Heart Rate Dynamics after Combined Endurance and Strength Training in Older Men

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ABSTRACT

KARAVIRTA, L., M. P. TULPPO, D. E. LAAKSONEN, K. NYMAN, R. T. LAUKKANEN, H. KINNUNEN, A. HÄKKINEN, and K. HÄKKINEN. Heart Rate Dynamics after Combined Endurance and Strength Training in Older Men. Med. Sci. Sports Exerc., Vol. 41, No. 7, pp. 1436–1443, 2009. Purpose: Aging alters cardiac autonomic function, which may contribute to a higher risk of cardiac events. Spectral measures of HR variability (HRV) and fractal-like behavior of HR are considered as markers of a healthy heart. The present study examined the effects of combining endurance and strength training compared with endurance or strength training alone on HR dynamics and physical fitness in older previously untrained men aged 40–67 yr. Methods: Subjects were randomized into endurance training (E, n = 23), strength training (S, n = 25), combined endurance and strength training (ES, n = 29), or control group (C, n = 16). Short-term fractal scaling exponent (α1) and spectral HRV were analyzed from maximal aerobic cycling tests and during supine rest, and leg extension one repetition maximum strength was measured. Results: Aerobic capacity and maximal strength increased in the training groups performing endurance and/or strength training, respectively. Only ES showed a decrease after training in fractal HR behavior during exercise, and the difference was significant between groups (P = 0.019). During supine rest, α1 only decreased significantly (P = 0.039) in ES from 1.18 (SD = 0.20) to 1.11 (SD = 0.22). The decrease in α1 at rest from 1.21 (SD = 0.19) to 1.11 (SD = 0.22) also approached significance (P = 0.061) in E. Changes in spectral measures of HRV were minor during the study period and only occurred during exercise. Conclusion: Fractal HR dynamics were improved more by combining strength training with endurance training in our older men compared with endurance training alone, although strength training alone produced no changes in fractal HR behavior. The synergistic effect in fractal HR behavior occurred regardless of changes in aerobic capacity. Key Words: CARDIAC AUTONOMIC FUNCTION, FRACTAL SCALING EXPONENT, INCREMENTAL EXERCISE TEST, MAXIMAL OXYGEN UPTAKE

The effects of aging on aerobic and neuromuscular performance are well documented as, for example, decreased aerobic capacity, skeletal muscle sarcopenia, and attenuated force production (1,17). Aging also alters cardiac autonomic function, which may contribute to a higher risk for cardiac events (34). For example, vagal activity is attenuated, which can be observed in decreased high-frequency (HF) power of HR variability (HRV) (4,40). In addition to the conventional measures of HRV, fractal measures are considered as more suitable markers of HR dynamics during nonstationary conditions, such as incremental exercise (29). Fractal-like behavior of HR is considered as a marker of a healthy heart because in different diseases or with aging, fractal dynamics have been shown to change toward uncorrelated randomness (16,38). Therefore, maintenance or improvement of the fractal-like behavior of HR in aging may decrease the mortality in the aging population at risk for cardiovascular disease.

Endurance training enhances aerobic capacity, blood flow, and cardiac autonomic function (24,37). Recently, positive changes have also been documented in fractal correlation properties of HR due to endurance training (12). However, effects of strength training on the cardiovascular system have received less research attention. Strength training enhances force production of trained muscles, thus minimizing the effects of aging on functional capacity (10,27,36). High-intensity strength training may, however, even increase arterial stiffness in large elastic arteries in contrast to endurance training (3,35). Although the effects of strength training have not yet been widely studied, it seems that strength training has no effect on traditional measures of HRV analyzed with time domain or frequency domain methods (5,7). In contrast, positive changes have been found with nonlinear analysis methods (13,14).
With concurrent endurance and strength training, both endurance and strength performance can be simultaneously improved in untrained subjects when the training volume is moderate and the duration of the training period is not too long (9,27,33,41). Prolonged high-volume training programs combining endurance and strength training may, however, compromise the strength gains (15,21). On the other hand, strength training combined with endurance training seems not to compromise development of maximal oxygen uptake (VO₂max), and it may even have synergistic effects on submaximal aerobic performance and time to exhaustion in older adults (6). Although the effects of concurrent endurance and strength training seem to be favorable in terms of aerobic performance, less is known about the effects of combined training on cardiovascular and especially cardiac autonomic function.

The present study examined the effects of combining endurance and strength training compared with endurance training or strength training alone on HR dynamics at rest and during incremental exercise as well as on physical fitness in older previously untrained men. HR dynamics were studied with both spectral and fractal measures to investigate whether the training effects appear similarly in linear and nonlinear analyses of HRV.

METHODS

Subjects. Healthy untrained men aged 40–67 yr were recruited for the study by advertising in newspapers and through e-mail lists. Exclusion criteria included known cardiovascular and pulmonary disease and medications known to influence cardiovascular performance or HR. The general health status of the subjects and the resting ECG were examined by a physician. In addition, the subjects who passed the medical examination performed a maximal exercise test with ECG monitoring to voluntary exhaustion under supervision of a physician. Men without evidence of cardiovascular diseases, 105 subjects out of the 127 who entered the clinical exercise test, continued participation in the study. The participants were informed about the design of the study and possible risks and discomforts related to the measurements after which the participants signed an informed consent. The study plan was approved by the Ethics Committee of the University of Jyväskylä.

Study design. The men were randomized into endurance training (E, n = 23), strength training (S, n = 25), combined endurance and strength training (ES, n = 29), or control group (C, n = 16). Endurance and strength training was performed twice a week so that the E and the S groups trained two times a week and the ES group trained a total of four times a week. The measurements were performed before the training period and were repeated in the middle of (at week 10) and after the 21-wk training period. The baseline characteristics of the subjects who completed the training period (n = 93, mean age = 55.6 yr, SD = 7.4 yr) in each group separately are presented in Table 1. Both the control group and the training groups were instructed to maintain the habitual physical activity throughout the study period at the same level as before.

Aerobic performance test. After the physical examination, the clinical exercise test with a recording of R-R intervals (Polar S810i online recording with infrared interface; Polar Electro Oy, Kempele, Finland) and an assessment of VO₂max was carried out on a mechanically braked bicycle ergometer (Monark Ergomedic 839E; Monark Exercise AB, Sweden). A standardized 5-min warm-up period at an exercise intensity of 50 W preceded the actual exercise test. The first 2-min stage of the test was performed using the same light exercise intensity of 50 W as in warm-up. The intensity was increased by 20 W every second minute until exhaustion. The subjects were asked to maintain a pedaling frequency of 60 rpm, which was monitored continuously. The ECG was monitored continuously during the test. Blood pressure was measured before and after the test, in the middle of every test stage, and during the recovery after 3 and 5 min of exhaustion. The test was supervised by a physician. The subjects were verbally encouraged by the researchers to continue cycling until volitional exhaustion. Oxygen uptake (VO₂), carbon dioxide production (VCO₂), ventilation (Ve), breathing frequency (Fr), and other standard respiratory parameters were measured continuously breath by breath (SensorMedics® Vmax229; SensorMedics Corporation, Yorba Linda, CA). Blood lactate concentrations were taken from the fingertip before the exercise, every second minute, and immediately and 3 and 5 min after termination of exercise for the determination of the maximal posttest level. The blood samples were analyzed with Lactate Pro LT-1710 analyzer (Arkray, Inc., Kyoto, Japan). For the individual determination of the endurance training intensity, the aerobic and anaerobic thresholds were analyzed based on the lactate values and respiratory parameters as described in detail previously (2). VO₂max was determined as the highest minute average of VO₂ during the test (28). Maximal aerobic work rate (Wmax) was calculated with the following formula: Wmax = Wcom + t / 120 × ΔW, in which Wcom is the last cycling load completed, t is the time in seconds the noncompleted load was maintained, and ΔW is the increment in watts (22).
the data was used in the analysis. The breathing frequency was spontaneous and remained at the normal respiratory frequency of supine rest throughout the recording.

**Spectral analysis.** HR and R-R intervals were collected for further analysis with Polar S810i HR monitors by using online recording with infrared interface and Polar Precision Performance software (Polar Electro Oy). R-R intervals were recorded with 1-ms time resolution. The Polar S810i HR monitor has been validated for HRV recording both at rest and during exercise with an accuracy better than 2 ms when compared with an ECG method (8,20). The subjects whose data contained more than 15% noise or ectopic beats per test stage were discarded from the further HRV analysis. For the other subjects, the measurement errors and the ectopic heart beats were eliminated by an automatic process in the software after which the data were inspected visually for possible further artifacts. The errors were corrected according to the length of the error sequence, taking the previous and the next normal R-R interval into account and maintaining the local trend in the R-R interval time series (19). Frequency domain variables HF power (0.15–0.40 Hz) and low-frequency (LF) power (0.04–0.15 Hz) were analyzed using an autoregressive model of order 18. Each 2-min test stage with the 20-W increments starting from 50 W was analyzed separately. The same variables were analyzed also from the 5-min light exercise intensity stage (the warm-up) and the 5-min supine rest.

**Detrended fluctuation analysis (DFA).** Fractal HR dynamics describe correlative properties of HR. We analyzed a short-term scaling exponent that represents the slope of the plotted root mean square fluctuations of the integrated and detrended data. The short-term (from 4 to 11 beats) scaling exponent (α1) was calculated by integrating the R-R interval time series and fitting least-squares line to the data. Integrated time series was then detrended by subtracting a local trend. A relationship between the average fluctuation and the size of the window of observation was then drawn to a double log graph. The scaling exponent represents the slope of this line (29). DFA analysis was performed by the Hearts software (Heart Signal Co, Oulu, Finland). Due to the large variation in the individual Wmax values (mean 211 W, SD = 37 W, range = 133–313 W), α1 was calculated also at the relative exercise intensities of 30%, 40%,..., 90% of Wmax to reveal the average prevailing pattern of fractal scaling exponent during incremental exercise.

**Leg extension strength measurement.** Concentric bilateral leg extension strength (hip, knee, and ankle extensors strength) based on one repetition maximum (1RM) in a horizontal leg press was measured on a David 210 dynamometer (David Fitness and Medical Ltd., Outokumpu, Finland). The test action was performed in a seated position with a hip angle of 110°. The subject performed a leg extension from a knee flexion of 70° to a full extension of 180°. The load was increased for each trial until the subject failed to extend the knees to the full extension. The load of the last successful performance was determined as 1RM, which was achieved usually within three to five trials.

**Endurance training.** Endurance training was carried out twice a week. The HR levels for endurance training were determined on grounds of the aerobic performance tests (9). All training sessions were supervised, and HR monitoring was used (Polar S610i, Polar Electro Oy). During the first 7-wk period, the subjects trained 30 min under the level of the aerobic threshold by bicycle ergometer. The first period included also a few training sessions during which the subjects were accustomed to the intensity above the aerobic threshold. During the weeks 8–14, one weekly session of 45 min was included, in addition to a 15-min warm-up and a 15-min cool-down under aerobic threshold, a 10-min interval between the aerobic-anaerobic thresholds, and a 5-min interval above the anaerobic threshold. The other of the two weekly training sessions was 60 min of cycling under the aerobic threshold. The focus of training during weeks 15–21 was to improve maximal endurance in a 60-min session with two times 10-min interval between the aerobic-anaerobic thresholds, two times 5 min above the anaerobic threshold, and 30 min under the aerobic threshold during the whole session altogether. Every other training session included 90 min cycling at a steady pace under the aerobic threshold.

**Strength training.** Strength training was carried out twice a week. All strength training sessions were supervised. The strength training program included 7–10 exercises per session, which activated a large amount of muscle bulk including all the main muscle groups (10). During the three 7-wk periods of the training, the program consisted of protocols 1) to improve muscle strength endurance and to reduce total fat, 2) to produce muscle hypertrophy to further increase the total muscle mass/fat ratio, and 3) to optimize gains in maximal strength of trained muscles. The muscle strength endurance exercises during the first 7 wk of the training were carried out with light loads (40%–60% of the 1RM) but with a high number (15–30) of repetitions with three sets. The training protocols to increase muscle mass were used primarily during weeks 8–14 so that the loads increased progressively up to 60%–80% of the maximum with 6–12 repetitions per set. To optimize the strength development during weeks 15–21, higher loads of 70%–85% of 1RM and five to eight repetitions per set were used. The overall intensity and amount of training increased progressively throughout the 21-wk training period.

**Combined endurance and strength training.** The subjects in this group performed both twice weekly endurance and twice weekly strength training, with a total of four training sessions per week as described above (9).

**Statistical analyses.** The results are expressed as means and SD. For analyses, a natural logarithmic transformation
was used to normalize the distributions of HF and LF. The effect of low-intensity exercise on $\alpha_1$ compared with resting condition was analyzed with the paired $t$-test for dependent samples. The effects of training were examined using the ANOVA for repeated measures followed by Bonferroni post hoc analysis. The Pearson’s correlation coefficient was used to evaluate the relationships between variables. The critical level for statistical significance in all tests was set at 0.05. The statistical analyses were carried out using the Statistical Package for the Social Sciences for Windows (version 13.0; SPSS Inc., Chicago, IL).

RESULTS

Physical performance. $\dot{V}O_{2}\text{max}$ increased ($P < 0.001$) after 21 wk of endurance training by 11.9% (11.0%) and after combined endurance and strength training by 10.1% (9.8%), whereas no changes were observed in S and C (Fig. 1). In maximal bilateral leg extension, strength training led to a significant increase of 21.1% (7.9%) in S and 22.1% (9.5%) in ES (both $P < 0.001$) compared with the increase of 7.1% (5.1%) in E or 5.0% (4.1%) in C (Fig. 1).

HR and fractal scaling exponent. At the baseline measurement in the total subject group, short-term fractal scaling exponent $\alpha_1$ was higher ($P < 0.001$) during 5-min low-intensity exercise at 50 W than at rest (1.43 [SD = 0.21] vs 1.16 [SD = 0.21], respectively). In addition, $\alpha_1$ decreased gradually during the graded exercise test from a mean value of 1.37 (SD = 0.22) at 30% to 0.54 (SD = 0.19) at 90% of $W_{\text{max}}$ (Fig. 2), reaching a value of 1.0 (i.e., fractal behavior) between 60% and 70% of $W_{\text{max}}$. The $\alpha_1$ value...
during supine rest decreased in ES from 1.18 (SD = 0.20) at baseline to 1.11 (SD = 0.21) \( P = 0.039 \) after 21 wk of training (Fig. 3). The decrease in \( \alpha_1 \) from 1.21 (SD = 0.19) at baseline to 1.11 (SD = 0.22) after 21 wk of training approached significance \( P = 0.061 \) also in E, but \( \alpha_1 \) did not change in S or C (Fig. 3). The between-group difference in the training-induced changes in \( \alpha_1 \) was not significant \( P = 0.28 \). E and ES demonstrated decreases \( P = 0.026 \) in resting HR by 4 (SD = 6) and 2 (SD = 5) beats min\(^{-1} \), respectively, whereas S and C showed no change (Table 2).

The \( \alpha_1 \) value measured during 5 min of exercise at light intensity (50 W) did not show any changes after 10 wk of training in any group but increased in ES between training weeks 10 and 21 from 1.39 (SD = 0.16) to 1.50 (SD = 0.16) \( P = 0.010 \) between groups. On the contrary, ES showed a decrease in \( \alpha_1 \) at the exercise intensities of 60% and 70% of \( W_{\text{max}} \) \( P = 0.002 \) and 0.029, respectively) but in ES also with the changes in HF at 60% of \( W_{\text{max}} \) \( P = 0.019 \). HR did not change in any of the groups at relative exercise intensities but decreased in E and ES at the exercise intensities of 90–150 W \( P = 0.020 \) to <0.001 and also in S at 130 and 150 W \( P = 0.027–0.047 \) (Fig. 4). In ES, the changes in resting HR correlated with the changes in \( \alpha_1 \) at rest \( r = 0.47, P = 0.009 \). In addition, the training-related changes in resting \( \alpha_1 \) correlated negatively with the initial level of \( \alpha_1 \) \( r = 0.48, P = 0.009 \). However, significant correlations were not found between the changes in VO\(_{2\text{max}}\) and the changes in \( \alpha_1 \) at rest or at any relative exercise intensity. In addition, the relative changes in \( \alpha_1 \) only correlated significantly with age at the exercise intensity of 90% of \( W_{\text{max}} \) \( r = -0.44, P = 0.023 \).

**Spectral measures of HRV.** HF increased at exercise intensities of 90–130 W in all groups except in S. In LF, there was a between-group difference \( P = 0.017 \) only at 50 W, in which LF increased \( P < 0.01 \) in E and ES. None of the groups showed significant changes in HF or LF either at supine rest (Table 2) or during low-intensity exercise. In both E and ES, the decreases in resting HR correlated with the changes in HF \( r = -0.46, P = 0.026 \) and \( r = -0.57, P = 0.001 \), respectively) but in ES also with the changes in HF \( r = -0.81, P < 0.001 \). There were no significant correlations between the training-induced changes in HF power and \( \alpha_1 \).

**DISCUSSION**
The unique approach of the present study was to investigate the effects of combining endurance and strength training compared with either type of training alone on HR dynamics to minimize the negative effects of aging. We found that in our combined endurance and strength training group the short-term fractal scaling exponent \( \alpha_1 \) decreased

![FIGURE 3—Short-term fractal scaling exponent \( \alpha_1 \) during supine rest before (0) and after 21 wk of training in the endurance (E), strength (S), combined endurance and strength training (ES), and control (C) group.](image-url)

**TABLE 2. HR measures at supine rest before and after 10 and 21 wk of training.**

<table>
<thead>
<tr>
<th>HR (beats min(^{-1}))</th>
<th>E (( n = 23 ))</th>
<th>S (( n = 25 ))</th>
<th>ES (( n = 29 ))</th>
<th>C (( n = 16 ))</th>
<th>( P ) value between Groups</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 wk</td>
<td>61 (10)</td>
<td>59 (9)</td>
<td>58 (8)</td>
<td>54 (5)</td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>60 (9)*</td>
<td>58 (8)</td>
<td>60 (8)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 wk</td>
<td>57 (8)*</td>
<td>59 (8)</td>
<td>57 (7)*</td>
<td>53 (6)</td>
<td>0.026</td>
</tr>
<tr>
<td>HF, ln (ms(^2))</td>
<td>5.3 (1.3)</td>
<td>5.3 (1.2)</td>
<td>5.0 (1.3)</td>
<td>5.7 (1.2)</td>
<td></td>
</tr>
<tr>
<td>0 wk</td>
<td>5.1 (1.3)</td>
<td>5.3 (1.0)</td>
<td>5.1 (1.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 wk</td>
<td>5.4 (1.2)</td>
<td>5.0 (1.0)</td>
<td>5.3 (1.3)</td>
<td>5.6 (1.1)</td>
<td>0.067</td>
</tr>
<tr>
<td>21 wk</td>
<td>6.1 (1.1)</td>
<td>6.1 (0.9)</td>
<td>5.9 (1.0)</td>
<td>6.2 (0.6)</td>
<td></td>
</tr>
<tr>
<td>LF, ln (ms(^2))</td>
<td>5.9 (1.1)</td>
<td>5.9 (1.0)</td>
<td>5.9 (1.0)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0 wk</td>
<td>6.1 (1.0)</td>
<td>5.8 (1.1)</td>
<td>5.8 (1.0)</td>
<td>6.0 (0.9)</td>
<td>0.56</td>
</tr>
<tr>
<td>10 wk</td>
<td>6.1 (1.1)</td>
<td>1.17 (0.18)</td>
<td>1.18 (0.20)</td>
<td>1.06 (0.27)</td>
<td></td>
</tr>
<tr>
<td>21 wk</td>
<td>1.17 (0.22)</td>
<td>1.17 (0.18)</td>
<td>1.11 (0.21)*</td>
<td>1.08 (0.25)</td>
<td>0.28</td>
</tr>
</tbody>
</table>

Values are presented as mean (SD). E = endurance, S = strength, ES = endurance and strength training group, and C = control group. *Significantly different from 0 wk, \( P < 0.05 \).
at supine rest and also during exercise of moderate intensity. The combined group showed a more fractal-like behavior of HR after the present 21-wk of training. Because endurance training had a less evident effect on $\alpha_1$, combining strength training with endurance training seems to enhance rather than compromise the positive effects of endurance training on HR dynamics.

With regard to aerobic capacity and force production, combined endurance and strength training led to similar improvements in $V\dot{O}_{2max}$ and maximal strength as endurance or strength training alone, respectively, in our previously untrained middle-aged to older men. Therefore, neither an interference effect of endurance training on strength gains nor a synergistic effect of strength training on endurance performance were observed with two weekly endurance and two weekly strength training sessions.

In addition to the decline in $\alpha_1$, combined training also decreased resting HR by 2 beats·min$^{-1}$ on average, decreased submaximal HR, and increased HF power at exercise intensities of 90 W and higher. The withdrawal of vagal activity increases $\alpha_1$ value (30), which was demonstrated also in the present study by the higher $\alpha_1$ during low-intensity exercise than at supine rest. In the present study, the training induced significant changes in the fractal scaling exponent at exercise intensities of 60%–70% of $W_{max}$, which correspond to about 70%–80% of maximal HR in our subjects. At these exercise intensities, the role of parasympathetic activity to the heart is minor, and sympathetic activity is increased (12). These observations together with the low correlation coefficient between the training-induced changes in HF and $\alpha_1$ in this study suggest that along with vagal activity, $\alpha_1$ may also reflect, for example, breathing frequency and other factors that are not yet fully established (31).

Strength training alone did not lead to significant changes in HR dynamics. Similarly, in several previous studies, strength training has been shown not to influence spectral measures of HRV (5,7,25). On the other hand, strength training has been shown to have an effect on nonlinear entropy measures and fractal scaling measures of HR complexity (13,14). Heffernan et al. (14) divided the resistance training group in two parts based on their initial level of $\alpha_1$. With this analysis, they showed that after only 6 wk of training, both the subjects with higher and the subjects with lower scaling exponent approached the value of 1.0, that is, fractal-like behavior of HR. Despite the fact that in the present study $\alpha_1$ before training was higher and above 1.0 in the majority of the subjects, $\alpha_1$ did not decrease after strength training. The training program does not seem to explain the dissimilar results because the aim in both studies was to elicit muscle hypertrophy and to improve maximal strength with high load exercises for all major muscle groups. In fact, the weekly volume per muscle group was even greater in our 21-wk training program. The contradiction between the findings could be explained by the older age of our subjects (mean age = 56 yr in our study vs 23 yr in the study of Heffernan et al. [14]) because it has been suggested previously that older men (40 yr) show less improvement in cardiac autonomic function than younger men (20 yr) in response to the same endurance training.

FIGURE 4—HR at exercise intensities of 50, 70, …, 150 W before (0) and after 10 and 21 wk of training in the endurance (E), strength (S), combined endurance and strength training (ES), and control group (C). *Significantly ($P < 0.05$) different from the baseline measurement, **$P < 0.01$, ***$P < 0.001$. A significant difference between groups was observed at the exercise intensities of 90–150 W ($P = 0.037$ to <0.001).
stimulus (4). It has been stated earlier that in older age, the deterioration of the physiological regulatory mechanisms may impair the ability to adapt to different physiological stimuli, such as stress (18,32). It could be suggested that adaptability of cardiovascular regulatory system to training may also decrease. However, older men are at a considerable higher risk of cardiac events than younger men, suggesting that the improvements in HR dynamics are of great importance in older age.

The positive effect of endurance training on cardiac autonomic function has been shown in many previous studies (11,23,37). Therefore, we expected to find greater changes in HF power and fractal scaling exponent in our study, given the effectiveness of our training program in increasing aerobic capacity and cardiorespiratory function. In a previous 5-yr training study in elderly men, neither HRV nor VO2max showed training-related improvements (39). In the present study, endurance training led to minor but nonsignificant changes in fractal dynamics of HR at rest and during exercise of different intensities and even smaller effects on spectral measures at rest. However, the expected effects of endurance training on spectral measures of HRV were seen at moderate exercise intensities of 90 W and higher. This finding is in line with previous findings with a similar endurance training program in younger men (mean age = 37 yr) who showed improved vagal control during submaximal exercise but not at rest (26).

To conclude, the present results showed that fractal HR dynamics were improved more in our older men by combining strength training with endurance training compared with endurance training alone, although strength training alone produced no changes in the fractal HR behavior. The synergistic effect in fractal behavior of HR occurred independently from the changes in aerobic capacity because the training-induced increases of endurance and combined endurance and strength training were similar. Whether this synergistic effect of combined training is due to the greater training volume or some underlying mechanisms of training adaptation cannot be clarified with the present study design. Therefore, further studies are required to reveal the mechanisms of the training adaptation and its significance in the prevention of cardiac events in individuals at a high risk of cardiovascular disease.

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