Baroreflex function in sedentary and endurance-trained elderly people

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Abstract

Objective: to determine the differences associated with age and endurance exercise training on the baroreflex function of healthy subjects.
Design: cross-sectional study.
Setting: university research department.
Participants: 26 (10 female) sedentary, healthy, normotensive elderly subjects (mean age 67 years, range 62-81), eight (two female) elderly endurance-trained athletes (66 years, 62-69) and eight (two female) young (30 years, 25-34) subjects.
Measurements: baroreflex sensitivity was quantified by the α-index, at high frequency (HF, 0.15–0.35 Hz) and mid frequency (MF, 0.05–0.15 Hz), derived from spectral and cross-spectral analysis of spontaneous fluctuations in heart rate and blood pressure.
Results: resting heart rate was significantly lower in endurance-trained athletes than sedentary elderly people (58 ± 12 versus 68 ± 11 min⁻¹, \(P < 0.05\)) but not different to that in healthy young subjects (63 ± 9 min⁻¹). \(\alpha_{HF}\) in sedentary elderly subjects (8.1 ± 4.2 ms.mmHg⁻¹) was lower than both endurance-trained elderly athletes (14.8 ± 4.8 ms.mmHg⁻¹, \(P < 0.05\)) and healthy young subjects (28.3 ± 21.8 ms.mmHg⁻¹, \(P < 0.05\)) and was not significantly different between endurance-trained elderly athletes and healthy young subjects (\(P = 0.10\)). \(\alpha_{MF}\) in healthy young subjects (15.4 ± 8.8 ms.mmHg⁻¹) was greater than in sedentary elderly subjects (6.5 ± 3.2 ms.mmHg⁻¹, \(P < 0.01\)) and endurance-trained elderly athletes (6.9 ± 2.0 ms.mmHg⁻¹, \(P < 0.01\)), while there was no significant difference between the two elderly groups (\(P = 0.66\)).
Conclusions: both components of the baroreflex measured by the α-index show a decrease with age. Elderly endurance-trained athletes have less reduction in the high, but not mid, frequency component of the α-index compared with sedentary elderly subjects. Some of the age-related changes in baroreflex sensitivity may be related to physical fitness and activity levels.

Keywords: ageing, baroreflex sensitivity, exercise, heart rate

Introduction

The baroreflex is a complex integrated system linking heart rate to blood pressure through the parasympathetic and sympathetic nervous systems. A measure of baroreflex sensitivity can be obtained by calculating the slope of the regression of the pulse interval response to induced perturbations of blood pressure. A significant and progressive decrease in baroreflex sensitivity is known to occur with ageing in man [1, 2] and is observed in hypertensive subjects of any age [1, 3]. This decrease in baroreflex sensitivity is partially reversible in hypertensive subjects [3, 4] by aerobic exercise training. The effect of aerobic exercise training on baroreflex sensitivity in normotensive subjects is unclear, with decreased [5–7] unchanged [8, 9] or increased [10] sensitivity being described. Apart from one study of 10 middle-aged individuals which found no change in baroreflex sensitivity after 12 weeks of aerobic exercise training [11], no studies have determined whether the age-associated decline in baroreflex can be altered by exercise training.

Traditionally the 'Oxford' method [12] has been considered to be the optimal method of measuring baroreflex sensitivity in man. In this technique bolus doses of phenylephrine are administered to induce a
rise in arterial pressure and reflex slowing of heart rate. Baroreflex sensitivity is calculated by relating the increase in pulse interval to the transient rise in blood pressure induced by phenylephrine. The slope of pulse interval against systolic blood pressure (ms RR interval/mmHg) is a measure of baroreflex sensitivity or gain. More recently, techniques have been described which utilize the spontaneous variability of heart rate and blood pressure [13, 14] to determine baroreflex gain described by the α-index. To determine the α-index, RR interval and systolic pressure spectra are calculated. These estimate the amplitude of fluctuations as a function of frequency. The ratio of changes in the RR interval to changes in systolic pressure obtained from the spectra therefore gives α, an estimate of baroreflex gain (ms.mmHg⁻¹) as a function of frequency. Some studies suggest that the mid frequency (MF) component of the α-index (0.05-0.15 Hz) is a quantitative index of the sympathetic activity controlling heart rate and vasomotor activity and the high frequency (HF) respiratory component of the α-index (0.15-0.35 Hz) reflects parasympathetic activity [15]. Good agreement between α-index estimated by spectral analysis and baroreflex sensitivity measured by the Oxford technique has been found [13]. Spectral and sequence analysis of finger blood-pressure determination agrees well with intra-arterial blood pressure recordings [16].

The aim of the present study was to determine the differences associated with age and with endurance training on baroreflex sensitivity as measured by the α-index. Baroreflex sensitivity was determined in healthy sedentary young people, healthy sedentary elderly people and endurance-trained elderly athletes.

Methods

Study design

Healthy sedentary young people, healthy sedentary elderly people and endurance-trained elderly athletes were studied on a single occasion. Subjects rested supine in a temperature-controlled quiet room for 20 min and recordings were made over a subsequent 20-min period. Subjects refrained from talking throughout the 40 min. The surface electrocardiogram (ECG) was recorded from a standard lead II whilst arterial pressure was measured using the Penaz technique (Finapres, Ohmeda) applied to the second finger of the right hand. Both ECG and blood pressure signals were digitized at 250 Hz (DAS-16 analogue to digital converter) and stored for subsequent offline analysis.

Subjects

Thirty-three healthy, sedentary elderly non-smoking individuals were recruited from the community. Data from 26 (16 male, 10 female; mean age 67 years, range 62-81) were available for analysis. Three subjects withdrew for personal reasons and data from four subjects were excluded because of poor signal quality or presence of multiple ventricular ectopics in the recordings. Eight endurance-trained healthy elderly athletes (six male, two female; mean age 66 years, range 62-69) were recruited from entrants to a local half-marathon. All undertook regular training, running an average 30 miles per week (range 20-40), and had been training for at least 5 years. All had run at least five half-marathons in the previous 2 years, with a mean time of 90 min (range 80-130). Eight (two female) healthy, sedentary young subjects taking no regular exercise (mean age 30 years, range 25-34) were recruited from university staff.

All subjects were non-smokers, taking no medication and with normal past medical history, physical examination, full blood count, random blood glucose concentration, hepatic, renal and thyroid function, urinalysis, fasting plasma lipids and resting ECG. Height, weight, body mass index, resting heart rate and blood pressure for each subject group are shown in Table 1. Sedentary and endurance-trained elderly subjects had a normal exercise ECG to maximum heart rate with no ST segment depression or significant arrhythmias. The study was approved by the Newcastle joint ethics committee.

α-index determination and heart rate variability

For each subject the α-index and peak power of heart rate variability was determined in the MF and HF ranges as previously described [20]. The ECG and arterial pressure signals were processed to give a sequence of RR intervals and corresponding systolic pressures. The RR interval sequence was corrected for occasional ectopic beats [17]. Each systolic pressure sequence contained some missing values due to the Finapres recalibration every 70 beats. These missing values were estimated by linear interpolation between measurements of systolic pressure immediately preceding and succeeding the recalibration period.

RR and systolic pressure sequences were resampled at 4 Hz using the method described by Berger [18] to give an RR interval tachogram and systolic pressure systogram sampled at regular intervals. Each 20 min resampled sequence was then divided into four 5-min periods, which were further divided into nine epochs each of length 512 samples and overlapping the preceding epoch by 424 samples. The mean value of each epoch was calculated and subtracted from each sample value. Each epoch was then padded with an equal number of 0s each side to a new length of 1024 samples. Zero-padded epochs were windowed with the Hanning function and transformed into the frequency domain using the fast Fourier transform algorithm. The nine spectra obtained from each 5-min...
period were averaged to give an estimate of the spectrum.

The RR interval and systolic pressure spectra were also used to compute the coherence spectrum, a measure of the consistency of the phase relationship between the RR interval and systolic pressure spectra [19]. Only frequencies where there was a coherence of 0.5 or greater between RR interval and systolic blood pressure were used to calculate the mean and standard deviation value of the \( \alpha \)-index in the MF and HF bands (a value of 0 indicating no coherence, 1 indicating perfect coherence). This method gives similar estimates of the \( \alpha \)-index to those obtained with other frequency analysis techniques [20].

Heart rate variability was estimated from the peak power values in the MF and HF bands of the RR interval spectrum. The spectrum was calculated from the ratio of the RR interval spectrum amplitude to systolic pressure amplitude. Mean heart rate was obtained from the 20 min period.

**Results**

**Resting heart rate and blood pressure**

Resting heart rate was lower in the endurance-trained athletes (58 ± 12 min\(^{-1}\)) than the sedentary elderly group (68 ± 11 min\(^{-1}\), \( P < 0.05 \)) but not the healthy young group (63 ± 9 min\(^{-1}\), \( P = 0.27 \)). There was no difference in resting heart rate between the sedentary elderly and healthy young groups (\( P = 0.18 \)). Resting systolic blood pressure was lower in young subjects (126 ± 13 mm Hg) compared with both sedentary elderly subjects (132 ± 23 mm Hg, \( P < 0.01 \)) and endurance-trained elderly subjects (134 ± 13 mm Hg, \( P < 0.01 \)) and did not differ between the two elderly groups (\( P = 0.19 \)).

**Heart rate variability**

Heart rate variability peak power data are shown in Table 2. There was no difference in heart rate variability at MF between the sedentary elderly people and the endurance-trained athletes (\( P = 0.86 \)).

### Table 2. High and mid frequency heart rate variability (HRV) in sedentary young, sedentary elderly and endurance-trained healthy subjects; data are mean values ± SD

<table>
<thead>
<tr>
<th>HRV (frequency)</th>
<th>Elderly people</th>
<th>Healthy sedentary (n = 26)</th>
<th>Endurance-trained (n = 8)</th>
<th>Healthy sedentary young people (n = 8)</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (0.15–0.35 Hz)</td>
<td>1533 ± 1323</td>
<td>1701 ± 582</td>
<td>3336 ± 2039*</td>
<td></td>
</tr>
<tr>
<td>Mid (0.05–0.15 Hz)</td>
<td>2146 ± 1228</td>
<td>2227 ± 1173</td>
<td>3918 ± 1262*</td>
<td></td>
</tr>
</tbody>
</table>

\*Significantly different from healthy sedentary elderly subjects; \(^*\)significantly different from endurance-trained elderly subjects (\( P < 0.05 \)).
Heart rate variability at MF in the young was significantly higher than in either sedentary \( (P < 0.01) \) or endurance-trained elderly \( (P < 0.01) \) subjects. There was no difference in HF peak power between the sedentary elderly people and the endurance-trained athletes \( (P = 0.67) \). HF peak power was higher in young people than in sedentary \( (P < 0.05) \) but not endurance-trained \( (P = 0.06) \) elderly people.

\( \alpha \)-index

Baroreflex sensitivity as measured by \( \alpha_{\text{MF}} \) was significantly higher in young subjects \( (15.4 \pm 8.8 \text{ ms.mHg}^{-1}) \) than sedentary elderly \( (6.5 \pm 3.2 \text{ ms.mHg}^{-1}, P < 0.01) \) and endurance-trained elderly \( (6.9 \pm 2.0 \text{ ms.mHg}^{-1}, P < 0.01) \) subjects (Figure 1). \( \alpha_{\text{MF}} \) was not significantly different between sedentary and endurance-trained healthy elderly groups \( (P = 0.66) \). Baroreflex sensitivity as measured by \( \alpha_{\text{HF}} \) was significantly lower in sedentary elderly people \( (8.1 \pm 4.2 \text{ ms.mHg}^{-1}) \) than in either endurance-trained elderly athletes \( (14.8 \pm 4.8 \text{ ms.mHg}^{-1}, P < 0.05) \) or healthy young people \( (28.3 \pm 21.8 \text{ ms.mHg}^{-1}, P < 0.05) \); levels in these two groups were not significantly different \( (P = 0.11; \text{Figure 2}) \).

Discussion

The main finding of this study is that the age-associated reduction in baroreflex sensitivity, as measured by the HF component of the \( \alpha \)-index is less marked in endurance-trained elderly subjects. The separate MF and HF components of the \( \alpha \)-index \( (\alpha_{\text{HF}} \text{ and } \alpha_{\text{MF}}) \) are differentially reduced in elderly endurance-trained athletes when compared with sedentary elderly subjects, suggesting that the two components of the \( \alpha \)-index represent different aspects of baroreflex sensitivity. These findings are in contrast to the results of exercise-training studies in young subjects with mild hypertension which resulted in increases in both \( \alpha_{\text{HF}} \) and \( \alpha_{\text{MF}} \) [13]. An age-associated reduction in heart rate variability was also confirmed in the present study, with a similar reduction present in endurance-trained and sedentary elderly subjects.

Resting heart rate was lower in endurance-trained athletes than sedentary elderly people of a similar age, providing evidence of a training effect, usually attributed to increased vagal activity [21]. Resting heart rate was not significantly different between young and elderly sedentary subjects, although larger studies have observed a reduced resting heart rate with ageing, suggesting an increase in vagal tone or reduced cardiac sympathetic drive [22, 23]. Reduced heart rate variability at MF and HF in older subjects was confirmed in our studies [24]. However, heart rate variability at MF and HF did not differ between sedentary and endurance-trained elderly subjects, suggesting that endurance training does not modify the age-associated reduction in heart rate variability. In contrast, heart rate variability in young subjects with hypertension is modified by exercise training, suggesting that the mechanisms causing reduced heart rate variability and baroreflex sensitivity in young hypertensive subjects differ from that causing reduced baroreflex sensitivity with age.

Integration of blood pressure and heart rate via the baroreflex is complex. In normal subjects, increased
stretch of the baroreceptors initiates increased afferent nerve outflow to the solitary tract nucleus. This results in activation of the vagal nucleus and inhibition of neurons of the vasomotor centre, increasing vagal tone to the heart and decreasing sympathetic outflow to the heart and blood vessels. The opposite happens if pressure falls in the vessels housing the baroreceptors. Baroreceptors in hypertensive subjects appear to be 'reset' so that higher systemic blood pressures are tolerated without causing a reduction in sympathetic activity which would reduce peripheral resistance, cardiac contractility and so return blood pressure to normotensive levels. Similar changes in baroreflex sensitivity are presumed to occur with healthy ageing, although it is quite possible that different mechanisms account for the age-associated reduction in baroreflex sensitivity. Exercise training has been found to increase baroreflex sensitivity in hypertensive young subjects and it may be that endurance training similarly ameliorates the age-associated decline in the HF component of the baroreflex.

Increased baroreflex sensitivity in young hypertensive subjects following exercise was considered to be due to simultaneous reduction of sympathetic influence and increased vagal modulation [13]. It was also considered that at-rest readjustment of sympatho-vagal balance with an increase in the gain of baroreflex sensitivity and enhanced vagal modulation was the major adaptive change in autonomic regulation induced by exercise training. In our studies endurance-trained elderly subjects had a higher HF but not MF $\alpha$-index than sedentary elderly people, with no change in MF or HF heart rate variability. Therefore, although exercise training may increase baroreflex sensitivity in both elderly normotensive and young hypertensive subjects, our findings suggest that the effects on individual components of baroreflex and heart rate control may differ in older subjects. In young hypertensive subjects there is pre-existing depression of vagal outflow and elevation of sympathetic outflow which can be modified by exercise training [25]. This abnormal state did not occur in our normotensive sedentary elderly subjects and so could not be modified by exercise. This suggests that mechanisms reducing baroreflex sensitivity with age differ from those affecting the baroreflex in hypertension.

The $\alpha$-index is not firmly established as a quantitative measure of baroreflex sensitivity. However both $\alpha_{MF}$ and $\alpha_{HF}$ have been demonstrated to correlate with measures of baroreflex sensitivity obtained by the phenylephrine pressor method [13]. It is likely that $\alpha_{MF}$ and $\alpha_{HF}$ are measuring different aspects of baroreflex control. $\alpha_{HF}$ may be more related to vagal tone and respiratory sinus arrhythmia and $\alpha_{MF}$ may relate more to baroreflex sensitivity as determined by other methods. It is noteworthy that $\alpha_{HF}$ and $\alpha_{MF}$ differed between endurance-trained and sedentary elderly subjects. Inter-individual variability in measurements of $\alpha$-index may have reduced the power of the present study to detect a difference in MF $\alpha$-index between sedentary and endurance-trained elderly subjects. Further studies comparing the $\alpha$-index with other measures of baroreflex sensitivity in endurance-trained and sedentary elderly subjects would be of interest.

The cross-sectional nature of the study may have resulted in selection bias influencing the finding of this study. Endurance-trained elderly athletes are a self-selected group who may have characteristics other than their exercise-trained status that influence baroreflex sensitivity. It is possible that occult disease in our healthy sedentary elderly subjects, particularly coronary disease, may have selectively influenced baroreflex sensitivity, although detailed screening procedures to exclude cardiac disease were undertaken. A longitudinal study of the effects of exercise training and detraining in elderly individuals would be of value in addressing these issues. A longitudinal intervention study might also have more statistical power to detect small differences in baroreflex sensitivity given the extent of inter-individual variability in measurements of $\alpha$-index.

In conclusion, observations in the present study confirm an age-associated decline in baroreflex sensitivity as measured by the $\alpha$-index and that that decline in baroreflex sensitivity as measured by $\alpha_{HF}$ is reduced in endurance-trained elderly individuals. These findings suggest that $\alpha_{HF}$ and $\alpha_{MF}$ are independent variables that may be modified separately. Some of the age-associated changes in baroreflex sensitivity may be related to age-associated changes in physical fitness and activity.

**Key points**

- Baroreflex sensitivity declines with age.
- The age-associated reduction in baroreflex sensitivity is less marked in endurance-trained elderly subjects.
- Reduction in heart rate variability occurs with increasing age, but this reduction does not differ between sedentary and endurance-trained old people.

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**References**


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