青年期の競技者と非競技者における身体活動量がダブルプロダクトに及ぼす効果

—ダブルプロダクトにおける身体活動量の効果—

Comparison the Effect of Physical Activity on Double Product: A Comparison between Adolescent Athletes and Non-Athletes

—The effect of physical activity on double product —

鈴木　石松　Ishimatsu Suzuki
（現代マネジメント学部）

鈴木　尊士　Takashi Suzuki
（中国　上海交通大学デザイン研究科博士課程）

加藤　彰浩　Akihiro Katoh
（家政学部こどもの生活学科）

Abstract

Objectives: Regular physical activity (PA) is vital for good physical and mental health. It is well known that participation in athletic activity improves physical fitness, coordination and self-discipline. The double product (DP) is the product of heart rate (HR) and systolic blood pressure (SBP). The DP is a benefit index rather than a single item of the circulatory function. The purpose of this study is to compare the effect of PA on DP between adolescent athletes and non-athletes.

Methods: The present study was carried out on 20 collegiate males of the age group of 20-22 yrs. They were divided into two groups, the study group (10 athletes) and the control group (10 non-athletes). Daily energy expenditure and PA were assessed using the Calorie Counter for six days. The HR and SBP were measured from a progressive submaximal bicycle ergometer exercise test with a pedaling frequency of 60/min.

Results: The PA in athletes was significantly higher than non-athletes. The results of HR, SBP, and DP during submaximal bicycle ergometer exercise were significantly lower in athletes than non-athletes. Although we found that PA was inversely related to DP in both athletes and non-athletes, the correlations were not statistically significant.

Conclusion: Our study considers that the participation of the university students in the sports club activities promotes increase of the physical active mass, and it may be effective for reduction of the circulation function stress at the time of daily life and the exercise.

Key words: Physical activity (PA), Double product (DP), Heart rate (HR), Systolic blood pressure (SBP), Circulation function

Contents:

1. INTRODUCTION

It is well known that physical inactivity may be responsible for various chronic diseases (4). Low levels of physical activity and physical fitness are both associated with higher risk of all cause and disease specific mortality (7). Also, regular exercise improves health as well as lowers health care costs.

The importance of physical fitness to health for all individuals has been well documented. Physical fitness is a required element for all the activities in our life (25). Several factors such as heredity, environment, diet, socioeconomic status and training are known to contribute to physical fitness of an individual (16). Physical fitness of an individual is mainly dependent on lifestyle related factors such as daily physical activity (PA) levels. It is believed that the low physical fitness level of an individual is associated with higher mortality rate (14). Thus, physical fitness reduces the risk of cardiovascular diseases and other diseases such as hypertension, diabetes obesity, and may cure respiratory problems such as asthma (2).

On the other hand, the double product (DP) known as the rate pressure product, is the mathematical product of the heart rate (HR) and systolic blood pressure (SBP). DP is used in cardiology and exercise physiology to determine myocardial oxygen consumption. Myocardial oxygen consumption correlates highly with the work of the heart. Because of essentially aerobic metabolism of myocardium, changes in maximal oxygen uptake (VO_2max) correlate highly with the work of the heart. DP is used to measure workload on the heart to provide adequate blood supply to the myocardium during exercise. Thus, the DP has long been used as a non-invasive measure of myocardial oxygen consumption during exercise (10). Moreover, The DP has been a useful index in cardiac rehabilitation settings to identify specific workloads at which signs and symptoms of ischemia occur and improvements in functional capacity relative to the onset of symptomatic ischemia (7).

Athletes are commonly associated with a physically active lifestyle beneficial to fitness as compare to non-athletes. Due to regular exercise, athletes tend to have an increase in fitness level compared to non-exercising individuals. Exercise builds and maintains healthy muscles, bones and joints. It helps to reduce risk for many chronic diseases such as hypertension, diabetes mellitus. Thus, exercise and PA impact on wellness and fitness. Participation in athletic activity improves physical fitness, coordination and self-discipline. Sport exposure encourages the development of motor skills, social skills, leadership and gives participate opportunity to learn teamwork. People who participate in sports have higher self-esteem and pride in them.

The purpose of this study is to evaluate whether PA is an effective physiological stimulus to improve DP in athletes than non-athletes.

2. SUBJECTS & METHODS

2-1 Subjects

The present study was carried out in 20 males (10 athletes and 10 non-athletes) of the age group between 20-22 years in Department of Contemporary Management, Aichi Gakusen University. All the athletes in the study group were doing minimum 3hrs exercise (the running, jogging, etc.) daily for 12 years. Control group comprises 10 males of the same age group having sedentary lifestyle. They were not doing any type of exercise at all. Written informed consent was obtained from the participants after making them to understand the importance of the project, their role in the project and the procedural part of the project.

Table 1. Personal characteristics of the study population

Variable	Athletes (n=10)		Non-athletes (n=10)		Mean Difference	*t*-value	*p*-value
	Mean	SD	Mean	SD			
Height (cm)	173.4	7.5	172.2	7.4	1.2	0.358	NS
Weight (kg)	71.9	10.3	68.9	12.8	3	0.575	NS
BMI (kg/㎡)	23.7	2	23.1	2.4	0.76	0.759	NS
Sports history	11	1.2	0	0	11	30.1	P < 0.001

* BMI = body mass index NS = Non significant

2-2 Body Mass Index (BMI)

Height measurements were taken by using the standard anthropometric rod to the nearest 0.5 cm. The subject's weight was measured with portable weighing machine to the nearest 0.5 kg. BMI was calculated as weight (kg) divided by height squared (m^2). The mean values and standard deviations of anthropometrics and sports history are presented in Table1.

2-3 Study protocol

Before the day of their appointment, all participants were well informed about the research procedures and became familiar with the lab and the test equipment. After the subject had rested in the sitting position for 10 min, resting HR, SBP and diastolic blood pressure (DBP) were measured non-invasive using an automated sphygmomanometer (Kyokko-Bussan, CM-4001). This machine has a 3-lead electrocardiograph before and during the cycle ergometer test at 60-s intervals under computer control.

After 5 min rest in the sitting position, subjects performed bicycle ergometer tests conducted to achieve HR of 65~70% HRmax. Bicycle ergometer tests were conducted on a mechanically Combi (232 CXL) bicycle ergometer. The protocol of the ergometer tests was showed in Fig 1. Seat height was adjusted so the legs were nearly extended when the pedals were in the down position. The HR, SBP and DBP were measured from a progressive submaximal bicycle ergometer exercise test with a pedaling frequency of 60/min. The protocol of gradually increasing workloads (increasing 20 watts with 2 min) was terminated when subjects finished 120 watts workloads.

2-4 Assessment of PA

PA and daily energy expenditure were measure by Calorie Counter (27). The validity and reliability of the Calorie Counter is acceptable and is reported (27). This machine consisted of an accelerometer that detects speed and an operational function that calculates basic

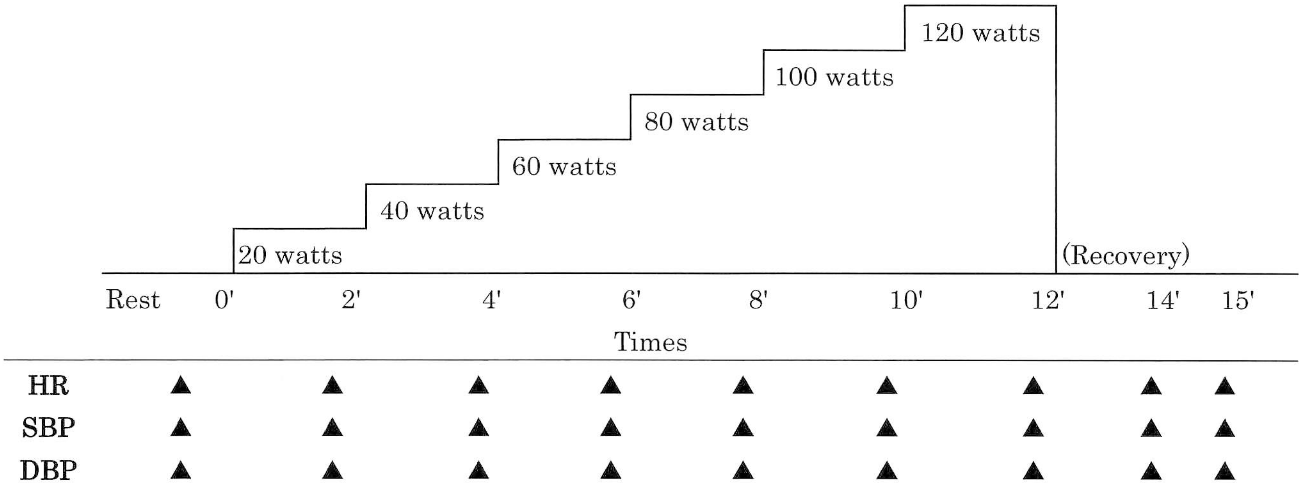

Figure 1. Protocol of the incremental exercise test

metabolism and energy expenditures on an acceleration basis. The basic metabolism was computed for sex, age, height and body weight. The exercise intensity obtained from the integrated value of acceleration detected every 3 seconds was measured in calories.

The instruments were attached early in the morning before the subject engaged in any PA and were removed and read late in the evening before the subject retired for the night. Each subject was asked to keep this Calorie Counter worn at his waist for 6 continuous days except for bathing and sleeping, during which the subject followed a normal lifestyle. Since this measuring machine in capable of making continuous measurements, the amounts of activity metabolism, indicated on the measuring machine, were read and entered on a recording sheet.

3. STATISTICAL ANALYSES

Data was expressed as means with ± standard deviation (SD). Independent samples *t*-tests were used to test if population means estimated by two independent samples differed significantly. The level of significance was set as a *p*-value < 0.05 throughout. The correlations given were computed as linear regression functions. Data were performed using the SPSS version 14.0 J software package.

Table 2. Energy expenditure, physical activity, and steps estimated by Calorie Counter method

Variable	Athletes (n=10)		Non-athletes (n=10)		Mean Difference	*t*-value	*p*-value
	Mean	SD	Mean	SD			
Energy expenditure (kcal/day)							
Mon	2621.9	154.3	2225.5	172.5	396.4	5.415	***
Tue	2663.6	127.1	2256.3	181.3	407.6	5.82	***
Wed	2639.6	139.4	2283.8	261.2	355.8	3.677	**
Thu	2666.1	156.9	2256.9	150.8	409.1	5.943	***
Fri	2647.9	131.8	2225.5	156.3	422.4	6.53	***
Sat	2674.6	116.5	2250.8	205.6	423.8	5.67	***
Mean	2652.2	127.6	2249.7	158.1	402.5	6.264	***
Physical activity (kcal/day)							
Mon	546.7	64.2	309.2	36.5	237.5	10.156	***
Tue	575.6	76.1	302.9	36.6	272.7	10.21	***
Wed	586.2	81.7	313.7	34.4	272.5	9.716	***
Thu	633.5	72.3	300.1	10.4	332.9	14.118	***
Fri	564.5	48.3	300.3	40.4	264.2	13.255	***
Sat	564.2	44.5	324.5	50.1	239.7	11.299	***
Mean	578.4	46.9	308.5	19.8	269.9	16.754	***
Step rate (steps/day)							
Mon	21942	1558	10998	2475	10944	11.829	***
Tue	23178	1862	10473	2074	12705	14.411	***
Wed	23856	2087	10878	2200	12978	13.531	***
Thu	24483	2403	10114	1883	14368	14.88	***
Fri	23897	1386	10405	2215	13492	16.322	***
Sat	23642	2169	10625	3181	13016	10.688	***
Mean	23500	1060	10582	1613	12917	21.153	***

** p < 0.01, *** p < 0.001

4. RESULTS

The mean values and standard deviations of daily energy expenditure, daily physical activity, and daily steps estimated for six days are presented in Table2. Mean values of daily energy expenditure, daily physical activity and daily steps estimated in athletes for six days were significantly higher than non-athletes.

The mean values and standard deviations of HR, SBP, DBP, DP at resting, during exercise, and after exercise were presented in Table 3.

We observed significant differences in HR, SBP, and DP during exercise between athletes and non-athletes. Correlational analyses between DP and PA was performed separately for the two groups of athletes and non-athletes (Fig 2). We found that the DP was inversely associated with PA in both groups, yet the correlations were not statistically significant.

Table 3. Changes in HR, SBP, DBP, and DP with duration of exercise and recovery period in athletes and non-athletes

Mean (SD)		Rest	During exercise						Recovery	
		Baseline	2 min	4 min	6 min	8 min	10 min	12 min	2 min	4 min
		0 watt	20 watts	40 watts	60 watts	80 watts	100 watts	120 watts	0 watt	0 watt
HR	A	62.5(5.3)	76.8(8.0)	81.6(8.8)	88.8(5.0)	97.1(5.4)	109.2(8.7)	122.3(7.0)	84.2(10.4)	74.7(9.2)
	B	67.0(4.6)	79.9(6.6)	89.0(6.6)	104.4(8.2)	119.7(2.9)	128.5(5.1)	134.0(2.6)	91.9(4.9)	83.3(4.1)
	Sig.	< 0.05		< 0.05	< 0.001	< 0.001	< 0.001		< 0.05	< 0.05
SBP	A	110.4(4.5)	117.5(8.7)	123.9(12.6)	130.7(7.3)	137.4(10.5)	146.3(10.0)	161.8(11.9)	137.5(8.3)	126.5(10.6)
	B	119.9(4.9)	128.1(10.7)	135.9(6.2)	141.5(4.6)	146.5(4.1)	162.8(6.1)	169.6(5.3)	151.8(7.5)	132.4(5.1)
	Sig.	< 0.05	< 0.05	< 0.05	< 0.001	< 0.05	< 0.001		< 0.001	
DBP	A	71.5(2.0)	61.9(8.3)	65.1(5.6)	61.9(5.4)	61.6(4.8)	62.7(5.2)	60.9(7.8)	69.3(4.0)	73.5(6.5)
	B	71.4(2.0)	73.9(4.3)	68.6(3.6)	68.1(7.2)	65.6(5.5)	64.6(9.4)	62.4(6.7)	63.6(6.7)	69.2(7.8)
	Sig.		< 0.001		< 0.05				< 0.05	
DP	A	6851(708)	9012(1516)	10124(1578)	11614(1009)	13366(1467)	16011(1965)	19810(2157)	11583(1644)	9460(1483)
	B	8029(601)	10229(1186)	12082(913)	14768(1213)	17529(397)	20912(990)	22730(968)	13941(897)	11041(883)
	Sig.	< 0.05		< 0.05	< 0.001	< 0.001	< 0.001	< 0.001	< 0.001	< 0.05

A: athletes; B: non-athletes; HR: heart rate; SBP: systolic blood pressure; DBP: diastolic blood pressure; DP: double product

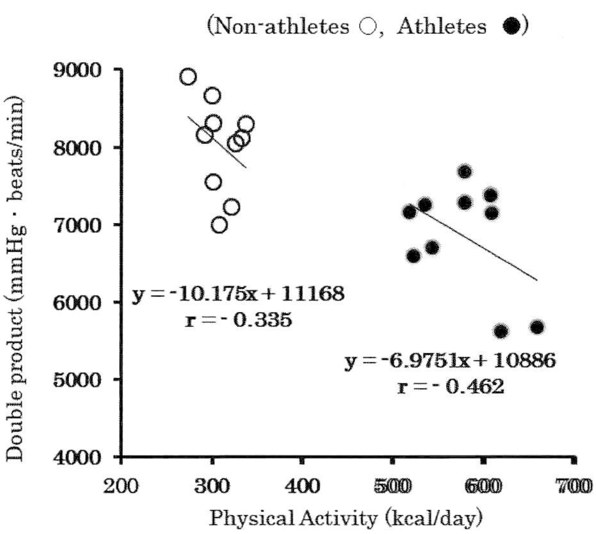

Figure 2. The relationship between PA and DP.

5. DISCUSSION

We set out to evaluate whether PA is a more effective physiological stimulus to improve myocardial economy in athletes than non-athletes. The results of the present study indicated that athletes had significantly higher PA, and significantly lower HR, SBP and DP than non-athletes.

5-1 PA and HR

Increased PA has been shown to lower HR in young (19) and middle aged (22). These results suggest that increased PA may be sufficient to affect the autonomic tone of the adults, similar to exercise modalities that have been shown to do so (15). The PA-induced lower resting HR, as it was found in our athlete group participants, may be related to increased stoke volume observed in exercising or physically active individuals (6). Thus, increased PA may provoke the physiological mechanisms that affect parasympathetic tone in the young athlete people.

Lower HR is, at least partially, the result of increased parasympathetic tone and may be related to the improvements in sympathetic control of vasomotor tone provoked by PA (24). Yet, it remains unclear why the above hemodynamic mechanism may hold true and explain the PA related HR decline in athletes.

5-2 PA and SBP

Arterial blood pressure is the lateral pressure exerted by the column of blood against the arterial walls. During the cardiac cycle the highest pressure attained is the systolic pressure and the lowest pressure is the diastolic pressure. Blood pressure is directly proportional to the effect of cardiac output on total peripheral vascular resistance and depends on the total blood volume and viscosity (11).

PA has been associated with the prevention of increased blood pressure, suggesting a mechanism which hypertensive patients can benefit from. The results of the present study confirmed the benefits of PA in lowering SBP in the young athlete people. It could be thought that SBP was independently associated with increased PA, indicating that a dose-response relationship may exist between levels of PA and SBP. Similar findings were reported in the study by Hagberg et al., (12) who reported that in old men and women SBP was marked lower after moderate exercise training. Also, it has been supported that in men a higher level of PA, such as vigorous exercise, is required to affect autonomic control and provoke changes in SBP (5).

Physiological mechanisms such as systemic adaptation of the arterial wall, reduction of pro-oxidant levels and arterial stiffness, increases in central nitric oxide synthase activity and improvement in endothelial function may explain the effects of increased PA levels on SBP, as it could be considerate in our study.

5-3 PA and DP

The term myocardial economy describes the ability of the heart to meet the needs of the working tissues for blood and oxygen supply with the minimum of myocardium stress (10). The DP is strongly and positively related to coronary blood flow and myocardial O_2 uptake (3). All of the above are positively related to myocardial O_2 demands and hence myocardial workload, being important non-invasive and inverse indicators of myocardial economy (8). Thus, DP is a valuable marker of cardiac function and an important index of myocardial economy. Moreover, in Japanese Ohasama populations, the DP at rest based on home blood pressure measurement was significantly associated with mortality (13). Notably, the association between the home-measured DP and mortality was stronger than that between mortality and SBP or HR (13).

The present study may be the first to examine the PA effects on DP in the young students. Despite the fact that higher PA tend to have lower SBP in both groups, no statistical significance was observed in the reduction of DP. In line with our results, Forjaz et al., (9) found that in young normotensives exercise of moderate intensity lowered HR. It is known that regular PA is associated with higher levels of cardiovascular fitness, as measured by VO_2 max and HR response to sub-maximal exercise (17).

Physiologically VO_2max is the intensity of an individual to increase metabolic processes with the requirements of increased physical efforts (21). It has been reported that there is a dose-response relationship between PA intensity and cardiovascular benefits: high-intensity PA tends to lead to greater cardiovascular functional gains than low-intensity PA (1). This is further supported by Rennie et al., (23) who suggested that parasympathetic tone may be increased by vigorous PA, compared to low PA, thus representing a possible mechanism by which PA reduces heart disease risk. Moreover, the study of cardiovascular fitness may clarify the contribution of PA with the decreased risk of cardiovascular disease (26). PA may be a crucial factor defining the dose-response relation between PA and DP. The WHO suggests that adults should perform at least 150 min of moderate-intensity PA/week (18).

The training of athletes includes different exercises such as running, jogging and stretching exercises regularly for 11 years. All these flexibility exercises such as stretching improve range of muscle movements and joints. In athletes lower DP may be attributed to specific character of their training high VO_2max yields more energy and better athletic activity. Moreover, in a previous study significantly higher values of cardiopulmonary efficiency in athletes were observed as compared to non-athletes (20). Our findings of higher PA and lower DP in athletes than non-athletes are in agreement with previous study. It was indicated that regular PA has beneficial effects on the cardiovascular, respiratory and locomotor systems.

6. CONCLUSION

In the present study, we found that the DP was lower in athlete groups with higher levels of PA than non-athlete group, but this association was not significant. Further investigation is needed to determine the precise dose-response relationship between DP and PA. Future research needs to be carried out to clarify how PA of longer duration and/or higher intensity may affect myocardial economy and cardiovascular responses in healthy middle aged.

7. ACKNOWLEDGEMENTS

The author thank to colleague Mr. Takashi Suzuki for his technical assistance on data analyzing. We would like to thank Dr. Yoko Urada and Prof. Joseph Blute (Aichi University) for their helpful comments & editing.

8. REFERENCE

1. Alansare A, Alford K, Lee S, Church T, Jung HC. 2018. The effects of high-intensity interval training vs. moderate-intensity continuous training on heart rate variability in physically inactive adults. Int J Environ Res Public Health 15: E1508.

2. Amusa L O and Goon D T. 2011. Health related physical fitness among rural primary school children in Tshannda, South Africa Scientific Research and Essays 6(22), 4665 - 4680.

3. Astrand PO, Rodahl K, Dahl HA, Stromme SB. 2003. Body fluids, blood and circulation. In: Bahkre MS, ed. Textbook of work physiology. Physiological Basis of Exercise (2nd), Champagne, IL: Human Kinetics

4. Booth F W, Gordon S E, Carlson C J, Hamilton M T. 2000. Waging war on modern chronic diseases: primary prevention through exercise biology. J Appl Physiol 88(2), 774-87.

5. Carpio-Rivera E, Moncada-Jiménez J, Salazar-Rojas W, Solera-Herrera A. 2016. Acute effects of exercise on blood pressure: a meta-analytic investigation. Arq Bras Cardiol 106: 422-433.

6. Chou TH, Akins JD, Crawford CK, Allen JR, Coyle EF. 2019. Low stroke volume during exercise with hot skin is due to elevated heart rate. Med Sci Sports Exerc 51: 2025-2032.

7. Durstine J L, American College of Sports Medicine. 2009. ACSM's exercise management for persons with chronic diseases and disabilities. Human Kinetics, Champaign, IL

8. Fletcher G F, Balady G J, Amsterdam E A, Chaitman B, Eckel R, et al. 2001. Exercise standards for testing and training: a statement for healthcare professionals from the American Heart Association. Circulation 104: 1694-1740.

9. Forjaz C L, Matsudaira Y, Rodrigues F B, Nunes N, Negrão C E. 1998. Post-exercise changes in blood pressure, heart rate and rate pressure product at different exercise intensities in normotensive humans. Braz J Med Biol Res 31: 1247-1255.

10. Gobel F L, Norstrom L A, Nelson R R, Jorgensen C R, Wang Y. 1978. The rate - pressure product as an index of myocardial oxygen consumption during exercise in patients with angina pectoris. Circulation 57: 549 - 556
11. Gori T, Wild P S, Schnabel R, Schulz A, Pfeiffer N, et al. 2015. The distribution of whole blood viscosity, its determinants and relationship with arterial blood pressure in the community: cross-sectional analysis from the Gutenberg Health Study. Ther Adv Cardiovasc Dis 9: 354-365.
12. Hagberg J M, Montain S J, Martin W H, Ehsani A A. 1989. Effect of exercise training in 60- to 69-year-old persons with essential hypertension. Am J Cardiol 64: 348-353.
13. Inoue R, Ohkubo T, Kikuya M, Metoki H, Asayama K, Kanno A, Obara T, Hirose T, Hara A, Hoshi H, et al. 2012. Predictive value for mortality of the double product at rest obtained by home blood pressure measurement: the Ohasama study. Am J Hypertens. 25(5):568–575.
14. Jourkesh M, Iraj Sadri I, Ojagi A Sharanavard A. 2011. Comparison of physical fitness level among the students of IAU, Shabestar Branch. Annals of Biological Research, 2(2), 460-465.
15. Karavirta L, Tulppo MP, Laaksonen DE. 2009. Heart rate dynamics after combined endurance and strength training in older men. Med Sci Sports Exerc 41: 1436-1443.
16. Khodnapur J P. 2012. Role of regular exercise on VO_2max and physiological parameters among residential and nonresidential school children of bijapur. International Journal of Biomedical and Advance Research. 3(5), 397-400.
17. Leon A S, Jacobs D R, DeBacker G, Taylor H L. 1981. Relationship of physical characteristics and life habits to treadmill exercise capacity. Am J Epidemiol 113: 653-660.
18. Marques A, Sarmento H, Martins J, Saboga-Nunes L. 2015. Prevalence of physical activity in European adults - Compliance with the world health organization's physical activity guidelines. Prev Med 81: 333-338.
19. Melo R C, Santos M D, Silva E, Quitério R J, Moreno M A, et al. 2005. Effects of age and physical activity on the autonomic control of heart rate in healthy men. Braz J Med Biol Res 38: 1331-1338.
20. Pakkala A, Veeranna N, Kulkarni S B. 2005. A comparative study of cardiopulmonary efficiency in athletes and non-athletes. J Indian Med Assoc. 103(10), 524, 526-527
21. Radosław Laskowski, Ewa Ziemann, Tomasz Grzywacz. 2009. Comparison of aerobic capacity in various groups of adolescent athletes. Archives of Budo. (Suppl5): 21-25.
22. Reimers A K, Knapp G, Reimers C D. 2018. Effects of exercise on the resting heart rate: a systematic review and meta-analysis of interventional studies. J Clin Med 7: E503
23. Rennie K L, Hemingway H, Kumari M, Brunner E, Malik M, et al. 2003. Effects of moderate and vigorous physical activity on heart rate variability in a British study of civil servants. Am J Epidemiol 158:135-143.
24. Shin K, Minamitani H, Onishi S, Yamazaki H, Lee M. 1997. Autonomic differences between athletes and nonathletes: spectral analysis approach. Med Sci Sports Exerc 29: 1482–1490.
25. Sinku, S. 2012. Cardiovascular fitness among sedenatry students. Journal of Exercise Science and Physiotherapy, 8(2), 109-112.
26. Suzuki I, Komiya H, Maeda J, Ifuku H. Kamada Y. 2019. Relationship of physical fitness and physical activity to cardiovascular disease risk factor in Japanese. Adv. Exerc. Sports Physiol. 25(2): 29-35.
27. Suzuki I, Kawakami N, Shimizu H. 1997. Accuracy of calorie Counter method to assess daily energy expenditure and physical activities in athletes and non-athletes. J Sports Med Phys Fitness. 37: 131-136.

（原稿受理年月日：2021 年 9 月 13 日）