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Original Article

The Effects of 12-week Home-Based Bench Stepping Exercise on Aerobic Capacity and Cardiac Autonomic Nervous Activities in Older Adults

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Abstract

Aim: To examine the effect of a 12-week home-based exercise intervention on the cardiac autonomic nervous system (ANS) in older adults.

Method: Twenty-two older subjects (male; n=12, female; n=10, >65 yr.) were divided into either an exercise intervention group (EX) or a control group (CO). The EX group participated in a 12-week intervention mainly consisting of home-based bench stepping exercise at the intensity of lactate threshold (LT). The EX subjects were instructed to perform >20 min/day of the bench stepping exercise at their home. Before and after the 12 weeks intervention, the ANS was assessed by the spectral analysis of R-R interval variability. Based on the power frequency algorism, we evaluated the high-frequency power (HF), low-frequency power (LF), sympathetic nervous activity (SNS), and TOTAL power (LF+HF). Additionally, the aerobic capacity was evaluated as the LT using a simple bench stepping test.

Results: In the EX patients, the LT was significantly increased after the intervention compared with the baseline levels ($p<0.05$), but was unchanged in the CO patients. There were no significant changes in ANS-related parameters in either group. The LT significantly correlated with the change in the HF and SNS ($p<0.05$). Furthermore, the weekly training time was significantly associated with the HF ($p<0.05$).

Conclusion: The present investigation could not find any apparent improvement in the ANS in older adults after the home-based bench stepping exercise at the LT for <140 min/week, due to the small improvements in the aerobic capacity caused by the short training duration.

KEY WORDS: Physical activity, Lactate threshold, Cardiology, Geriatric Medicine, Elderly

Introduction

Active lifestyles can elicit numerous health benefits. The individuals with higher levels of physical activity (PA) have a reduced incidence of lifestyle-related diseases such as the obesity, hypertension, diabetes, and hyperlipidemia, as well as the risk of all cause mortality [1-3]. These desirable health benefits associated with the regular exercise can be obtained in older individuals independently from the individual's past exercise history [4]. Therefore, not only healthy adults, but also all adults, should be encouraged to participate in regular PA to obtain the associated health benefits. One of main mechanisms responsible for these exercise-induced benefits is the improvement of the autonomic nervous system (ANS) [5]. It is well known that the ANS is associated with weight control, food intake, blood pressure, and fat metabolism [6]. Additionally, the power spectral of heart rate variability (HRV), which is a simple useful noninvasive indicator of the ANS related to the risk factors for cardiac sudden death and all-cause mortality [7]. Several investigations have demonstrated that regular exercise training can improve the autonomic nervous system (ANS) [5,8,9]. Further, improvements were noted in body weight, fat mass, systolic blood pressure, and HDL cholesterol following exercise intervention, effects we associate with changes in the ANS. Therefore, the improvements in the ANS have been considered to be important outcomes of exercise-based intervention studies.

One of the main factors that cause an ANS decline is aging [5,6]. However, there have been few reports that have examined the influence of exercise training on the ANS in an older population. We developed a home-based practical exercise program for older adults using a bench stepping exercise, including a graded exercise test to assess the lactate threshold (LT) and a motivational exercise program [10-12]. The home-based exercise program has behavioral advantages such as exercise adherence.

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Similarly, the bench stepping exercise is a cost-effective, user-friendly and practical exercise mode. Additionally, the exercise at LT is well known as a safe and desirable exercise intensity, and older subjects can obtain health benefits by participating in regular exercise at the LT [13-15]. We have already confirmed that this exercise program can improve the physical fitness levels and the health outcomes in the elderly [10,12]. We therefore hypothesized that this home-based bench stepping exercise program can improve the ANS in the elderly.

The purpose of the present investigation was to examine the effects of a 12-week home-based bench stepping exercise program on the ANS in the elderly.

Methods

Subjects

Thirty-two individuals participated in the present investigation. These volunteers were recruited using the newspapers and the local news magazine from Sapporo-city (Hokkaido, Japan). The subjects of the present investigation were over 65 years of age, and were not participating in the regular exercise (>30 min/day for >2 days/week) for current one year. The volunteers of the present investigation were recruited mainly from individuals living in Sapporo-city, using the weaving newspaper fliers. All volunteers were independently living, and they did not have any history of hospitalization within current one year. Furthermore, they were not restricted their exercise habits by medical doctors. Thirty-two elderly were included as the subjects for the intervention. The 32 subjects were randomly assigned into a training group (EX) and a control group (CO) using a table of random numbers. However, of the 32 subjects, the data of the ANS was lack of the sufficiently in ten subjects, because of the fails with the diet and smoking control before measurements, the faster breathing and/or sleeping during the measurements, and the absence for the measurements due to the private reasons. Thereafter, the data for the remaining 22 subjects were processed for the study analysis.

Of 22 subjects, 18 subjects were defined as hypertension (>140 mmHg of systolic blood pressure and/or >90 mmHg diastolic blood pressure), 9 subjects was defined as high total cholesterol (high total cholesterol was above 220 mg/dl), 2 subjects was defined as high triglyceride (triglyceride was above 140 mg/dl), 2 subjects were defined as diabetes mellitus (fasting blood glucose >126 mg/dl and HbA1-c > 6.5%).

After an explanation of the study design and requirements, each subject read and signed a consent form. All procedures performed in the present investigation were approved by the ethics committee of Hokkaido University, and that it conforms to the provisions of the declaration of Helsinki.

Measurements

The height, body weight, fat mass, ANS, and aerobic capacity were assessed before and after the intervention. Additionally, in the EX group, the step test was performed in the middle of the total training period (6th week) in order to re-consider the exercise prescription. Although some of participants had some medications, but all subjects did not have it on the experimental day in order to avoid the measurements error due to the medications.

Height and body weight were measured using the standardized methods. The body mass index was calculated as the body weight (kg) divided by the height (m) squared. The percentage of body fat was measured by dual energy X-ray absorptiometry (QDR-2000, Hologic, Waltham, MA). The characteristics of the subjects are presented in ***Table 1***. There were no significant differences in any of the measurements between the two groups.

Table 1 The characteristics of the study subjects

	EX (n=11)		CO (n=11)	
	Male	Female	Male	Female
N	5	6	7	4
Age [yr.]	71 ± 3	71 ± 6	68 ± 2	69 ± 4
Height [cm]	163.9 ± 3.3	149.4 ± 3.5	164.8 ± 4.6	154.8 ± 2.3
Body weight [kg]	63.2 ± 5.1	51.3 ± 9.2	64.6 ± 7.7	57.2 ± 4.9
Body fat [%]	25.2 ± 5.5	36.7 ± 4.4	23.7 ± 5.1	38.1 ± 4.8
SBP [mmHg]	150 ± 14	145 ± 16	148 ± 15	150 ± 20
DBP [mmHg]	92 ± 5	83 ± 11	93 ± 9	89 ± 9
Total Cholesterol [mg/dl]	211 ± 41	240 ± 49	192 ± 29	220 ± 21
Triglyceride [mg/dl]	79 ± 16	120 ± 80	95 ± 33	104 ± 31
HDL-C [mg/dl]	61 ± 13	64 ± 15	69 ± 33	81 ± 21
Blood glucose [mg/dl]	92 ± 8	101 ± 17	98 ± 12	108 ± 25
Hb A1-c [%]	5.0 ± 0.2	5.4 ± 0.8	5.6 ± 0.9	6.0 ± 1.1

Data are expressed as the means and standard deviations.
None of the variables differed significantly between the 2 groups.
EX; Exercise group, CO; Control group.

Electrocardiograms (ECGs) were taken while the subject was seated in a comfortable chair. The subject was instructed to relax and not to move or sleep during the measurements. The subject was asked to avoid strenuous activity, eating, and smoking 3 hours before testing. After the subject had rested sufficiently, a CM_5 lead ECG was continuously amplified by a bioelectric amplifier (AB-621G, Nihon Kohden Corporation, Shinjyuku-ku, Tokyo, Japan) and recorded on a cassette data recorder (MR-30, TEAC CORPORATION, Osaka-city, Osaka, Japan) for 6 min. During the testing, the subject breathed in synchrony with a metronome at 15 times/min (0.25 Hz) to ensure that respiratory-linked variations in the heart rate did not overlap with low-frequency heart rate fluctuations (below 0.15 Hz) from other sources [16]. ECG measurements were performed before the exercise program started, and after the 12 weeks exercise program.

We used a power spectral analysis of the HRV to measure the ANS under the resting condition. Our R-R interval power spectral analysis procedures have been fully described elsewhere [5,8,9]. An analog output of the ECG recorded on a cassette data recorder was digitized via an analog-to-digital converter (PS-2032GP, TEAC) at a sampling rate of 1k Hz, and was stored sequentially on a hard disk for later analysis. The off-line analysis was conducted with the assistance of a personal computer. The power spectral analysis by means of fast Fourier transform was then performed on consecutive 240 s time series of R-R interval data obtained during the test.

To evaluate the ANS in each subject in the present study, we analyzed low frequency (LF; 0.03-0.15 Hz), high frequency (HF; 0.15-0.5 Hz), and total power (TOTAL; 0.03-0.5 Hz) by integrating the spectrum for the respective bandwidth. The off-line analysis was conducted with the assistance of a personal computer. The stored R-R interval data were converted into equally-spaced samples with an effective sampling frequency of 2 Hz. Next, the DC component and trend were completely eliminated by digital filtering for the band-pass between 0.03 and 0.5 Hz as described elsewhere. The root mean square value (RMS) of the R-R interval was calculated as representing the average amplitude. After passing through the Hamming-type data window, the power spectral analysis by means of the fast Fourier transform was then performed on consecutive 240 s time series of R-R interval data obtained during the test.

The graded exercise test used a submaximal graded step test, following the previous investigation [11,12]. Exercise intensity was decided according to the exercise habits and aerobic capacity individually. The platform height was 20 or 25 cm, and the stepping rate was from 15 to 40 ascends /minute. The METs value estimated by the bench height and the stepping frequency was 4-7 METs at a first stage, and was increased 0.97 METs every stage. Exercise duration was 4 minutes per stage, and a 2-minute rest period was set between stages. We measured the LA and HR at rest, HR for 30 sec before conclusion of each work stage, and the LA and rating of perceived exertion (RPE) immediately after conclusion of each work stage. The LA was measured by taking 5 µl of blood from the earlobe by a portable blood lactate measuring device (Lactate Pro, ARKRAY, Inc. Kyoto-city, Kyoto, Japan). Also, the HR and RPE were measured with an HR monitor, (Accurex Plus, Polar Electric, Finland) and the Borg Scale, respectively. After the measurements, LT was assessed using a previously described assessment.

The subjects in the EX group participated in the home-based bench stepping exercise program. The subjects were instructed to perform the bench stepping exercise at least 20 min per day (140 min/week). The exercise intensity was set at the LT based on the step test, and was re-set at the middle of the training period if necessary. Subjects recorded their training duration in a diary everyday. The exercise diary was checked every 2 weeks, and the subjects was encouraged to extend their time for bench stepping if the weekly exercise time was <140 min/week.

All data are expressed as the means ± SD. A repeated-measure ANOVA was performed to compare the data between groups. A paired *t*-test was performed to compare the data from before and after the 12 weeks exercise program. When the data were not normally distributed, a Mann-Whitney's U test was used. The Pearson's correlation coefficient test was used for the related analysis. Spearman's correlation coefficient by the rank test was used for the data that were not normally distributed and the discrete variables. *P* values < 0.05 were considered to be statistically significant.

Results

The heart rate and ANS index before and after training are shown in ***Table 2***. The ANS indexes did not differ significantly between men and women. The two-way repeated measure of variance showed that there were no significant differences or interactions between any variables with regard to the ANS. The exercise intensity at LT significantly increased from 4.4±0.6 METs to 5.4±0.8 METs (p<0.01) in the EX group, but was not significantly changed in the CO group. The training duration averaged over 12 weeks was 19±7 min/day in the EX group. Of the 11 subjects in the EX group, only five subjects achieved the prescribed weekly exercise duration (>140 min/week).

Table 2 The heart rate and cardiac autonomic nervous system activities before and after the 12-wk exercise intervention

	EX (n=11)		CO (n=11)	
	Pre	Post	Pre	Post
Training duration [min/week]	133 ± 49		–	
Lactate threshold [METs]	4.4 ± 0.6	5.4 ± 0.8**	4.4 ± 0.7	4.4 ± 0.5
Body weight [kg]	56.7 ± 9.6	56.1 ± 9.6	56.7 ± 9.6	56.1 ± 9.6
% Body fat [%]	31.5 ± 7.6	31.5 ± 7.6	28.9 ± 8.7	29.3 ± 9.3
Heart rate [bpm]	67.9 ± 7.7	65.3 ± 10.1	68.3 ± 8.2	68.3 ± 10.3
Total [ms2]	208.4 ± 184.2	134.2 ± 106.5	227.8 ± 222.2	154.3 ± 111.9
HF [ms2]	67.9 ± 66.0	57.8 ± 57.9	79.0 ± 71.3	74.6 ± 87.1
SNS [LF/HF]	2.45 ± 1.19	2.72 ± 3.95	2.38 ± 1.50	2.40 ± 3.15

Data are expressed as the means and standard deviations (mean±SD).
**Significantly different compared with that baseline level (p=0.001).
EX; Exercise group, CO; Control group. Total; Total power, HF; High frequency,
SNS; Sympathetic nervous system activity was calculated by dividing the low frequency power by the high frequency power.

Fig. 1 shows the relationships among the changes in the LT, the ANS, and the training duration. The magnitude of the changes in the LT was significantly associated with the changes in the HF and SNS (r=0.755, p<0.05, and r=−0.809, p<0.05). Additionally, the average weekly training duration over the 12 weeks intervention significantly correlated with the changes in the HF.

Discussion

The present study examined the effects of a home-based exercise program using a bench stepping exercise on the ANS in elderly patients. As a result, almost half of the subjects in the EX group failed to accumulate the prescribed amounts of the bench stepping exercise (>140 min/week). We were unable to find any significant improvement in all of the indices of the ANS after the intervention. The changes in the ANS after the exercise training from the baseline level were significantly associated with the amounts of the bench stepping and the changes in aerobic capacity. These results indicate that the home-based exercise program using a bench stepping at the intensity of LT for <140 min/week could not improve the ANS due to small improvement of the aerobic capacity and the lack of a sufficient training duration.

A total of 140 min/week of aerobic exercise at the intensity of the LT has been shown to be an effective exercise program to treat high blood cholesterol, high blood pressure, glucose intolerance, and to improve physical fitness levels [13-15]. A previous investigation showed that the training duration at LT was significantly associated with changes in the HDL-cholesterol, and that 140 min/week was a lower threshold for the improvement of HDL-cholesterol [15]. Thereafter, the past guidelines by the Japanese Health Welfare Committee, with regard to the PA for preventing lifestyle-related diseases, recommended accumulating >140 min/week of aerobic exercise at an intensity of 50% of the maximal oxygen uptake, which was an alternative assessment of the LT for older individuals [17]. Additionally, it was demonstrated that a home-based exercise program using a bench stepping exercise could also successfully improve the aerobic capacity

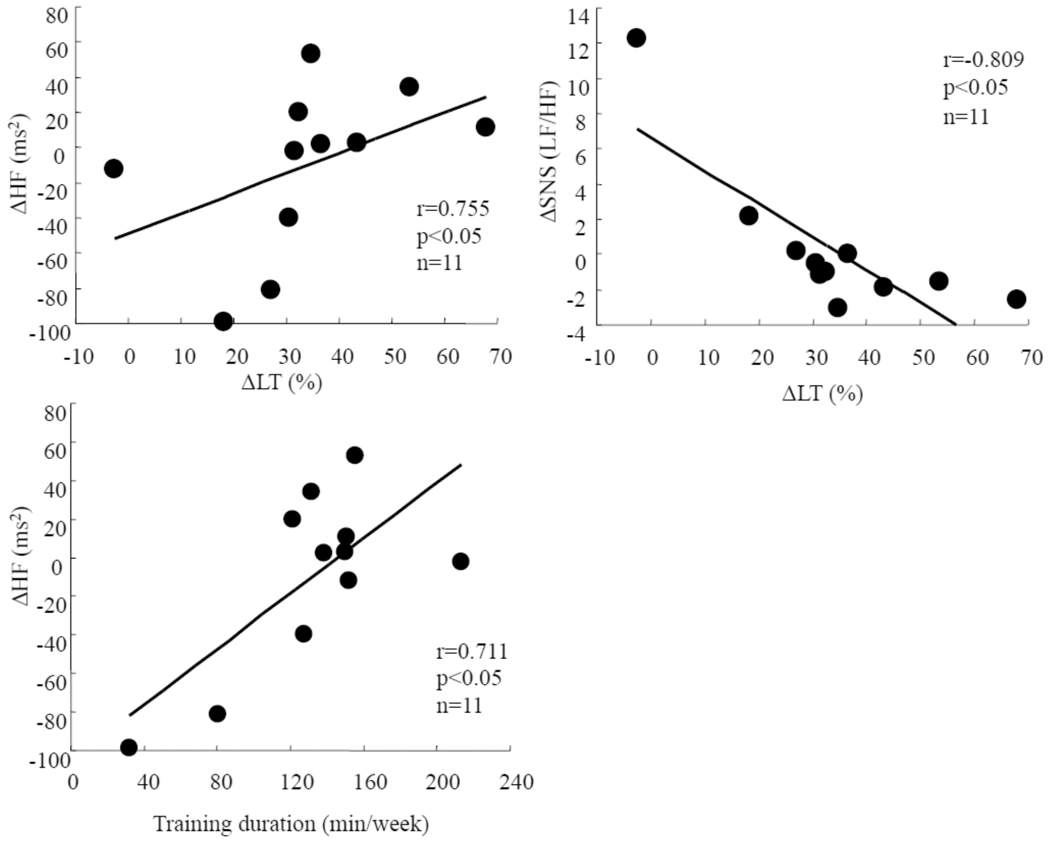

Fig. 1. **The relationship between the changes in cardiac autonomic nervous activities, aerobic capacity and training duration**

The upper illustration shows the relationships between the changes in the lactate threshold and the changes in autonomic nervous activity, the lower illustration shows the relationships between the training volume and the changes in the autonomic nervous system.

ΔHF; Changes in the high frequency power after the intervention from the baseline level, ΔSNS; Changes in the sympathetic nervous system activity after the intervention from the baseline level, ΔLT; Changes in the lactate threshold after the intervention from the baseline level.

and muscular power of study subjects [10,12]. Similarly, the present study also found a significant improvement of the LT after the intervention.

In contrast, we could not find any significant effects of aerobic exercise training on the ANS in ours study. In the present investigation, at baseline level, the mean for the ANS was similar with the previous finding [5]. One of the main reasons for the present results was speculated to be the inter-individual variability in the training duration and the improvement of aerobic capacity. This is one of the main disadvantages of a home-based exercise program where the exercise supervisors cannot completely control the training habits, whereas the home-based exercise program has several advantages, such as exercise adherence and practicality. Similar to the previous investigations [10,12], we found inter-individual variability in the training duration. In the present investigation, the training duration was 133±49 min/week, ranging from 32 to 213 min/week, although all subjects were instructed to accumulate >140 min/week of exercise training. Only 5 of all subjects achieved the target duration of exercise training (>140 min/week).

Additionally, the training duration was significantly associated with the changes in the HF activity (***Fig 1***), and the linear regression (*The changes in the HF activity = 0.675*Exercise duration per week −98.55*) showed that 146 min/week of the exercise training was the lower threshold for improvement of the HF. Thus, these results suggested that the amount of exercise training in the current subjects was not sufficient to improve their ANS. However, the present findings do not indicate that >140 min/week of exercise training at the intensity of LT cannot improve the ANS in the elderly. Furthermore, the present study found a significant relationship between the ANS and the changes in aerobic capacity. It is well known that physically active individuals have a higher aerobic capacity [18]. Although the present investigation could not find any significant association between the training duration and the changes in aerobic capacity due to the small sample size, the training responses were dependent on the training volume [3]. As a result, we found that both the changes in aerobic capacity and the training duration were significantly associated the changes in ANS. A recent study showed that a higher aerobic capacity, rather than a greater amount of daily PA, has an important role for maintaining a healthy lifestyle [19]. Additionally, we could find any significant relationship between the ANS activity and the aerobic capacity at baseline level, whereas the inter-individual variability of the ANS was not small. Although it is unclear whether the aerobic capacity is more closely associated with the ANS than the daily PA levels, older individuals should be encouraged not only to accumulate PA, but also to improve their aerobic capacity.

There are some limitations with regard to the present investigation. First, the sample size of the present investigation was very small, and the subjects were relatively healthy. Thus, the results of the present investigation have to be confirmed in a larger, heterogeneous population of subjects. Second, the present investigation assessed the aerobic capacity and the training duration by the LT and the diary methods. Although the LT has been considered a valid index of aerobic capacity, the maximal oxygen uptake seems to be more closely associated with the central nervous system. The diary-based assessment of the training volume, used in the previous studies, is not objective, and may result in inaccurate reflections of the time spent engage in exercise.

In summary, the present study examined the effects of a home-based exercise program using a bench stepping exercise on the ANS in elderly patients. The results of the present investigation indicate that the home-based exercise program using bench stepping at the intensity of the LT for <140 min/week could not improve the ANS due to the small improvement of aerobic capacity and the short training duration of most of the subjects. The results of the present investigation will need to be confirmed in a larger heterogeneous population.

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Competing interests

None of the authors have any professional relationship with companies or manufactures that will benefit from the results of the present study.

Conflict of interest statement

The authors declare no financial or other conflicts of interest in the writing of this paper.

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