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Heart rate and blood pressure responses to isometric exercise in young and older men

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Abstract The aim of this study was to examine the isometric endurance response and the heart rate and blood pressure responses to isometric exercise in two muscle groups in ten young (age 23–29 years) and seven older (age 54–59 years) physically active men with similar estimated forearm and thigh muscle masses. Isometric contractions were held until fatigue using the finger flexor muscles (handgrip) and with the quadriceps muscle (one-legged knee extension) at 20%, 40%, and 60% of the maximal voluntary contraction (MVC). Heart rate and arterial pressure were related to the the individual's contraction times. The isometric endurance response was longer with handgrip than with one-legged knee extension, but no significant difference was observed between the age groups. The isometric endurance response averaged 542 (SEM 57), 153 (SEM 14), and 59 (SEM 5) s for the handgrip, and 276 (SEM 35), 94 (SEM 10) and 48 (SEM 5) s for the knee extension at the three MVC levels, respectively. Heart rate and blood pressure became higher during one-legged knee extension than during handgrip, and with increasing level of contraction. The older subjects had a lower heart rate and a higher blood pressure response than their younger counterparts, and the differences were more apparent at a higher force level. The results would indicate that increasing age is associated with an altered heart rate and blood pressure response to isometric exercise although it does not affect isometric endurance.

Key words Isometric exercise · Aging · Endurance · Cir-culatory responses

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Introduction

It has been found that compared to dynamic exercise, isometric contractions elicit marked increases in both systolic and diastolic blood pressures, while the rise in heart rate is less pronounced (Lind et al. 1966). When comparing young and older individuals, some studies have found comparable responses in heart rate to isometric exercise (McDermott et al. 1974; Sagiv et al. 1988), whereas others have observed a lower heart rate in the aged persons (Petrofsky and Lind 1975; Taylor et al. 1991, 1995). In contrast, it has been shown that the older persons exhibit either a similar (McDermott et al. 1974; Sagiv et al. 1988; Taylor et al. 1991) or a greater (Petrofsky and Lind 1975) blood pressure response to isometric contractions. These differences in findings may have arisen from variation in subject population, in experimental protocol (fatiguing vs nonfatiguing contractions), or in the muscle group tested. Comparisons of younger and older age groups may also have been confounded by age-related changes in physical activity and reductions in skeletal muscle mass and muscle strength (Evans 1995).

The present experiments examined the heart rate and blood pressure responses to fatiguing isometric exercise in two age groups of healthy men. The groups were similar in physical activity and estimated limb muscle mass. Because it has been demonstrated that the level of force (Lind et al. 1966; Seals 1993) and the size of active muscle mass may (Mitchell et al. 1980; Williams 1991) influence the circulation during isometric exercise, the measurements were carried out using two muscle groups at three different levels of force.

Methods

Subjects

Ten young and seven older men were the subjects of the study (Table 1). They were normotensive, healthy, and non-smoking. According to the results of a questionnaire, all subjects kept themselves physically active by performing conditioning exercises 2–4 times a week. The physical activity history was very similar between the groups both with respect to occupational and leisure-time activities. The young men practised aerobic training (e.g. jogging, swimming, and indoor bandy) and strength training. The most common form of exercise among the older men was walking, followed by jogging and strength training. The groups were also similar with respect to estimated forearm and thigh muscle masses. The study procedures followed the Helsinki Declaration.

Experiment protocol

Before the experiments, each subject had a medical examination which included a clinical exercise test using a 12-lead electrocardiogram (ECG). Before the present study, all the subjects had participated in other types of exercise tests in the laboratory and they were familiar with the equipment applied.

The subjects visited the laboratory three times. Each session started with the measurement of the isometric maximal voluntary contraction (MVC) of the finger flexor muscles (handgrip strength), and of the quadriceps muscle (one-legged knee extension) of the dominant side of the body. After the electrodes and blood pressure cuff had been attached, the subjects sat for 5 min to obtain baseline measurements. Then the subject was asked to maintain an isometric contraction for as long as possible either by handgrip or one-legged knee extension at one of the three levels of MVC (20%, 40%, 60%). After 10 min of recovery, isometric exercise was performed with the other muscle group. During any 1 day, only one handgrip and one one-legged knee extension test were carried out and sessions were randomized. At least 24 h of rest was allowed between the visits.

Measurements

Percentage of body fat was estimated from skinfold thickness measurements at four sites (Durnin and Womersley 1974). Circumference, length, and skinfold thickness were used to calculate forearm and thigh muscle volumes (Clarys and Marfell-Jones 1986), and the quadriceps muscle mass as 30% of the lean thigh volume (Jones and Pearson 1969).

All the force and endurance tests were carried out in an upright sitting position on a specially designed chair (Heikkinen et al. 1984), in which the limb positions could be defined. Knee extensor force was measured at a knee angle of 90° using a strap around the ankle connected to a strain-gauge and displayed on a chart recorder. The handgrip force was measured with an adjustable handle at an elbow angle of 90°. The MVC was defined as the highest force obtained in three 2-s trials separated by at least 2 min. In the endurance tests, the subjects maintained the predetermined force by monitoring visually the marked level on the chart recorder. The isometric endurance was the time elapsed until the subject could no longer maintain the required force level. The subjects were asked to breathe as normally as possible and to avoid holding their breath.

Blood pressure was recorded from the subject's middle finger of the non-dominant hand by photoplethysmography (Finapres blood pressure monitor no. 2300, Ohmeda, USA), while the hand rested at heart level. An ECG was recorded from two electrodes on the opposite sides of the chest with an impedance pneumograph (Resp I Impedance Pneumograph, UFI, USA). In addition, three electrodes were attached to the chest for monitoring clinical ECG (OLLI 297 Cardiac Monitor, Kone, Finland). Blood pressure and ECG signals were digitized at 200 Hz with a 12-bit resolution. The blood pressure signal was used to calculate systolic, diastolic, and mean arterial blood pressure ($\overline{BP}_a$) using a digital computer. The $\overline{BP}_a$ series were derived by averaging the blood pressure signal over each heart beat. Heart rate was computed from the R-waves of the ECG. Finally, the time series were averaged over 0–20%, 20%–40%, 40%–60%, 60%–80% and 80%–100% of the contraction times. The blood pressure results from the 60% MVC could not be used for analysis because of poor technical quality.

To estimate the degree of effort, the rating of perceived exertion (RPE) was asked at 15 or 30-s intervals and at the end of contraction using the numerical scale 6–20 that has been established by Borg (1970).

Statistical analyses

Student's *t*-test was used to test the group differences in physical characteristics. The data on muscle force, endurance time were analysed using 2-way analysis of variance (age, muscle group) with repeated measures on one factor (muscle group). The circulatory responses were analysed in two ways. First, the whole data on $\overline{BP}_a$ and heart rate were analysed using a 4-way analysis of variance (age, muscle group, force level, time), and then each test condition was analysed separately by 2-way analysis of variance (age, time). The results were considered statistically significant when $P < 0.05$.

Results

Maximal strength and endurance

Mean handgrip MVC was 665 (SEM 117) N and 599 (SEM 102) N (NS) among the young and older men, respectively, while one-legged knee extension MVC was higher in the young group [924 (SEM 114) N] than in the older men [729 (SEM 195) N] ($P < 0.05$).

The endurance time was ($P < 0.01$) longer with the handgrip compared to the knee extension, and the difference was most pronounced at 20% MVC. When the two age groups were compared, no significant difference

Table 1 Physical characteristics of the subjects. *BMI* Body mass index, *NS* not significant

Variable	Young ($n = 10$)		Older ($n = 7$)		P
	mean	SD	mean	SD	
Age (years)	26.3	2.3	57.0	1.5	
Height (cm)	184.2	4.8	177.1	6.6	NS
Mass (kg)	81.7	11.1	80.8	5.8	NS
BMI ($kg \cdot m^{-2}$)	24.0	2.2	25.9	3.4	NS
Body fat (%)	17.6	5.1	24.2	4.1	< 0.01
Forearm muscle volume (ml)	975	121	921	72	NS
Quadriceps muscle volume (ml)	1961	279	1871	183	NS

was observed between the endurance times. During handgrip, the endurance time averaged 490 (SEM 161), 126 (SEM 40), and 52 (SEM 10) s among the young subjects at the three MVC levels, respectively. The corresponding mean values for the older subjects were 616 (SEM 309), 191 (SEM 55), and 68 (SEM 28) s. During knee extension, the young men's mean endurance time was, at the three MVC levels, 225 (SEM 131), 84 (SEM 32), and 40 (SEM 12) s, respectively. The older subjects' endurance time averaged 350 (SEM 144), 107 (SEM 49), and 60 (SEM 23) s, respectively.

Rating of perceived exertion

The age groups did not differ in RPE at any of the MVC levels for either of the two muscle groups (Table 2).

Heart rate and $\overline{BP}_a$

Both heart rate and $\overline{BP}_a$ increased ($P < 0.001$) with time (Fig. 1). Also, both variables were at a higher level during knee extension than during the handgrip ($P < 0.001$). Heart rate increased with increasing level of force in both muscle groups ($P < 0.01$) and $\overline{BP}_a$ was also higher at 40% than at 20% MVC, especially at the end of the contraction ($P < 0.05$).

The older subjects had a lower ($P < 0.001$) heart rate response than their young counterparts during isometric exercise (Fig. 2), and especially so during 40% and 60% MVC knee extension, and 60% MVC handgrip.

The $\overline{BP}_a$ was higher ($P < 0.001$) in the older than in the young subjects, and there was a tendency for the difference to increase towards the end of contraction (Fig. 3). The older subjects had a higher $\overline{BP}_a$ response during 40% MVC both in handgrip and knee extension ($P < 0.05$).

Discussion

The main finding of this study was that the older men had a lower heart rate and a higher blood pressure response to isometric exercise compared to the young men. To reduce the effects of differences in exercise habits and the existence of chronic diseases (i.e. to minimize the effects of possibly confounding variables), we purposely selected well-trained older, healthy men who had similar estimated limb muscle volumes and physically activity levels as the young men.

Age and heart rate response to isometric exercise

In accordance with the findings of Funderburk et al. (1974), Mitchell et al. (1980) and Seals (1993), heart rate

Table 2 Rating of perceived exertion at the end of contraction at different percentages of maximal voluntary contraction

Group		Handgrip			Knee extension		
		20%	40%	60%	20%	40%	60%
Young men	Mean	19.5	19.4	18.4	19.1	18.6	18.0
	SD	1.0	0.7	1.6	1.4	1.6	1.2
Older men	Mean	19.0	18.9	18.6	19.0	18.6	18.3
	SD	1.8	1.8	1.6	1.8	1.6	1.8

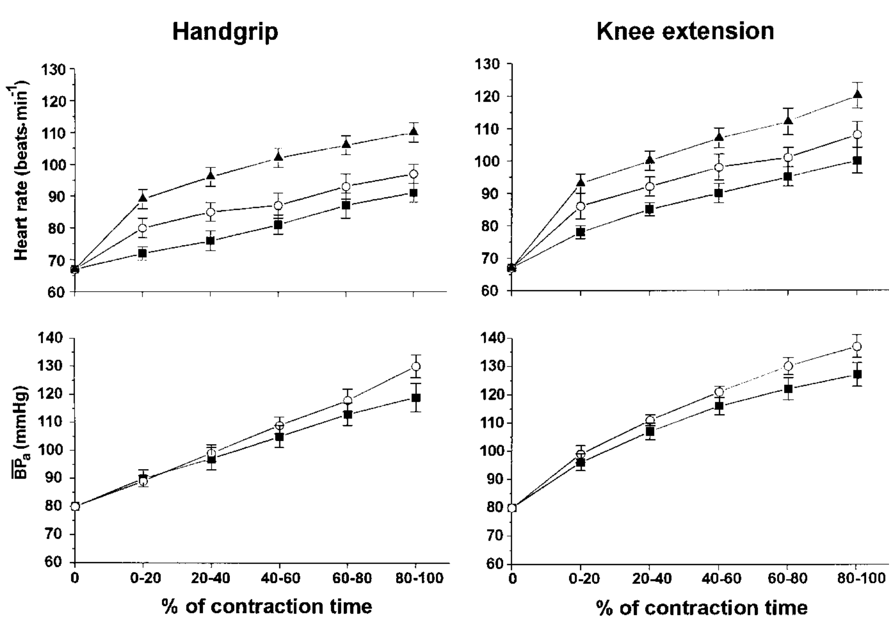

Fig. 1 Mean heart rate (SEM) and mean arterial pressure ($\overline{BP}_a$) during isometric exercise using handgrip and knee extension muscles at different levels of force. *Filled squares* 20% maximal voluntary contraction (MVC), *unfilled circles* 40% MVC, *filled triangles* 60% MVC

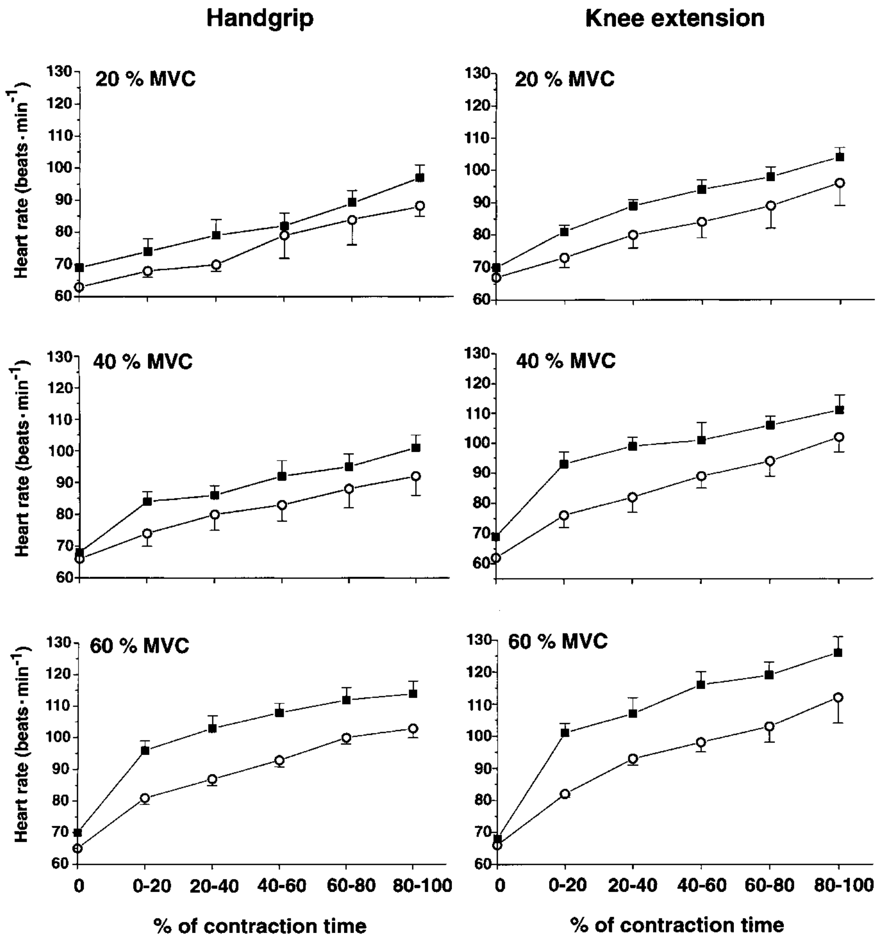

Fig. 2 Mean heart rate (SEM) during isometric exercise using handgrip and knee extension muscles at three different force levels in young (■) and older (○) subjects. *MVC* Maximal voluntary contraction

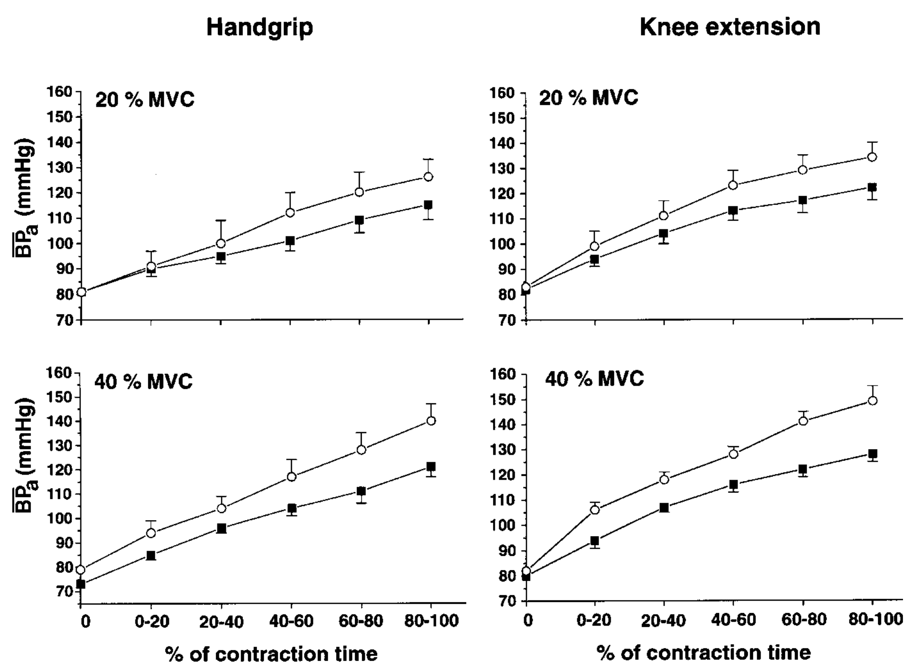

Fig. 3 Mean (SEM) arterial pressure ($\overline{BP}_a$) during isometric exercise using handgrip and knee extension muscles at two different force levels in young (■) and older (○) subjects. *MVC* Maximal voluntary contraction

increased with increasing levels of force and size of muscle group. The rise in heart rate has been suggested to be mediated primarily by the "central command", which is related to the number of motor units activated and/or to reflex effects from the active muscle mechanoreceptors (Victor et al. 1989). The sympathetic system may play some role in increasing the heart rate during isometric exercise (see Victor et al. 1989) but most of the rise in heart rate has been found to occur through an inhibition of cardiac vagal nerve activity (Freyschuss 1970; Martin et al. 1974).

Increased age was associated with an attenuated rise in heart rate and this became more apparent at the highest force level (60% MVC) and with a greater muscle mass at the 40% MVC level. The age-related attenuation of heart rate response during isometric exercise was in agreement with results by Petrofsky and Lind (1975), Ordway and Wekstein (1979), Taylor et al. (1991), but in contrast with McDermott et al. (1974) and Sagiv et al. (1988). It must be noted that the subjects of McDermott et al. (1974) were not of similar age (43–52 years) and that Sagiv et al. (1988) used "dead lift", as opposed to isolated muscle groups.

Recently, Taylor et al. (1995) have shown that the smaller tachycardia during isometric exercise in older humans is associated with a reduced baseline vagal tone and to a lesser vagal withdrawal. Our results would suggest that the greater inhibition of cardiac vagal activity with increasing force is coupled with a greater age-related attenuation in heart rate.

Age and blood pressure response to isometric exercise

The present view is (Rowell 1993) that during an isometric contraction the first immediate rise in $\overline{BP}_a$ is attributable to the central command and its withdrawal of vagal activity to the heart, which increases heart rate and cardiac output. After a delay, sympathetic activity begins to increase due to the accumulation of metabolites in the contracting muscles (so-called chemoreflex). Seals (1993) has shown that muscle sympathetic nerve activity and $\overline{BP}_a$ during sustained isometric contraction are independent of force above 20% MVC. Similarly, we also found that $\overline{BP}_a$ was slightly, but significantly lower at 20% MVC compared to 40% MVC.

A large discrepancy seems to exist in the findings on blood pressure and age. Ordway and Wekstein (1979) have shown that increased age was associated with a reduced blood pressure response. In their experiments, the contractions (at 30% MVC) were, however, only held for 3 min, and the possible differences in endurance times were not accounted for. Petrofsky and Lind (1975) have studied 100 industrial workers (men) ranging in age from 22 to 62 years. They found that the largest increase in systolic blood pressure during fatiguing isometric handgrip (40% MVC) was observed in the older men, whereas the rise in diastolic blood pressure was unrelated to age. In contrast to Petrofsky and Lind (1975), Sagiv et al. (1988) and Taylor et al. (1991) did not see any difference in blood pressure response between young and older men. The two latter groups of authors used 3-min contractions whereas the former study employed fatiguing contractions. Our results are in accordance with the results of Petrofsky and Lind (1975), as we observed a greater $\overline{BP}_a$ in the older compared to the younger men. Our data also indicated that the age-related difference in blood pressure response was unrelated to the muscle group examined.

Time dependency might be one explanation for the different blood pressure findings, because Taylor et al. (1991) compared two groups with similar endurance, whereas we and Petrofsky and Lind (1975) observed a tendency to a greater endurance in the older men. The greater increase in blood pressure in the older men might also have indicated age-related changes in baroreflex function in opposing the rise in blood pressure and/or a greater sympathetic activation from the chemosensitive fibres in the active muscles (Rowell 1993). Baroreflexes oppose increasing blood pressure by increasing vagal activity to the heart (Rowell 1993), an action which seems to be reduced in older persons (Taylor et al. 1995). In future studies, improved control for the baseline status of the autonomic nervous system might be crucial for explaining the differing results.

Age and isometric endurance time

As in the present study, two earlier investigations (Petrofsky and Lind 1975; Larsson and Karlsson 1978) have shown that isometric muscle endurance tends to increase with age. The first study (Petrofsky and Lind 1975) employed handgrip exercise, and the second (Larsson and Karlsson 1978) two-leg knee extension until fatigue. In contrast, Taylor et al. (1991) have found no difference in handgrip endurance times between young and older men. The tendency for longer endurance times with age might be due to an increasing number of type I fibres with age as has been observed in the human muscle (Larsson et al. 1978). One possibility might also be that greater $\overline{BP}_a$ response in older subjects compared to younger ones is coupled with a greater perfusion pressure in the contracting muscle, resulting in a longer endurance time.

In conclusion, the results indicated that increasing age is associated with altered heart rate and $\overline{BP}_a$ responses to isometric exercise, although it does not significantly affect isometric endurance. The age-related differences in heart rate and $\overline{BP}_a$ were more apparent at a higher force level.

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