Experimental Physiology

The effects of isometric exercise training on resting blood pressure and orthostatic tolerance in humans

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Isometric exercise training has been shown to reduce resting blood pressure, but the effect that this might have on orthostatic tolerance is poorly understood. Changes in orthostatic tolerance may also be dependent on whether the upper or lower limbs of the body are trained using isometric exercise. Twenty-seven subjects were allocated to either a training or control group. A training group first undertook 5 weeks of isometric exercise training of the legs, and after an 8 week intervening period, a second training group containing six subjects from the initial training group, undertook 5 weeks of isometric arm-training. The control group were asked to continue their normal daily activities throughout the 18 weeks of the study. In all subjects orthostatic tolerance, assessed using lower body negative pressure (LBNP), and resting blood pressure were measured before and after each of the 5 week training or control periods. Estimated lean leg volume was determined before and after leg-training. During all LBNP tests, heart rate and blood pressure were recorded each minute, and the time taken to reach the highest heart rate was derived (time to peak HR). Resting systolic blood pressure (mean ± S.D.), when measured during the last week of training, was significantly reduced after both leg (−10 ± 8.7 mmHg) and arm (−12.4 ± 9.3 mmHg; $P < 0.05$) isometric exercise training, compared to controls. This reduction disappeared when blood pressure was measured immediately before the LBNP tests, which followed training. Orthostatic tolerance only increased after leg-training (20.8 ± 16.4 LTI; $P < 0.05$) and was accompanied by an increased time to peak HR (119.8 ± 106.3 beats min^{-1}; $P < 0.05$) in this group. Blood pressure responses to LBNP did not change after arm-training, leg-training or in controls ($P > 0.05$). There was a small but significant increase in estimated lean leg volume after leg-training (0.1 ± 0.1 l; $P < 0.05$). These results suggest that lower resting blood pressure is probably not responsible for the increased orthostatic tolerance after isometric exercise training of the legs. Rather, it is possible that the training altered some other aspect of cardiovascular control during orthostatic stress that was apparent in the changes in heart rate. Leg-training was accompanied by increases in estimated lean leg volume. The effects of isometric training on orthostatic tolerance appear to be specific to limbs that are directly involved in LBNP testing. *Experimental Physiology* (2002) **87.4**, 507–515.

Cardiovascular responses and factors affecting tolerance to orthostatic stress have been studied for many years (e.g. Johnson *et al.* 1974; Luft *et al.* 1976; Abboud *et al.* 1979). However, a full understanding of factors that influence the cardiovascular responses leading to syncope remains elusive. The main components of the cardiovascular responses to orthostatic stress studied previously have been heart rate (Wahbha *et al.* 1989) and blood pressure responses (Stevens, 1966; Sather *et al.* 1986), and factors such as lower limb compliance (Luft *et al.* 1976; Stevens *et al.* 1992) and lower limb muscle tension (Coles *et al.* 1957; Smith *et al.* 1987).

During orthostasis, the primary challenge to the cardiovascular system is to maintain blood pressure and thus adequate cerebral perfusion (Rowell, 1993). Blood pressure responses to lower body negative pressure (LBNP) are often characterised by a reduction in systolic blood pressure (Stevens, 1966; Sather *et al.* 1986) which often reaches a value of less than 80 mmHg, and this has been established as a sign of pre-syncope. It has been suggested

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that a lower initial systolic blood pressure during orthostatic stress could result in early syncope (Stevens, 1966) and therefore, resting blood pressure could be an important factor in determining responses and tolerance to LBNP.

Short duration isometric exercise training has been shown to lower resting systolic blood pressure by between 4 and 14 mmHg (Kiveloff & Huber, 1971; Wiley *et al.* 1992; Ray & Carrasco, 2000; Peters *et al.* 2001). However, since these studies did not assess changes in orthostatic tolerance, the effects of such training-induced blood pressure changes on orthostatic tolerance remain unclear. The majority of studies that have investigated the effects of isometric training on resting blood pressure have used the relatively small muscle mass of the upper body (unilateral handgrip exercise; Wiley *et al.* 1992; Ray & Carrasco, 2000; Peters *et al.* 2001). There are no reports of the effects of isometric training involving larger muscle groups in the legs.

Finally, there remains a possibility that adaptations may occur in the exercise-trained muscle, such as increases in muscle mass or resting muscle tension. These adaptations are known to be associated with changes in LBNP tolerance (Luft *et al.* 1976; Smith *et al.* 1987; Convertino *et al.* 1988). However, this appears to be evident only when the muscle group being trained is the same as that which is directly exposed to LBNP (i.e. the legs). Therefore, it is necessary to compare LBNP tolerance and resting blood pressure in exercise-trained limbs that are exposed to LBNP with exercise-trained limbs that are not. No previous studies have assessed the effects of isometric exercise training of both the arms and the legs, upon resting blood pressure and orthostatic tolerance.

Therefore, the purpose of this study was to investigate the effects of isometric exercise training of the arms and the legs upon resting blood pressure and orthostatic tolerance (LBNP), with account being taken of possible changes in muscle volume.

METHODS

Subjects

Twenty-seven subjects were recruited to the study and allocated to either 'training' or 'control' group. Of the eleven subjects initially recruited to the exercise training programme, nine completed the first phase (training of the legs; T1) and eight completed the second phase (training of the arms; T2). Six subjects completed the entire training study (18 weeks – including the 5 weeks each of leg- and arm-training and intervening 8 week period). Two groups of eight subjects were allocated to the control groups (leg- or arm-training control period; C1 and C2 respectively). All subjects volunteered to participate in this study and were asked to complete a 'medical history' screening questionnaire. Each subject provided written informed consent prior to participation in the study and they were given a verbal and written description of all experimental procedures. The study was approved through the De Montfort University 'Procedures for Ethical Approval of Research'. The study was performed in accordance with the Declaration of Helsinki.

The nine subjects who completed the isometric exercise training of the legs (T1) comprised 7 males and 2 females (mean ± S.D.; age 21.1 ± 1.2 years, stature 178.4 ± 7.5 cm and mass 78.6 ± 10.2 kg). The eight subjects who completed the isometric exercise training of the arms (T2) comprised 6 males and 2 females (aged 21.0 ± 1.4 years, stature 177.1 ± 9.9 cm and mass 78.3 ± 10.3 kg). Resting blood pressures, recorded prior to the isometric exercise training period, for the four groups are given in Table 1. Resting blood pressure and orthostatic tolerance (LTI, see below) were not different from pre-training values (after the 5 week leg-training programme and subsequent 8 week intervening period) when subjects commenced the isometric arm-training phase.

Two groups of eight subjects who acted as controls (C1 and C2) comprised 11 males and 5 females (age 24.5 ± 6.1 years, stature 177.9 ± 9.9 cm and mass 75.8 ± 7.0 kg). They completed all aspects of the study except for the isometric exercise training.

Equipment

Lower body negative pressure (LBNP) tests. The LBNP chamber used in this study, the LBNP test procedure and methods of data collection have been described in detail elsewhere (Howden *et al.* 2001). Briefly, subjects placed their lower extremities inside a plywood chamber and were then sealed at the level of the iliac crests. Internal chamber pressure was reduced initially by 20 mmHg for 3 min. Subsequent reductions in internal chamber pressure of 10 mmHg were made every 3 min until the onset of established pre-syncopal signs and/or symptoms. The pre-syncopal signs and symptoms used in this study were: reductions in systolic blood pressure (SBP) of more than 25 mmHg or 15 mmHg for diastolic blood pressure (DBP) between successive 1 min readings; a single SBP reading of less than 80 mmHg; a precipitous fall in heart rate of more than 15 beats min^{-1}; subject light-headedness, subject nausea or subject request for the test to be stopped.

Following an initial orientation LBNP exposure to –40 mmHg, all subjects completed an LBNP test before ($LBNP_1$), and after ($LBNP_2$) the exercise training period. Subjects reported to the laboratory for LBNP testing after abstaining from exercise and consumption of alcohol for 24 h and 2 h postprandial. Subjects were required to maintain their usual diet and level of physical activity during the course of the study. The LBNP tolerance index (LTI; Lightfoot & Tsintgaris, 1995) was used to quantify orthostatic tolerance. LTI is the cumulative sum of the products of stage duration and the reduction in negative pressure at each stage (when all stages of LBNP are of equal duration and negative pressure drop; ΔmmHg min^{-1}). This technique has shown test–retest variability of (mean ± S.D.) 1.05 ± 9.34 LTI (Howden *et al.* 2001).

Blood pressure (BP), electrocardiography (ECG) and electromyography (EMG). All measures of BP were taken with an automated blood pressure recording device (TM-2541R, AND Instruments, Oxford, UK) using the oscillometric technique and a pneumatic cuff placed around subject's upper left arm. This technique measured the changes in pressure waves from the brachial artery exerted on the pneumatic cuff. The first recorded wave was taken as systolic blood pressure (SBP). Diastolic blood pressure (DBP) was defined as the point at which the pressure waves became constant. These devices have been shown to agree with standard sphygmomanometry (Clark *et al.* 1991; Imai *et al.* 1992; Palatini *et al.* 1998). BP was measured and recorded during the last 20 s of each minute during all LBNP tests. Reported values for resting blood pressure were the mean of at least five measures of BP, recorded in all subjects following each week of the 5 week isometric exercise training programmes. These measures of BP were taken before any isometric exercise was performed on the day of that measurement.

During all LBNP tests surface ECG and EMG recordings were made from a standard three-lead configuration and the right vastus medialis muscle, respectively, using an analog-to-digital converter (PowerLab, ADInstruments, Hasting, UK). Heart rate was calculated continuously by expressing each recorded R-R interval as beats per minute, automatically, by data acquisition software (Chart v 4.0.4; ADInstruments). The EMG data were recorded for two purposes. Firstly, EMG signals were used during LBNP to ensure that lower limb muscle tension did not increase, thus aiding venous return. Secondly, an integrated signal was calculated from the EMG data by data acquisition software (Chart v 4.0.4; AD Instruments) and used as an indicant of resting muscle tension.

Estimated lean leg volume (LLV). Before and after isometric exercise training of the legs, lean limb volume was estimated using the anthropometric method of Jones & Pearson (1969), which was shown to have a high level of agreement with limb volume measures using water displacement. Briefly, limb circumference was determined at seven sites, partitioning the leg into six truncated cones. Measures of skin-fold thickness from four leg sites were also recorded to enable calculation of fat-free limb volume. These sites were the anterior and posterior thigh, and lateral and medial calf.

Isometric exercise training. All isometric exercise training was performed using an isokinetic dynamometer (Kin-Com, Chattanooga Group Inc., TN, USA), with subjects suitably restrained. For both the arm and leg isometric exercise conditions, the forearm grip attachment (part no. 70187) was modified by replacing the rubber grip with a 480 × 30 mm aluminium bar which had been drilled at one end to allow it to fit over the cylindrical section of the forearm grip attachment. This bar was secured to the forearm grip attachment with two hexagonal drive screws. The length of this bar enabled subjects to perform bilateral isometric exercise.

Isometric exercise of the legs was performed by contracting the knee extensors at a knee joint angle of 120 deg (a knee joint angle of 90 deg was avoided since bilateral maximum force of the legs may have exceeded the 2000 N capacity of the dynamometer). Isometric exercise of the arms was performed by contracting the elbow flexors at an elbow joint angle of 90 deg. At the start of each session subjects were required to perform at least two (a maximum of five) maximum voluntary contractions (MVC), separated by 1 min of rest, that were not different by more than 20 %. The maximum force produced from these two MVCs was used to calculate the isometric exercise intensity for that session.

Table 1. Resting systolic blood pressure (SBP) and diastolic blood pressure (DBP), recording immediately prior to the isometric exercise training period

Group	SBP (mmHg)	DBP (mmHg)
T1	121 ± 9.6	70 ± 7.4
T2	114 ± 11.3	65 ± 5.6
C1 and C2	118 ± 8.6	71 ± 6.4

Values are means ± S.D.

The isometric exercise training protocol used in this study was a modified version of the protocol reported by Wiley *et al.* (1992). In each exercise session, four 2 min bouts of isometric exercise were performed by subjects at either 30 % (arm-training) or 20 % (leg-training) of MVC. Each 2 min bout of exercise was separated by 3 min of seated rest. Sessions were repeated three times per week for 5 weeks. Subjects failing to attend more than two consecutive sessions or missing more than three sessions were excluded from the study. This condition resulted in two subjects being excluded from the arm-training and control groups. Two subjects from the leg-training group were also excluded due to illness.

Five weeks of isometric exercise training resulted in all subjects showing an improvement in MVC. Significant increases in the mean MVC were apparent in the final week of exercise training, compared with the first week (mean ± S.D. 603.4 ± 219.9 *vs.* 1024.8 ± 127.8 N; T1 (legs) and 257.4 ± 56.4 *vs.* 345.1 ± 96.9 N; T2 (arms); $P < 0.05$, Student' s paired t test; Fig. 1).

Overall study design

A graphical representation of the overall study design is given in Fig. 2. Subjects were allocated to either 'training' or 'control' groups for the duration of the study (18 weeks in total). The 'training' group first attended for isometric exercise training of the legs on three occasions per week for 5 weeks. Before commencing this training programme, and within 10 days of its completion, all subjects were assessed for resting blood pressure and orthostatic tolerance. After completion of the 5 week leg-

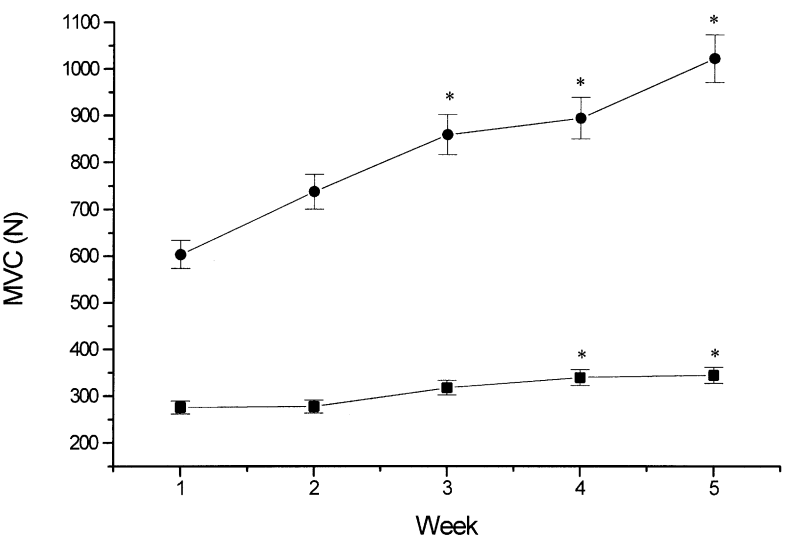

Figure 1

Mean ± S.D. maximum voluntary contraction (MVC) during 5 weeks of isometric training of the legs (●) and arms (■). * Significant increase when compared to week 1.

Table 2. Tolerated duration and magnitude of negative pressure at pre-syncope

	Group	$LBNP_1$	$LBNP_2$
Duration of negative pressure	T1	20.4 ± 4.3	22.1 ± 4.1
	C1	19.5 ± 3.5	18.7 ± 3.0
	T2	21.5 ± 6.9	18.9 ± 3.3
	C2	18.9 ± 1.7	19.1 ± 0.9
Magnitude of negative pressure	T1	−82 ± 13	−87 ± 13
	C1	−78 ± 7	−78 ± 10
	T2	−81 ± 15	−78 ± 13
	C2	−75 ± 5	−76 ± 5

Values are group means ± S.D.

training programme all subjects returned to their 'normal daily activities' for 8 weeks. After this intervening period subjects attended for isometric exercise training of the arms. Again, they attended on three occasions per week for 5 weeks. Again, they were assessed for orthostatic tolerance and resting blood pressure at the commencement and at the completion of this training programme. The control group was asked to continue with their 'normal daily activities' for the duration of the study. They were asked to attend the laboratory for LBNP tests and resting blood pressure measurement on similar occasions to the 'training' group subjects.

Statistical analysis

Comparisons between group means for SBP and DBP before exercise training, during exercise training and immediately before the second LBNP test and groups were calculated using a one-way repeated measures analysis of variance (ANOVA). P values less than 0.05 were considered to show a statistically significant difference between given variable means. From data that produced statistically significant results, the Student-Newman-Keuls test was used to identify the significance of specific differences. Differences between group means in the magnitude of blood pressure reduction (leg condition *vs.*arm condition), LTI, resting heart rate, responses to LBNP and the resting blood pressures, and LTIs prior to each exercise training period of the subjects who completed both conditions, were assessed using a 2 × 4 ANOVA. P values of less than 0.05 were considered to show a significant difference between the means and the location of these differences were assessed using Student's t tests following an adjustment to the α level using Bonferroni. Significant relationships between changes in LTI and differences in the haemodynamic responses to LBNP were reported and assessed using Pearson's correlation coefficient (r).

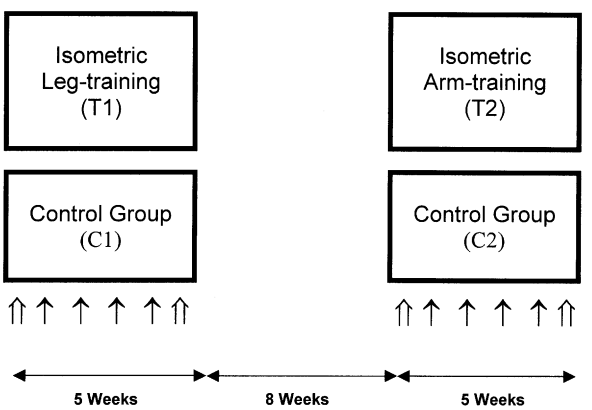

Figure 2

Schematic representation of the overall study design for assessment of the effects of isometric exercise training upon resting blood pressure and orthostatic tolerance (wide arrows indicates LBNP test and resting blood pressure measurement; thin arrows indicates resting blood pressure measurement).

RESULTS

Isometric exercise training and resting blood pressure

Resting SBP was reduced in both the leg (T1) and arm conditions (T2) following isometric exercise training (120.7 ± 9.6 *vs.* 110.7 ± 8.4 mmHg for T1; 114.3 ± 11.3 *vs.* 101.9 ± 7.7 mmHg for T2; $P < 0.05$, ANOVA; Fig. 3). The magnitude of SBP change was not different after leg-training compared to arm-training (10.0 ± 8.7 *vs.* 12.4 ± 9.3 mmHg; $P > 0.05$, ANOVA). Resting SBP was not significantly different immediately before the $LBNP_2$ test when compared to that before isometric exercise training in both T1 and T2 (120.7 ± 9.6 *vs.* 115.6 ± 12.1 mmHg and 114.3 ± 11.3 *vs.* 117.0 ± 12.3 mmHg, respectively; $P > 0.05$ ANOVA; Fig. 3).

Resting SBP in the control groups (C1 and C2) did not change during either of the 5 week periods equivalent to the exercise training programmes, and was not different immediately prior to the $LBNP_2$ test (118.0 ± 8.6 *vs.* 119.6 ± 6.1 *vs.* 118.3 ± 7.8 mmHg for C1; 116.9 ± 9.6 *vs.* 115.2 ± 12.2 *vs.* 114.0 ± 10.1 mmHg for C2; $P > 0.05$, ANOVA). The resting SBP of the six subjects who completed both exercise training conditions was not significantly different when comparing SBP prior to the leg exercise training condition with that prior to the arm exercise training condition (119.5 ± 2.8 *vs.* 123.3 ± 7.4 mmHg; $P > 0.05$, ANOVA). Resting DBP did not change significantly during the isometric exercise training period in T1, T2, C1 or C2, compared to pre-training DBP (70.3 ± 7.4 *vs.* 66.7 ± 11.2 mmHg, 64.8 ± 5.6 *vs.* 58.8 ± 12.3 mmHg, 70.8 ± 6.4 *vs.* 72.8 ± 9.4 mmHg and 71.2 ± 8.3 *vs.* 72.2 ± 7.3 mmHg, respectively; $P > 0.05$, ANOVA; Fig. 3).

Isometric exercise training and orthostatic tolerance (LBNP tolerance index; LTI)

There was a significant increase in LTI after isometric exercise training of the legs (T1) when comparing $LBNP_1$ with $LBNP_2$ (226.2 ± 40.9 *vs.* 247.0 ± 39.5 LTI; $P < 0.05$, ANOVA). There was not a significant difference in LTI between $LBNP_1$ and $LBNP_2$ after training of the arms (T2) and control (C1 and C2) groups (231.9 ± 55.6 *vs.* 212.8 ± 34.9, 217.5 ± 37.3 *vs.* 211.1 ± 30.9 and 218.4 ± 35.4 *vs.* 216.6 ± 32.5 LTI, respectively; $P > 0.05$, ANOVA; Fig. 4). Also the pre-training orthostatic tolerance (LTI) was not different when comparing the subjects who completed both leg- and arm-training (234.8 ± 63.0 *vs.* 235.8 ± 33.6 LTI; $P > 0.05$, ANOVA). Further, for the purposes of comparison with previous studies that have used LBNP, the duration of negative pressure and maximum magnitude of negative pressure tolerated are given in Table 2.

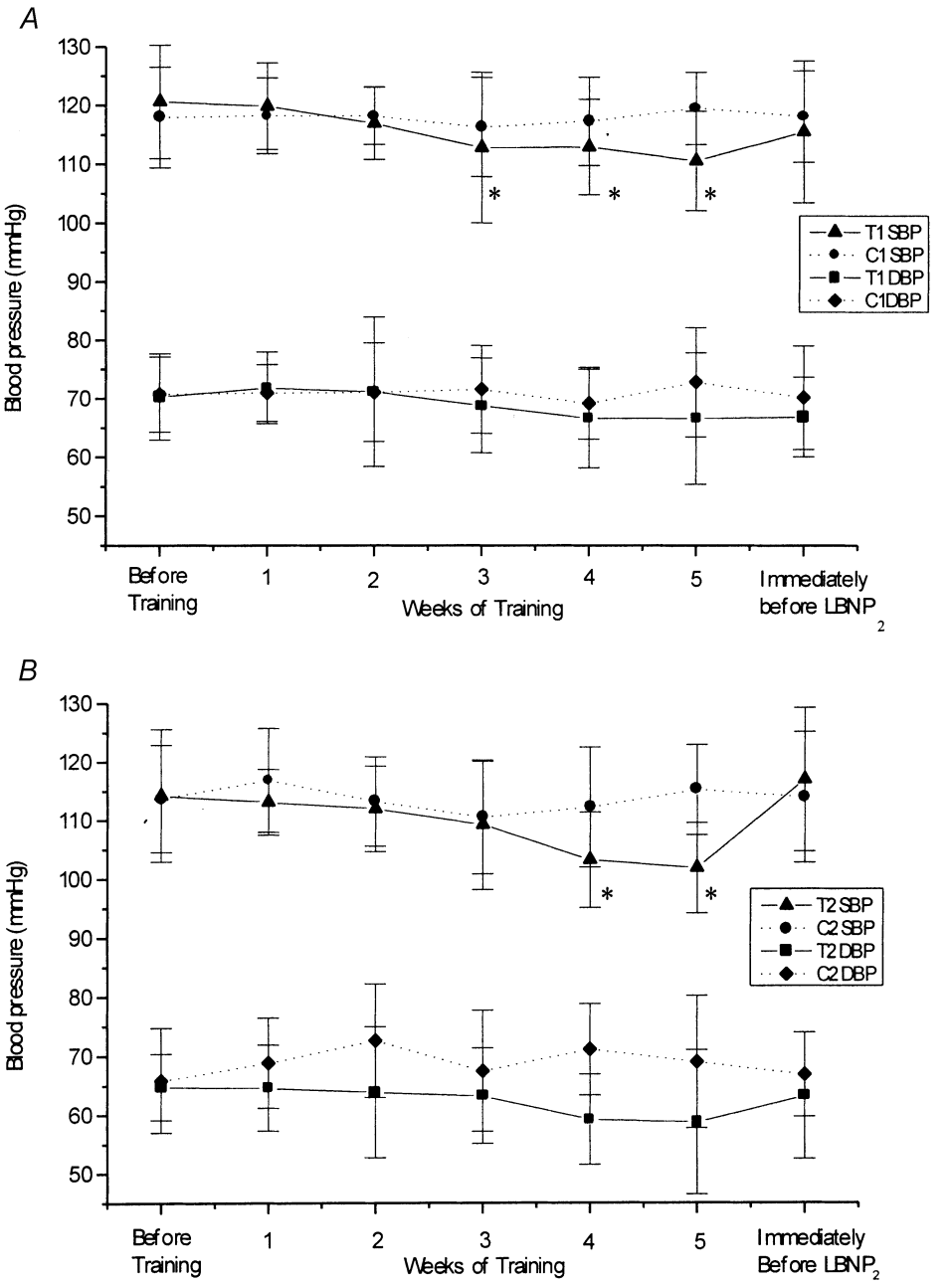

Figure 3

Mean ± S.D. resting systolic (SBP) and diastolic (DBP) blood pressure, before training, during 5 weeks of training and immediately before the final LBNP test for leg-training (*A*) and arm-training (*B*). * Significant reduction when compared to 'before training'.

Isometric exercise training and responses to orthostatic stress

There were no differences in the change (Δ) in HR, SBP or DBP during $LBNP_1$ or $LBNP_2$ in groups T1, T2, C1 or C2 (Table 3; $P > 0.05$ Student' s paired t test). However, the time to peak HR was significantly increased during the LBNP test, which followed leg-training (Table 3; $P < 0.05$ Student's paired t test). The time to peak HR was not significantly different between LBNP tests in the T2, C1 and C2 groups (Table 3; $P > 0.05$, Student's paired t test). The differences in time to peak HR between $LBNP_1$ and $LBNP_2$ were correlated with the difference in LTI between the two LBNP tests and produced a significant relationship ($r = 0.84$; $P < 0.05$ Pearson's correlation coefficient; Fig. 5). Figure 5 includes the data from both the C and T groups.

The slope of the integrated EMG signal was calculated during the final minute of the control period immediately before LBNP. There were no significant changes in the integrated EMG slope in $LBNP_2$ compared to $LBNP_1$ (Table 3; $P > 0.05$, Student's paired t test).

Isometric exercise training and estimated lean leg volume

There was a small, but significant increase in estimated lean leg volume following isometric exercise training of the legs (from 7.3 ± 1.4 to 7.4 ± 1.4 l; $P < 0.05$, Student's paired t test). This increase in estimated lean leg volume was not apparent in the control (C1) group (from 7.5 ± 0.5 to 7.5 ± 0.6 l; $P > 0.05$, Student's paired t test).

DISCUSSION

The aim of this study was to assess the effect of isometric exercise training upon resting blood pressure and orthostatic tolerance. In both the leg and arm isometric exercise training conditions, there was a significant reduction in resting SBP ($P < 0.05$) but not in DBP ($P > 0.05$). Tolerance to orthostatic stress increased following leg isometric exercise training ($P < 0.05$), but was not different after arm exercise training ($P > 0.05$). There were no differences in the magnitude of changes during, or immediately before, LBNP in HR, SBP or DBP before compared to after exercise training in either group ($P > 0.05$).

Isometric exercise training and resting blood pressure

The reductions in SBP in both the leg and arm isometric exercise training conditions were similar to those reported previously (Wiley *et al.* 1992). However, the mechanisms associated with reductions in SBP following isometric exercise training, and the dynamics of that change after training are poorly researched. Wiley *et al.* (1992) suggested that the observed reductions in BP following isometric exercise training might be associated with baroreceptor resetting after repeated exposure to the

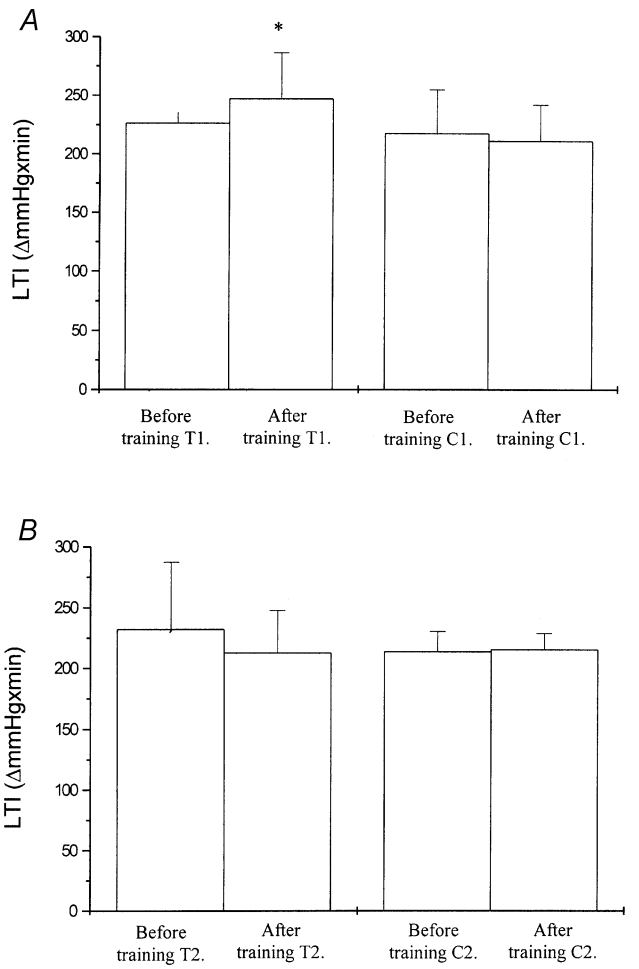

Figure 4

Group mean ± S.D. LBNP tolerance index (LTI) before and after training of the legs (*A*; T1 and C1) and arms (*B*; T2 and C2). * Significant increase when compared to 'before training'.

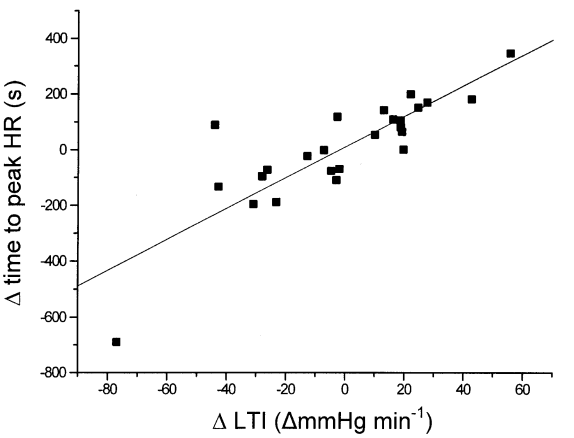

Figure 5

Relationship between the difference in time to peak HR during LBNP, between $LBNP_1$ and $LBNP_2$, and changes in LTI from $LBNP_1$ to $LBNP_2$ ($r = 0.84$, $P < 0.05$).

Table 3. HR and BP responses during LBNP

	Group	$LBNP_1$	$LBNP_2$
Time to peak HR (s)	T1	1462.4 ± 257.2	1582.2 ± 257.8*
	C1	1390.8 ± 353.1	1390.6 ± 196.4
	T2	1485.6 ± 388.3	1383.9 ± 199.2
	C2	1417.4 ± 131.5	1385.9 ± 41.4
ΔSBP during LBNP (mmHg)	T1	−20 ± 18	−19 ± 15
	C1	−20 ± 12	−16 ± 9
	T2	−14 ± 12	−15 ± 13
	C2	−19 ± 14	−16 ± 8
ΔDBP during LBNP (mmHg)	T1	−5.6 ± 8.9	−11.0 ± 15.6
	C1	−3.0 ± 15.4	−6.0 ± 14.0
	T2	−12.6 ± 9.9	−6.8 ± 7.3
	C2	−8 ± 11	−6 ± 11
ΔHR during LBNP (beats min^{-1})	T1	64.4 ± 18.8	70.9 ± 50.9
	C1	48.1 ± 16.2	52.5 ± 15.6
	T2	57.5 ± 16.1	57.4 ± 13.2
	C2	50.6 ± 15.4	47.4 ± 13.4
Integrated EMG slope ($mV\ s^{-1}\ s^{-1}$)	T1	0.01 ± 0.02	0.01 ± 0.01
	C1	0.01 ± 0.02	0.01 ± 0.02
	T2	—	—
	C2	—	—

Values are group means ± S.D. Δ represents baseline value minus greatest change during LBNP, excluding blood pressure and HR at pre-syncope. * Significant difference comparing $LBNP_1$ and $LBNP_2$ ($P < 0.05$).

established pressor response to isometric contractions (Blomqvist, 1985; Hanson & Nagle, 1987; Longhurst & Stebbins, 1992). However, a resetting of baroreceptors to a lower operating point in response to the hypertensive stimulus of isometric exercise would be unlikely. In hypertension, baroreceptors appear to operate at a point that is proportional to the blood pressure stimulus and are therefore reset to a higher pressure (Eckberg & Sleight, 1992).

An important consideration when interpreting the results in the present study was the transient nature of the BP reductions (Fig. 3). Wiley *et al.* (1992) provided evidence to suggest that SBP could remain significantly reduced for up to 14 days after completion of isometric exercise training. In our study all post-training LBNP tests were conducted within 10 days of completion of the exercise training and were immediately preceded by 'resting' blood pressure measurement. However, by this time the significant reductions in resting blood pressure (for both the leg- and arm-trained condition) had disappeared. Therefore, it is possible that these reductions in blood pressure were not sustained during the 10 days between completion of training and the post-training LBNP test. Alternatively, it is possible that this recording of blood pressure did not reflect resting SBP since the measurement was made immediately before LBNP. In particular, subjects might have been anticipating the impending discomfort at this point. Therefore, the results of the present study must be viewed with caution. Future comprehensive assessment of the effect of reduced blood pressure on orthostatic tolerance would require the demonstration of reduced blood pressure immediately before the LBNP test.

Isometric exercise training and orthostatic tolerance

The differences in the change in LBNP tolerance between T1 and T2 suggest that the effect of reduced SBP on orthostatic tolerance was not consistent between the arm and leg isometric exercise training modes. Thus, since the reductions in SBP were accompanied by concomitant changes in LBNP tolerance following leg-training only, there remains a possibility that this observation was due to factors specific to isometric exercise training of the legs. Following isometric exercise training, changes in the volume of the musculature of the exercise-trained limbs (LLV) may have influenced the cardiovascular responses to LBNP, if those limbs were directly exposed to the negative pressure (i.e. the legs). Indeed, a previous study has shown that lower limb venous compliance is negatively correlated with lower limb muscle cross-sectional area (Convertino *et al.* 1988). There is some evidence that such increases in muscle cross-sectional area may decrease venous transmural pressure, thus attenuating venous distension during increases in hydrostatic pressure (e.g. LBNP; Convertino *et al.* 1988).

A negative correlation between lower limb compliance and LBNP tolerance has also been demonstrated (Luft *et al.*

1976). Reductions in lower leg compliance would have attenuated the established reduction in venous return (Al-Shamma & Hainsworth, 1985; Hainsworth & Al-Shamma, 1988) and may explain the increased time to peak heart rate during LBNP in our subjects after leg-training. The difference in time to peak HR was significantly correlated with the difference in LTI in this group ($r = 0.86$; $P < 0.05$). This relationship was also evident when these data from all subjects were included in the correlation analysis ($r = 0.84$; $P < 0.05$; Fig. 5). However, support for such an explanation of our data would additionally require measures of limb compliance in future studies. Indeed, the indirect estimates of lean leg volume that we used are limited in their sensitivity and accuracy (Jones & Pearson, 1969), especially when used to detect such small changes in limb volume as noted in our study. Conversely, it should also be noted that the measures of leg volume in the C1 group were almost identical before and after the 5 week training period.

The small increase in estimated lean leg volume might reflect possible changes in lower limb muscle tension following isometric exercise training of the legs. This would be another partial explanation of the increases in LTI following leg-training. Smith *et al.* (1987) demonstrated an attenuated reduction in stroke volume and cardiac output during LBNP with increased lower limb muscle tension. This attenuation of the reduction in cardiac output during LBNP was attributed to the compression of the peripheral vascular system, thus maintaining venous return. However, in the present study, calculation of the slope of the integrated EMG signal during the final minute of the control period immediately before LBNP revealed no difference after isometric exercise training, thus indicating no change in resting muscle tension.

Reduced resting blood pressure and orthostatic tolerance

The findings of the present study suggest that there is little evidence to support a link between reduced resting blood pressure and reduced orthostatic tolerance. The limitations of the possible transient changes in blood pressure in our study and the lack of direct measures of leg muscle tension and lower leg compliance make discussion of this link rather speculative. Nevertheless, the increase in LBNP tolerance in the leg-training group could be related to the reduction in resting SBP. However, the changes in the lower limb following leg-training could have masked the effect of reduced resting blood pressure on LBNP tolerance. The absence of similar increases in LBNP tolerance after arm-training suggests that the increase in tolerance to orthostatic stress observed in T1 was associated with factors peculiar to the leg-training . Such contrasting results for arm-training may have been due to the direct involvement of the legs in the LBNP testing. Therefore the LBNP test may not be specific enough to detect changes after arm-training.

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