. Taller and heavier swimmers tended to have higher lung capacities than others.

Recommendations for further investigation

According to the findings of present research, the author suggests that further investigation should take into two directions: Research Recommendation and Practical Recommendation.

Research Recommendation

(1) The researcher feels that the new determination of independent variables may not be limited to gender, age, height and weight.

(2) The relationship of genetic endowment and training in the development of lung volumes and capacities in swimmers can also be tested in the future.

(3) More data of Asian or even Western swimmers should be collected to validate the predicted equations of pulmonary functions obtained in this research.

(4) If the height of the subjects (both sex) were matched, but female was heavier. In this case, would the pulmonary functions of female better off?

Practical Recommendation

(1) In order to enhance performance of athletes, the ability to distinguish pulmonary functions of high-performed athletes from low performed athletes is desirable.

(2) Standing height was used to predict equations in the current study. However, Rosentswieg et al. (1986) used sitting height to estimate the equations. Therefore, the author suggests that comparison of the two methods can be carried out in the future.

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