

The Third Heart Sound after Exercise in Athletes: An Exploratory Study

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Abstract

The purpose of our study was to investigate the frequency of the third heart sound (S3) of athletes after exercise, and to determine whether the frequency and amplitude of S3 were related to cardiac function. The phonocardiogram exercise test (PCGET) was used in this study, and healthy volunteers consisting of 84 athletes (age 21.0 ± 1.7 years; 62 males and 22 females) and 45 non-athletes (age 24.1 ± 2.0 years; 33 males and 12 females) were enrolled. All subjects were healthy except one with a cardiac murmur without known cause. Immediately after exercise, S3 occurred in 21 athletes (25.0%) and 10 non-athletes (22.2%) during PCGET. There were very significant differences between pre-exercise and post-exercise in the frequency of S3 ($P < 0.01$), and no significant difference between athletes and non-athletes ($P > 0.05$). The prevalence of $S3/S2 \geq 1$ was significantly ($P < 0.05$) higher for the athlete group (47.1%) as compared to the non-athlete group (10%). Those results indicated that the emergence of S3 was an indicator of heart burden, and S3 after exercise in the athlete group was physiological. Our study showed that the amplitude of S3 had a very sensitive response to cardiac function reduction and $S3/S2 \geq 1$ could eventually be used to assess cardiac fatigue states.

Key Words: third heart sound, heart burden, cardiac fatigue, exercise testing, phonocardiogram

Introduction

The diastolic sound that occurs during rapid ventricular filling is called the third heart sound (S3) (4, 7, 22, 25). S3 is thought to be caused by abrupt deceleration of left ventricular inflow during early diastole, increased left ventricular filling pressures and decreased left ventricular compliance (28). In the setting of preliminary studies, S3 was present in both pathological and physiological situations and it has important clinical and prognostic implications in heart diseases (1, 3, 13, 21). Frequently, children and young adults have an audible S3 or will develop one during exercise and pregnancy. At these times, the occurrence of S3 is considered as a normal cardiac adaptation to stress state, and is called physiological S3 (9). Fatigue of the body and the heart is associated

with overtraining which is defined as the state resulting from an imbalance between training stress and recovery (15, 23) that often occurs in athletes. Overtraining is not solely related to physical training, but also to non-training stressors (15). Training fatigue is a normal fatigue that is experienced following several days of heavy training associated with an overload-training. This fatigue is reversed and supercompensation occurs by the last few days of a period of reduced training load. However, it was established that cardiac fatigue persists longer than an appropriate regeneration period (10) and cardiac fatigue even results in the decline of the cardiac function (17, 19) and performance became lower than previous standards after a period of active recovery (11). Thus, it is necessary and important to identify whether the heart of an athlete is overloaded or suffering from

Table 1. Physical characteristics of the test groups (in means \pm standard deviation)

Group	N	Age (years)	Height (m)	BM (kg)	BMI (kg·m ⁻²)
Athletes	84	21.0 \pm 1.7*	1.75 \pm 0.08	64.5 \pm 9.8	21.0 \pm 2.1 [#]
Non-athletes	45	24.0 \pm 2.0	1.69 \pm 0.07	58.1 \pm 9.4	20.3 \pm 2.1

m: meters, BM: body mass, kg: kilograms, BMI: body mass index. * $P < 0.01$ vs. non-athletes, [#] $P < 0.05$ vs. non-athletes.

Table 2. Frequency of S3, heart rate and CCCT in athlete and non-athlete groups

	Group	Athlete	Non- athlete
S3 N (%)	pre-exercise	0 (0%)	0 (0%)
	post-exercise	21 (25.0%)*	10 (22.2%)*
Heart rate (beats·min ⁻¹)	pre-exercise	68.79 \pm 9.09	71.84 \pm 9.93
	post-exercise	159.31 \pm 11.05 [#]	165.38 \pm 12.65 [#]
CCCT		7.43 \pm 3.36	6.44 \pm 2.36 [†]

CCCT: cardiac contractility change trend. ** $P < 0.01$ vs. pre-exercise, [†] $P < 0.05$ vs. athlete.

cardiac fatigue in exercise training.

The purpose of our study was to investigate the frequency of S3 in athletes after exercise, and to investigate the relationship between the frequency of S3 and heart burden. Furthermore, we specifically explored the amplitude of S3. However, there are many factors that can influence the absolute amplitude of S3 including the thickness of the chest wall, the distance between the heart and the chest wall, physiopathologic conditions, the emotions of different subjects, different postures, respiratory depth, the position of sensor on the chest wall and others. Hence, the absolute amplitude of S3 cannot be used independently. In order to resolve this problem, we adopted the relative value method to introduce a new group of indicators, including the ratio of the third heart sound amplitude to the second heart sound amplitude (S3/S2), as an assessment of the intensity of S3. This is because the first heart sound (S1) and the second heart sound (S2) are two main components in the phonocardiogram and can be clearly identified. S1 amplitude dramatically varies with breathing and increased sharply after accomplishing the whole designed exercise workload. Therefore, the S2 amplitude, which is relatively stable and low, had been selected as the reference value and that made S3/S2 more reliable and stable.

Reports available indicate that due to different detection methods and instability of S3 itself, the prevalence of S3 shows significant differences. The presence of S3 after exercise has been extensively studied; however, the frequency of S3 immediately after exercise in athletes, especially the amplitude of S3, has never been reported before. This paper reports the related methods and results.

Materials and Methods

Subjects

Two groups of subjects, 129 volunteers in all, were enrolled in this study. All subjects were healthy except one with a cardiac murmur without known cause. The first group of subjects consisted of 84 athletes from a physical education department with a mean age of 21.0 \pm 1.7 (range 17 to 27), including 62 males and 22 females. The second group consisted of 45 students from general subjects departments with a mean age of 24.1 \pm 2.0 (range 21 to 29), including 33 males and 12 females. The physical makeup of the two groups is summarized in Table 1. Subjects of both groups were students from Chongqing University, Chongqing, China. Experimental procedures were approved by the Ethics Committee of the Chongqing University, and all subjects gave written informed consent to participate in the study conforming to the policy statement with respect to the Declaration of Helsinki.

In our previous studies, cardiac contractility change trend (CCCT), which was defined as the increase of the amplitude of S1 after accomplishing exercise workloads with respect to the amplitude of S1 recorded at rest (37), was confirmed as a non-invasive and objective indicator for measuring and evaluating cardiac function (35, 36). And the data of the subjects' cardiac function (reflected in CCCT) are shown in Tables 2 and 4.

The S3/S2 ratio had a dimensionless value. When calculating S3/S2, we used the amplitude of S3 divided by the amplitude of S2 in each cardiac cycle. And the S3/S2 values were calculated automatically by the CCM heart-sound analysis software. We found that the amplitude values of S3 were higher than those of S2 in some subjects. S3 is characterized by low volume and energy. These characteristics make the

Table 3. Comparison of S3/S2 between athlete and non-athlete groups

	Athlete	Non-athlete
N	21	10
S3/S2 \geq 1	12 (57.1%)*	1 (10%)
S3/S2 < 1	9 (42.9%)*	9 (90%)

* $P < 0.05$ vs. non-athlete.

amplitudes of S3 lower than those of S2 under general conditions. In this research, we defined S3/S2 \geq 1 as that in continuous 5 cardiac cycles, at least 3 of the S3 amplitudes were greater than that of the S2 amplitudes. Otherwise, it would be defined as S3/S2 < 1.

Equipment

A cardiac contractility monitor (CCM, developed by Bo-Jing Medical Informatics Institute, Chongqing, China) based on a personal computer was used for this study. The CCM hardware consisted of a phonocardiographic sensor (placed on the subject's precordium) and a heart-sound signal preprocessing box. The software included a fundamental heart-sound measurement system which had several end-user-friendly capabilities. The development environment was Visual Basic 6.0 and the Access relational database, with the Windows 98/2000/XP (Microsoft, Inc.) operating platform. This equipment gave a flat frequency response in the whole frequency range of usual heart sounds (from 30 to 800 Hz). The heart sound signals were recorded through the sound card of PC at sampling frequency of 11,025 Hz.

Exercise Testing

The phonocardiogram exercise test (PCGET) (34) was used for this study. All subjects were not allowed to do any hard physical work in the half hour or longer preceding testing, and they were told to keep quiet and relaxed during the test. A trained researcher placed a PCG sensor on the subject's precordium. In order to avoid human-induced errors, every testing operator was required to press the sensor with similar strength against the same area of each volunteer's chest in two conditions. Phonocardiograms were recorded both in the sitting position at rest and immediately after a step-climbing exercise of 23-cm height. The subjects completed the designed exercise workload as soon as possible and the signals of cardiac cycle were immediately collected and recorded by CCM. With the purpose of recognizing S3 accurately, at least four cardiac cycles were recorded during each testing.

There are many exercise workload protocols

Table 4. Comparison of CCCT in the athlete group

	S3/S2 < 1	S3/S2 \geq 1	Without S3
N	9	12	63
CCCT	7.56 \pm 2.46 [#]	6.32 \pm 2.24*	7.63 \pm 3.63

CCCT: cardiac contractility change trend. * $P < 0.05$ vs. without S3, [#] $P = 0.82$ vs. without S3.

in PCGET. In this investigation, the total workload of 7000 J was used. The step-climbing number was calculated according to the target workload, step height and the subject's body weight. The end point of the exercise test was usually limited by patient symptoms or by achievement of the designed exercise workload. Most of the subjects took the test in our Heart Sound Collecting Laboratory supported by Chongqing University and Bo-Jing Medical Informatics Institute, and a few recordings from athletes were collected in the office of the physical education department.

Statistical Analysis

Descriptive statistics are presented as Means \pm SD. Comparing differences between groups and differences within each group between pre and post exercise were analyzed for statistical significance using Independent *t*-test for heart rate and *Chi*-squared test for S3. Comparison of S3/S2 between athletes and non-athletes was performed using *Chi*-squared test. Statistical significance was accepted at $P < 0.05$ and all analyses were performed in SPSS 15.0.

Results

Table 2 shows that immediately after exercise, S3 was obtained from phonocardiograms in 21 athletes (25.0%) and 10 non-athletes (22.2%), while at rest S3 was not present in any group. There were significant differences between pre-exercise and post-exercise in terms of the audible S3 ($P < 0.01$), and there was no significant difference between athletes and non-athletes ($P > 0.05$). The mean heart rates of 84 athletes and 45 non-athletes at rest were 69.10 ± 9.38 beats/min and 72.21 ± 10.00 beats/min, respectively. Immediately after accomplishing the exercise, the values of heart rates were 159.63 ± 10.83 beats/min and 165.93 ± 12.06 beats/min. There were statistically significant increases in the sets of heart rate data from the pre-exercise to post-exercise ($P < 0.01$). Accordingly, cardiac burden was aggravated in terms of exercise workload.

The two prototypes of phonocardiogram with S3 were presented in Fig. 1 (S3/S2 < 1) and Fig. 2 (S3/S2 \geq 1). The ratio of S3/S2 of the 21 athletes and the

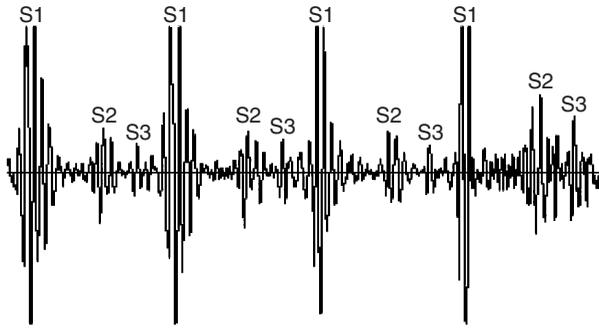


Fig. 1. The cardiac cycles of the PCG recording from a 23 years old female non-athlete. The S2 amplitudes are obviously greater than S3.

10 healthy non-athletes are shown in Table 3. There were a total of 31 subjects with S3 after exercise consisting of 13 $S3/S2 \geq 1$ (1 from non-athletes, 12 from athletes) and 18 $S3/S2 < 1$ (9 from athletes, 9 from non-athletes). The prevalence of $S3/S2 \geq 1$ was significantly ($P < 0.05$) higher in the athlete group (47.1%) as compared to the non-athlete group (10%).

Discussion

This study was an initial attempt to investigate the frequency and amplitude of S3 in athletes at stress, and the aim of the study was to explore the relationship between S3 and heart burden. The results of this longitudinal study in athletes clearly showed that S3 occurred more frequently after exercise than at rest (25% vs. 0%, $P < 0.01$, see Table 2). Similar to our study, Aronow *et al.* (2) observed that an S3 occurred more frequently during and after exercise (60%) than at rest (15%). Previous studies of patients with acute myocardial infarction (12, 14, 18, 29) and myocardial ischemia induced by exercise testing (6, 20, 30) showed that S3 occurred more frequently during exercise than at rest. Breuer (5) found that S3 was audible in up to 80% of pregnant women. In our study, the heart rate increased highly after exercise which supports the notion that heart burden was heavier due to exercise. It is also well accepted that pregnant women or patients with cardiac disease endure heavier heart burden in comparison with the healthy population. Therefore, the frequency of S3 is higher in individuals with heavier heart burden. S3, which is highly correlated to decreased cardiac output, reduces ejection fraction and elevates end-diastolic pressures, is thought to evaluate cardiac function, and the pathological S3 has been long regarded as a validated indicator of left ventricular dysfunction (16, 24, 27, 31). Our results and recent evidences referenced above all suggest that the emergence of S3 is an indicator of heart burden. Moreover, no signi-



Fig. 2. The cardiac cycles of the PCG recording from a 21 years old male athlete. The S2 amplitudes are obviously less than S3 in this sample.

ficant difference ($P > 0.05$) was found in frequency of S3 between athlete and non-athlete group (Table 2). Therefore, different from patients, the emergence of S3 after exercise in athlete group is a physiological phenomenon in line with the study by Wilbert and Aronow (32).

As Table 3 presents, the proportion of $S3/S2 \geq 1$ in the athlete group is much higher than that in the non-athlete group (57.1% vs. 10.0%, $P < 0.05$). Sawayama *et al.* (26) observed that the amplitude of S3 was greater in patients with angina than in healthy subjects and suggested the amplitude of S3 had a very sensitive response to cardiac function reduction. In our previous studies, CCCT was confirmed as a noninvasive and objective indicator for measuring and evaluating cardiac function (35, 36). Table 4 shows that the CCCT of athletes with $S3/S2 \geq 1$ was lower than that without S3 (6.32 ± 2.24 vs. 7.63 ± 3.63 , $P < 0.05$). It may be recognized that the cardiac function of those athletes with $S3/S2 \geq 1$ was reduced. The status of transiently reduced function of the heart in response to a highly intensive activity has been defined as cardiac fatigue (8, 33). All the athletes in our study had taken continuous training for at least a month. In addition, 8 of the 12 athletes with $S3/S2 \geq 1$ had a competitive activity half an hour before, and one had a history of systolic murmur. Those evidences demonstrated that athletes with $S3/S2 \geq 1$ were those that took prolonged strenuous exercises and their hearts were overloaded. Therefore, the phenomenon of $S3/S2 \geq 1$ may suggest cardiac fatigue. Clearly, their performance and well being could be affected if athletes developed cardiac fatigue. Hence, it is needed to provide an objective and reliable method for identifying athletes' risk of developing cardiac fatigue. Our study showed that $S3/S2 \geq 1$ could be used to assess cardiac fatigue states.

The frequency of S3 and $S3/S2$ ratio detection can be a safe and easy technique, and could simultaneously detect heart rate and PCG. Based on this and other previous studies discussed above, we can conclude that the emergence of S3 is an indicator of heart burden and the value of $S3/S2$ may have a

significant value in assessing cardiac fatigue. Moreover, BHPCGT can be used as a new method for evaluating cardiac function in both athletes and non-athletes.

However, our researches on the frequency and amplitude of S3 are only at a primary stage, and there are still several limitations. First, the potential maturation on the heart of males and females is different. However, we did not carry out a gender-based control study due to lack of samples. Second, the age and body-mass index were of significant differences between these two groups, as shown in the *t*-test results. Third, the study is also limited by the sample size. Further sample of large population and multi-centre studies are still needed.

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References

1. Abdulla, A.M., Frank, M.J., Erdin, R.A. and Canedo, M.I. Clinical significance and hemodynamic correlates of the third heart sound gallop in aortic regurgitation. A guide to optimal timing of cardiac catheterization. *Circulation* 64: 464-471, 1981.
2. Aronow, W.S., Uyeyama, R.R., Cassidy, J. and Nebolon, J. Resting and postexercise phonocardiogram and electrocardiogram in patients with angina pectoris and in normal subjects. *Circulation* 43: 273-277, 1971.
3. Bonow, R.O., Dodd, J.T., Maron, B.J., O'Gara, P.T., White, G.G. and McIntosh, C.L. Long-term serial changes in left ventricular function, and reversal of ventricular dilatation after valve replacement for chronic aortic regurgitation. *Circulation* 78: 1108-1120, 1988.
4. Braunwald, E. and Morrow, A.G. Origin of heart sounds as estimated by analysis of the sequence of cardiodynamic work. *Circulation* 18: 971-974, 1958.
5. Breuer, H.W. Auscultation of the heart in pregnancy. *Munchen. Med. Wochensh.* 123: 1705-1707, 1981.
6. Cohn, P.F., Thompson, P., Strauss, W., Todd, J. and Gorlin, R. Diastolic heart sounds during static (handgrip) exercise in patients with chest pain. *Circulation* 47: 1217-1221, 1973.
7. Craige, E. On the genesis of heart sounds-Contributions made by echocardiographic studies. *Circulation* 53: 207-209, 1976.
8. Douglas, P.S., O'Toole, M.L., Hiller, W.D., Hackney, K. and Reichel, N. Cardiac fatigue after prolonged exercise. *Circulation* 76: 1206-1213, 1987.
9. Drzewiecki, G.M., Wasicko, M.J. and Li, J.K. Diastolic mechanics and the origin of the third heart sound. *Ann. Biomed. Eng.* 19: 651-667, 1991.
10. Fry, R.W., Morton, A.R., Garcia-Webb, P., Crawford, G.P.M. and Keast, D. Biological responses to overload training in endurance sports. *Eur. J. App. Physiol.* 64: 335-344, 1992.
11. Fry, R.W. and Morton, A.R. Overtraining in athletes: an update. *Sports Med.* 12: 32-65, 1991.
12. Gould, L., Umali, F. and Gomprecht, R.F. The presystolic gallop in acute myocardial infarction. *Angiology* 23: 549-553, 1972.
13. Hammermeister, K.E., Fisher, L., Kennedy, W., Samuels, S. and Dodge, H.T. Prediction of late survival in patients with mitral valve disease from clinical, hemodynamic, and quantitative angiographic variables. *Circulation* 57: 341-349, 1978.
14. Hill, J.C., O'Rourke, R.A., Lewis, R.P. and McGranahan, G.M. The diagnostic value of the atrial gallop in acute myocardial infarction. *Am. Heart J.* 78: 194-201, 1969.
15. Kentta, G., Hassmén, P. and Raglin, J.S. Training practices and overtraining syndrome in Swedish age-group athletes. *Int. J. Sports Med.* 22: 460-465, 2001.
16. Kono, T., Rosman, H., Alam, M., Stein, P.D. and Sabbah, H.N. Hemodynamic correlates of the third heart sound during the evolution of chronic heart failure. *J. Am. Coll. Cardiol.* 21: 419-423, 1993.
17. Kuipers, H. and Keizer, H.A. Overtraining in elite athletes: review and future directions. *Sports Med.* 6: 79-92, 1988.
18. Lee, E., Michaels, A., Selvester, R. and Drew, B. Frequency of diastolic third and fourth heart sounds with myocardial ischemia induced during percutaneous coronary intervention. *J. Electrocardiol.* 42: 39-45, 2009.
19. Levin, S. Overtraining causes olympic-sized problems. *Physician. Sports Med.* 19: 112-118, 1991.
20. McNair, J.D. The pathologic third heart sound in angina pectoris. *Cardiologia* 51: 79-91, 1967.
21. Nirav, J.M. and Ijaz, A.K. Third heart sound: genesis and clinical importance. *Int. J. Cardiol.* 97: 183-186, 2004.
22. Nixon, P.G.F. The genesis of the third heart sound. *Am. Heart J.* 65: 712-714, 1963.
23. Nuno, M. and Richard, J.W. Trainability of young athletes and overtraining. *J. Sport Sci. Med.* 6: 353-367, 2007.
24. Patel, R., Bushnell, D.L. and Sobotka, P.A. Implications of an audible third heart sound in evaluating cardiac function. *Western J. Med.* 158: 606-609, 1993.
25. Sakamoto, T., Ichiyasu, H., Hayashi, T., Kawaratani, H. and Amano, K. Genesis of the third heart sound phonocardiographic studies. *Jpn. Heart J.* 17: 150-162, 1976.
26. Sawayama, T., Niki, I., Matsuura, T. and Ichinose, S. Exercise phonocardiogram: significance of the third and atrial sounds. *Jpn. Circulation J.* 30: 1153-1159, 1966.
27. Shah, P.M., Gramiak, R., Kramer, D.H. and Yu, P.N. Determinants of atrial (S4) and ventricular (S3) gallop sounds in primary myocardial disease. *New. Engl. J. Med.* 278: 753-758, 1968.
28. Shah, S.J., Marcus, G.M., Gerber, I.L., Mckeown, B.H., Vessey, J.C., Jordan, M.V., Huddleston, M., Foster, E., Chatterjee, K. and Michaels, A.D. Physiology of the third heart sound: novel insights from tissue doppler imaging. *Am. Soc. Echocardiogr.* 21: 394-400, 2008.
29. Stock, E. Auscultation and phonocardiography in acute myocardial infarction. *Med. J. Australia* 1: 1060-1062, 1966.
30. Tavel, M.E. The appearance of gallop rhythm after exercise stress testing. *Clin. Cardiol.* 19: 887-891, 1996.
31. Tribouilloy, C.M., Enriquez-Sarano, M., Mohty, D., Horn, R.A., Bailey, K.R., Seward, J.B., Weissler, A.M. and Tajik, A.J. Pathophysiologic determinants of third heart sounds: a prospective clinical and Doppler echocardiographic study. *Am. J. Med.* 111: 96-102, 2001.
32. Wilbert, S. and Aronow, J.C. Five-year follow-up of resting and postexercise phonocardiogram in asymptomatic persons. *Cardiology* 60: 247-250, 1975.
33. Wu, W.Z., Guo, X.M., Xie M.L., Xiao, S.Z., Yang, Y. and Xiao, Z.F. Research on first heart sound and second heart sound amplitude variability and reversal phenomenon-A new finding in athletic heart study. *J. Med. Biol. Eng.* 29: 202-205, 2009.
34. Xiao, Y.H., Xiao, S.Z., Cao, Z.H., Zhou, S.Y. and Pei, J.H. The phonocardiogram exercise test. *IEEE. Eng. Med. Bio.* 18:

- 111-115, 1999.
35. Xiao, S.Z., Guo, X.M., Sun, X.B. and Xiao, Z.F. A relative value method for measuring and evaluating cardiac reserve. *Biomed. Eng. Online* 6: 1-6, 2002.
36. Xiao, S.Z., Guo, X.M., Wang, F.L., Xiao, Z.F., Liu, G.C., Zhan, Z.F. and Sun, X.B. Evaluating two new indicators of cardiac reserve. *IEEE. Eng. Med. Biol. Mag.* 22: 147-152, 2003.
37. Xiao, S.Z., Wang, Z.G. and Hu, D.Y. Studying cardiac contractility change trend to evaluate cardiac reserve. *IEEE. Eng. Med. Bio. Mag.* 21: 74-76, 2002.