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Correlation between physical efficiency index using Harvard step test and heart rate variation in college students

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The purpose of this study is to investigate the relationship between physical efficiency index (PEI) calculated by the Harvard step test and heart rate variation (HRV), and to identify parameters of HRV that can predict PEI in college students. Sixteen college students were participated in this study and they were randomly divided into two groups; higher PEI group (HPEI, n=6) and lower PEI group (LPEI, n=10). To investigate the relationship between PEI and HRV, we were measured HRV and Harvard step test. HRV test was the resting, immediately, 15 min and 30 min after the Harvard step test using electrocardiography device polyG-I. Relationship between PEI and HRV were determined Pearson correlation coefficient, and multiple regression analysis was performed for examining HRV parameters to predict PEI. As shown in the result, not only PEI was negatively correlated with root mean squared differences between adjacent normal RR intervals (RMSSD), but had a positive correlation with low-frequency/high-frequency, but also normalized low frequency (normLF), the ratio of LF, and RMSSD, the change in RR interval showed a significant difference at each time point of measurement according to PEI levels. But, there were no significant differences among the HRV variables except normLF and RMSSD. Our findings suggest a critical information that PEI calculated by the Harvard step test can be used as an index to predict the autonomic nerve function, and high PEI may have a positive effect on changes in autonomic nerve activity during recovery after exercise intervention.

Keywords: Harvard step test, Physical efficiency index, Heart rate variation, College student

INTRODUCTION

The autonomic nervous system consists of the sympathetic nerve and parasympathetic nerve, and these two nerves work to dynamically maintain homeostasis according to the environment changes. In an emergency, the sympathetic nervous system increases heart rate, respiration, and blood pressure, while turning back to a stable state activates the parasympathetic nerves, leading to the recovery of damaged cells and tissues through energy mobilization (McCorry, 2007). Recently, there have been increasing studies on the relationship between autonomic nerves and various metabolic diseases. A few previous studies suggested that patients with heart attack or myocardial infarction should predominantly activated sympathetic nerves (Florea and Cohn, 2014; Thayer et al., 2010), but, regular exercise might promote the function of autonomic nerves to induce additional treatment of heart disease (Goodman et al., 2016; Pearson and Smart, 2018; Taylor et al., 2014).

Heart rate is not stable, but constantly changes in response to physical and mental condition (De Jong and Randall, 2005). Heart rate variability (HRV) is variation in the time interval (RR variability) between successive heart beats and it has been known as a valid indicator for assessing autonomic function (Sandercock and Brodie, 2006). In the clinical diagnosis, HRV results can be evaluated by time domain analysis, frequency domain analysis, and nonlinear methods (Maestri et al., 2006; Sassi et al., 2015). According to previous studies on HRV, Aubert et al. (2003) suggested that aerobic exercise had a positive effect on the increase in autonomic nerve activity, and that an increase in maximum oxygen uptake

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(VO_{2max}) after regular high-intensity aerobic exercise improved autonomic nervous system controls (Kiviniemi et al., 2007). In the field of sports science, the VO_{2max} is used as an index to evaluate aerobic capacity. But, there is difficult to measure it in clinical trials. It has been well known that the Harvard step test is a representative field test to examine aerobic capacity, and the physical efficiency index (PEI) can be confirmed by the heart rate during resting period after Harvard step test for 5 min. However, Esco et al. (2010) suggested negative results that aerobic capacity increased by regular aerobic exercise did not have a positive effect on autonomic nervous system controls. These contradictory previous findings are still controversial. In addition, although previous studies have been conducted to confirm the relationship among post-exercise heart rate recovery, aerobic capacity (VO_{2max} and PEI) and HRV (Buchheit and Gindre, 2006; Tonello et al., 2016), reliable findings have not yet been presented.

Therefore, the present study applied the Harvard step test, which can examine cardiopulmonary function without high test cost, long measurement time, and location restrictions, and we analyzed the changes in PEI and HRV variables during resting and post-exercise recovery. The purpose of this study is to investigate the relationship between PEI calculated by the Harvard step test and HRV, and to identify parameters of HRV that can predict PEI in college students.

MATERIALS AND METHODS

Participants

The participants in this study were 16 college students who did not have cardiovascular and musculoskeletal diseases within the last 6 months were selected. As shown in Tables 1 and 2, all participants were allocated to the higher PEI group (HPEI, n=6. male=3, female=3) and lower PEI group (LPEI, n=10. male=5, female=5). Higher (≥90 PEI) and lower (≤89 PEI) PEI were divided into two groups on the criteria by Fox et al. (1973). Before beginning the measurement, participants were informed about study orally and they submitted their written informed consent to researchers. And this research was conducted ethically according to international guidelines.

Table 1. Physical characteristics of the subjects

Sex	LPEI	HPEI	Total
Male	5	3	8
Female	5	3	6
Total	10	6	16

LPEI, lower physical efficiency index; HPEI, higher physical efficiency index.

HRV test

HRV was measured for quantitative evaluation of the autonomic nervous system at the resting, immediately, 15 min and 30 min after exercise using by polyG-I in biceps brachii (LAXTHA, Inc., Seoul, Korea). HRV was recorded at the time and frequency domain parameters. Time domain parameters were consisted of mean RR intervals, standard deviation of all normal RR interval (SDNN) and root mean squared differences between adjacent normal RR intervals (RMSSD). Frequency domain parameters were consisted of low frequency power (LF power: 0.04–0.15 Hz) and high-frequency power (HF power: 0.15–0.4 Hz) and the LF/HF ratio. All time and frequency domain data were calculated using the Telescan program (ver. 3.03, LAXTHA, Inc.).

Harvard step test

Harvard step test was performed on a 50-cm bench for male and 40 cm for female, and measured for 5 min at a metronome speed of 120 bpm. After completing the Harvard Step test for 5 min, heart rate was measured between 1 to 1.5 min, between 2 to 2.5 min and between 3 to 3.5 min during the recovery period on the chair. To determine the PEI levels, the three heart rates were summed and then calculated using the following formula: (100×test duration in seconds) divided by (2×sum of heart beats in the recovery periods).

Statistical analysis

All analyses were performed using IBM SPSS Statistics ver. 23.0 (IBM Co., Chicago, IL, USA). Data were expressed as mean± standard deviation. Pearson correlation coefficient was used to analyze associations of PEI and HRV. Multiple regression analysis was performed to predict the body efficiency index. Statistical significance was considered $P<0.05$.

Table 2. Change of heart rate variability and physical efficiency index after Harvard step test

Group	1 min–1.5 min	2 min–2.5 min	3 min–3.5 min	PEI
LPEI (n=10)	66.10±1.20	57.60±2.41	54.60±2.67	83.80±1.99
HPEI (n=6)	61.00±2.53	53.33±2.16	50.50±1.52	90.50±2.74
Total (n=16)	64.19±3.08	56.00±3.10	53.06±3.04	86.31±4.01

Values are presented as mean±standard deviation.
LPEI, lower physical efficiency index; HPEI, higher physical efficiency index; PEI, physical efficiency index.

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Table 3. Correlation between PEI and HRV

Variable	PEI	LF	HF	VLF	TP	RMSSD	SDNN	normLF	normHF
LF	-0.30								
HF	-0.17	-0.79**							
VLF	-0.22	0.32	0.07						
TP	-0.32	0.10	0.40	0.82**					
RMSSD	-0.56*	-0.05	0.63**	0.58*	0.84**				
SDNN	-0.43	0.07	0.46	0.79**	0.97**	0.89**			
normLF	0.49	0.22	-0.49	0.02	-0.10	-0.44	-0.12		
normHF	-0.49	-0.22	0.49	-0.02	0.10	0.44	0.12	-1.00**	
LF/HF	0.51*	-0.86**	0.55*	-0.26	-0.08	-0.12	-0.06	0.31	-0.31

PEI, physical efficiency index; HRV, heart rate variability; LF, low frequency; HF, high frequency; VLF, very low frequency; TP, total power; normLF, normalized low frequency; normHF, normalized high frequency; LF/HF, low frequency/high frequency ratio; RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; SDNN, standard deviation of all NN intervals.
*P<0.05. **P<0.01.

Table 4. Heart rate variability predicting physical efficiency index

Variable	R^2	Adj R^2	R^2 change	Unstandardized coefficients		Standardized coefficients	t
				Beta	Standard error	Beta	
RMSSD	0.31	0.26	0.31	-0.16	0.06	-0.51	-2.589*
LF/HF	0.51	0.44	0.20	0.18	0.08	0.45	2.286*

RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; LF/HF, low frequency/high frequency ratio; R^2, R-squared; Adj R^2, adjusted R-squared.
*P<0.05.

RESULTS

Correlation between the PEI level and HRV

As shown in Table 3, PEI was negatively correlated with RMSSD ($r=-0.56$, $P<0.05$), but had a positive correlation with LF/HF ($r=0.51$, $P<0.05$). LF was found to be negatively correlated with HF ($r=-0.79$, $P<0.01$) and LF/HF ($r=-0.86$, $P<0.01$), and HF was negatively correlated with RMSSD ($r=0.63$, $P<0.01$). In addition, LF/HF ($r=0.55$, $P<0.05$) showed a positive correlation. Very low frequency (VLF) was found to be positively correlated with total power (TP) ($r=0.82$, $P<0.01$), RMSSD ($r=0.58$, $P<0.01$), SDNN ($r=0.79$, $P<0.01$), and RMSSD was found to have a positive correlation with SDNN ($r=0.89$, $P<0.01$). normLF showed negative correlation with normHF ($r=-1.00$, $P<0.01$), but SDNN and normHF showed no statistically significant correlation with other variables.

Predictive value of the PEI

We conducted multiple regression analysis to predict the PEI, and confirmed the results shown in Table 4. RMSSD ($t=-2.589$, $P<0.022$) and LF/HF ($t=2.286$, $P<0.04$) were statistically significant. R^2, which can explain PEI prediction, was confirmed to

Table 5. Difference of RMSSD, normLF, LF/HF according to PEI

Variable	Source	DF	SS	MS	F
RMSSD	Intercept	1	3,355.75	3,355.75	141.43***
	Group	1	8.61	8.61	0.36
	Error	14	332.17	23.73	
	Period	3	4,525.857	1,508.619	33.701***
	Group×period	3	720.394	240.131	5.364**
	Error (period)	42	1,880.112	44.765	
normLF	Intercept	1	28,650.65	28,650.65	5,169.47***
	Group	1	4.34	4.34	0.78
	Error	14	77.59	5.54	
	Period	3	453.931	151.310	15.356***
	Group×period	3	104.900	34.967	3.549**
	Error (period)	42	413.835	9.853	
LF/HF	Intercept	1	47,407.66	47,407.66	241.55
	Group	1	5.83	5.83	0.03
	Error	14	2,747.75	196.27	
	Period	3	2,013.353	671.118	10.380
	Group×period	3	389.315	129.772	2.007
	Error (period)	42	2,715.562	64.656	

RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; normLF, normalized low frequency; PEI, physical efficiency index; DF, degrees of freedom; SS, sum of squares; MS, mean sum of squares; LF/HF, low frequency/high frequency ratio.
**P<0.01. ***P<0.001.

explain 51% PEI with RMSSD 31% and LF/HF 20%.

Changes in HRV at each test point according to the level of PEI

As shown in Table 5, RMSSD ($F = 5.364$, $P < 0.003$) and normLF ($F = 3.549$, $P < 0.022$) showed a statistically significant difference in the interaction between group and period. For LF/HF, there was no statistically significant difference between group and time period ($F = 2.007$, $P < 0.128$). In results on relationship between PEI levels and the time point of measurement (Table 6), normLF showed a significant difference at 15 ($F = 5.581$, $P < 0.033$) and 30 ($F = 13.239$, $P < 0.003$) minutes after the Harvard step test

Table 6. Comparison of HRV between LPEI and HPEI

HRV	Period	LPEI	HPEI	Total	Group × period
LF	Resting	10.89 ± 13.96	6.03 ± 1.17	9.07 ± 11.11	
	Immediately	9.73 ± 14.56	5.41 ± 0.39	8.11 ± 11.48	
	After 15 min	8.66 ± 11.29	5.28 ± 1.16	7.39 ± 8.93	
	After 30 min	10.39 ± 13.32	5.48 ± 1.06	8.55 ± 10.63	
HF	Resting	5.76 ± 1.99	5.11 ± 0.69	5.51 ± 1.62	
	Immediately	3.56 ± 1.25	4.32 ± 0.59	3.85 ± 1.09	
	After 15 min	2.95 ± 1.35	3.68 ± 0.63	3.23 ± 1.17	
	After 30 min	4.02 ± 1.49	4.51 ± 0.73	4.20 ± 1.26	
VLF	Resting	6.81 ± 0.49	6.43 ± 0.93	6.67 ± 0.69	
	Immediately	7.94 ± 0.47	8.13 ± 0.40	8.01 ± 0.44	
	After 15 min	5.50 ± 0.61	5.89 ± 0.42	5.65 ± 0.56	
	After 30 min	6.35 ± 0.56	6.27 ± 0.55	6.32 ± 0.54	
TP	Resting	2,412.78 ± 916.47	1,825.74 ± 1,768.84	2,192.64 ± 1,277.90	
	Immediately	3,343.03 ± 1,592.17	3,920.55 ± 1,420.05	3,559.60 ± 1,508.83	
	After 15min	536.14 ± 411.67	792.55 ± 563.33	632.29 ± 473.18	
	After 30min	1,230.14 ± 418.63	1,076.28 ± 708.31	1,172.44 ± 527.55	
normLF	Resting	51.01 ± 3.17	53.90 ± 2.25	52.09 ± 3.13	Resting - Immediately, $F = 2.407$, $P < 0.143$ Resting - After 15 min, $F = 5.581$, $P < 0.033$ Resting - After 30 min, $F = 13.239$, $P < 0.003$
	Immediately	56.06 ± 3.18	55.72 ± 2.33	55.93 ± 2.81	
	After 15 min	61.66 ± 5.22	58.74 ± 2.78	60.56 ± 4.58	
	After 30 min	58.62 ± 4.22	54.67 ± 3.07	57.14 ± 4.21	
normHF	Resting	49.00 ± 3.17	46.10 ± 2.25	47.91 ± 3.13	
	Immediately	43.94 ± 3.18	44.28 ± 2.33	44.07 ± 2.81	
	After 15 min	38.34 ± 5.22	41.26 ± 2.78	39.44 ± 4.58	
	After 30 min	41.38 ± 4.22	45.33 ± 3.07	42.86 ± 4.21	
LF/HF	Resting	43.81 ± 12.13	52.95 ± 4.24	47.23 ± 10.73	
	Immediately	54.24 ± 15.23	56.54 ± 4.78	55.10 ± 12.17	
	After 15 min	66.11 ± 26.09	63.30 ± 6.29	65.06 ± 20.58	
	After 30 min	58.22 ± 19.95	54.59 ± 6.06	56.86 ± 15.95	
RMSSD	Resting	36.02 ± 12.40	22.57 ± 12.32	30.98 ± 13.71	Resting - Immediately, $F = 5.123$, $P < 0.040$ Resting - After 15 min, $F = 6.580$, $P < 0.022$ Resting - After 30 min, $F = 10.933$, $P < 0.005$
	Immediately	6.35 ± 3.98	7.86 ± 3.08	6.91 ± 3.64	
	After 15 min	7.99 ± 4.48	10.28 ± 5.32	8.85 ± 4.77	
	After 30 min	12.50 ± 5.35	16.09 ± 7.70	13.85 ± 6.34	
SDNN	Resting	53.06 ± 10.63	41.90 ± 20.59	48.88 ± 15.50	
	Immediately	61.38 ± 13.68	67.78 ± 13.90	63.78 ± 13.67	
	After 15 min	23.26 ± 6.74	27.31 ± 9.18	24.78 ± 7.71	
	After 30 min	35.37 ± 5.79	32.50 ± 11.30	34.30 ± 8.05	

Values are presented as mean ± standard deviation.
HRV, heart rate variability; LPEI, lower physical efficiency index; HPEI, higher physical efficiency index; PEI, physical efficiency index; LF, low frequency; HF, high frequency; VLF, very low frequency; TP, total power; normLF, normalized low frequency; normHF, normalized high frequency; LF/HF, low frequency/high frequency ratio; RMSSD, square root of the mean of the sum of the squares of differences between adjacent NN intervals; SDNN, standard deviation of all NN intervals.

when compared to resting period, and there was significant difference in RMSSD immediately ($F = 5.123$, $P < 0.040$), 15 ($F = 6.580$, $P < 0.022$) and 30 min ($F = 10.933$, $P < 0.005$) after the Harvard step test. But the HPEI group showed a higher recovery rate than LPEI group at resting, 15 min ($F = 5.581$, $P < 0.033$) and 30 min ($F = 13.239$, $P < 0.003$) after exercise.

DISCUSSION

It has been well known that cardiovascular fitness (VO_{2max}) and autonomic functions are improved by high-intensity aerobic exercise intervention (Heydari et al., 2013), and HRV is a good indicator for assessing autonomic nervous system controls (Vanderlei et al., 2009). Measuring parameters of HRV consists of RR, NN, SDNN, RMSSD, standard deviation of the averages of NN intervals, the number of pairs of successive NN (R-R) intervals that differ by more than 50 msec (NN50), the proportion of NN50 divided by the total number of NN (R-R) intervals, stress index, the standard deviation of the differences between successive NN intervals, time domain, frequency domain, nonlinear. The present study first calculated PEI level after the Harvard step test, and then analyzed the correlation between HRV and PEI. Finally, we investigated parameters of HRV that can predict PEI in college students.

As shown in the results, in the correlation analysis between PEI and HRV, it was found that PEI had a significant relationship between RMSSD and LF/HF values. RMSSD is a parameter that confirms the rapid change of each RR interval, and since it has a high correlation with HF in the frequency domain, it represents a change in the parasympathetic nervous system (Berntson et al., 2005). In addition, LF/HF is an index that analyzes the balance between sympathetic and parasympathetic activity, and this ratio enhances when the sympathetic nerve activity increases or the parasympathetic nerve activity decreases (Khan et al., 2019). In previous studies on HRV and exercise intervention, increase in VO_{2max} by high-intensity aerobic exercise training showed a positive correlation with HRV and PEI (Lombardi, 2002), and the higher the cardiovascular fitness, the better the autonomic nerve control ability (Hautala et al., 2009; Lavie et al., 2015). We believe that a high body efficiency index can reduce the occurrence of autonomic dysfunction by maintaining the balance of autonomic nerve function, and can be partially used as an index for predicting/preventing cardiovascular disease. But, in contrast to these positive studies, some previous studies reported that the correlation between VO_{2max} and autonomic nervous system control is insufficient, so additional studies are needed to enhance the reliability of HRV parameters and PEI.

Monitoring HR and HRV after moderate to high-intensity exercise means examining the balance of the sympathetic and parasympathetic nerve activity as well as recovery from physiological stress caused by exercise. The present study showed a significant difference in normLF, the ratio of LF, and RMSSD, the change in RR interval, at each time point of measurement according to PEI levels. Specifically, RMSSD showed statistically significant results in the HPEI group compared to those in LPEI group immediately, 15 min and 30 min after exercise, and normLF showed a significant difference at 15 and 30 min after exercise, excluding immediately after exercise, compared to resting period. These findings indicate that the difference in sympathetic nerve activity before and after exercise depends on the level of cardiovascular fitness. In previous studies that provide important evidence on the relationship between heart rate recovery and HRV in elite athletes, Boullosa et al. (2014) proposed that the rate of decline in HR after the cessation of exercise is a representative marker for diagnosing the level of parasympathetic activation, and that VO_{2max} and high heart rate recovery in marathon athletes showed a positive correlation with sympathetic activation (Du et al., 2005; Javorka et al., 2002). These findings presented in various previous studies are partially consistent with our results. However, in this study, there were no significant differences among the HRV variables except normLF and RMSSD. Previous studies that reported no significant difference in VO_{2max}, HRV and heart rate recovery in healthy college students, young women, and obese adolescents support the present findings (Bosquet et al., 2007; Gamelin et al., 2007).

Our findings suggest a critical information that PEI calculated by the Harvard step test can be used as an index to predict the autonomic nerve function, and high PEI may have a positive effect on changes in autonomic nerve activity during recovery after exercise intervention. However, there are limitations in generalizing the results of this study due to the small sample size. Therefore, research is need to magnify the sample size in the future.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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