Cardiovascular responses to orthostatic challenge in the endurance-trained services athletes

Major KK Tripathi
Military Hospital, Deolali 422 401, India

Dr PK Banerjee
Department of Physiology, IAM, IAF, Bangalore 560 017, India

L/Nk Sanjay Kumar
665 Recce & Obsn Sqn, c/o 56 APO, India

Twenty-one endurance-trained services athletes were evaluated for physical fitness on a modified Harvard step test protocol vis-à-vis their cardiovascular responses to an orthostatic challenge contemplated in the form of a 70° head-up tilt (HUT). Heart rate (HR), systolic blood pressure (SBP), diastolic blood pressure (DBP), pulse pressure (PP) and mean arterial pressure (MAP) were recorded in supine posture till stabilized, following which a 70° HUT was given and the parameters recorded every 2 min, for 20 min. Endurance status, determined as physical fitness index (PFI), ranged from 111 to 171 with a mean value of 130 + 18, confirming to a very good status of physical fitness. Mean resting supine values of HR, SBP, DBP, PP and MAP were 62 ± 8 ppm, 125 + 11 mmHg, 84 ± 8 mmHg, 41 ± 8 mmHg, respectively. The maximum changes, from the resting supine, during the 20 min HUT period were in the form of an increase in HR of 25 ± 5 bpm, in DBP of 24 + 5 mmHg and in MAP of 17 ± 6 mmHg and a fall of 4 ± 13 mmHg and 26 ± 7 mmHg in SBP and PP, respectively. The changes, except for those in SBP, were statistically significant. Three subjects (14.29%) suffered from vasodepressor syncopal reactions during the tilt between 12 and 14 min. Compared to the results of tilt table studies conducted on untrained population, the data when rearranged into two groups, viz. the fainters and non-fainters, revealed that the former had a significantly greater increase in DBP and MAP and a significantly greater fall in SBP at the 2nd min on HUT even though PFI scores and values of HR and PP (both resting supine and at 2 min on HUT) were not significantly different in the two groups. The results indicates that endurance status does not have any simple and straightforward relation with the orthostatic cardiovascular responses. It does not appear to enhance the susceptibility of an individual to suffer from a vasodepressor syncope. However, the results suggest that the syncopal reactions which occur suddenly and dramatically in susceptible individuals can possibly be predicted by the observation of changes in diastolic blood pressure and mean arterial pressure.

Keywords: Head-up tilt; Endurance training; Physiological response.

Specificity of endurance status in relation to its influence on an individual's cardiovascular responses to orthostatic challenge, whatever form, is a controversial issue. Even in the absence of a definite correlation between physical fitness and physiological response, a poor tolerance to orthostatic challenge has often been affirmed [1–3] and denied [4–6] in the western literature in those engaged in varying degree of endurance training.

Cardiovascular responses to orthostatic challenge, given in the form of a 70° head-up tilt (HUT), have been well standardized in untrained, but not necessarily sedentary, Indian population [7]. However, the corresponding data on those engaged in moderate to high intensity of endurance training are largely lacking.

The present study was conducted with an aim to evaluate physical fitness *vis-à-vis* cardiovascular responses of individuals to 70° HUT in a group of endurance-trained services athletes.

Material and methods

Thirty-six healthy male volunteers ranging from 19 to 38 years in age served as subjects for this study. The subject population (age: 27 ± 5 yr, ht: 170 ± 6 cm, wt: 70 ± 13 kg, mean ± SD) consisted of long-distance runners, swimmers, hockey players, PT instructors and wrestlers from Indian Army, Navy and Air Force. Many of them were distinguished sportsmen and had represented the Services or/and National teams. The subject population was divisible, on the basis of history, into two groups: (1) endurance-trained group (comprising long-distance runners, swimmers, hockey players and PT instructors), and (2) group of individuals with a mixed-training status (comprising wrestlers). The training schedule in both the groups consisted predominantly of aerobic exercises. However, the subjects in the latter group also underwent a substantial amount of strength training. With the exception of age, other physical attributes in the two groups were not significantly different.

The study, comprising of two sessions, was carried out in a comfortable environment in the MI Room at 665 Recce & Obsn Squadron between 1500 and 1900 h, 3–4 h after the subjects had their lunch.

Tilt table test. Resting supine values of heart rate (HR) and blood pressure (BP) were recorded after initial stabilization of the subjects on a standard tilt table. He was then rapidly given a 70° head up tilt (HUT). HR and BP were recorded every 2 min for a period of 20 min or less when there were any presyncopal or syncopal features. Thereafter, the subject was tilted back to horizontal and parameters were recorded at similar intervals for 4 min during recovery.

Step test. After completion of HUT, subjects were evaluated on a modified Harvard Step Test protocol for the determination of physical fitness index (PFI) [8, 9]. During the test, the subjects performed a stepping exercise

Table I. Cardiovascular variables: resting supine and HUT pooled data ($n = 33$)†

Variable	Pretilt resting supine (RS) value	HUT					
		Average			Extreme		
		Value attained	Difference from RS	t	Value attained	Difference from RS	t
HR (bpm)	62 ±9	81 ±9	19 ±5	21.03*	86 ±9	25 ±6	22.52*
SBP (mmHg)	126 ±10	127 ±11	1 ±7	0.94	120 ±13	−5 ±10	3.72*
DBP (mmHg)	88 ±9	102 ±9	14 ±6	14.69*	108 ±10	21 ±7	16.56*
PP (mmHg)	38 ±8	26 ±7	−11 ±10	8.86*	19 ±8	−20 ±10	11.17*
MAP (mmHg)	100 ±8	110 ±9	10 ±5	11.12*	116 ±10	16 ±6	14.13*

†Fainters excluded.
*$p < 0.01$.

on a 40 cm stool with a stepping frequency of 20/min for 300 s or till exhaustion. PFI was calculated as

$$PFI = \frac{\text{duration of exercise in seconds} \times 100}{2\,(\text{sum of } 1'\ 1'30'',\ 2'\ 2'30'' \ \&\ 3'\ 3'30''\ RP)}$$

where RP denotes recovery pulse.

The PFI score thus obtained was classified [8] as follows:

<100	– poor,
100 to 160	– average,
>160	good.

Statistical analysis. Correlation coefficients (r) were calculated to ascertain any possible relationship between PFI and various cardiovascular parameters (both resting supine as well as following HUT). To ascertain the significance of difference between two means, Student's t test was performed. A proportion

Table 2. Comparison between endurance-trained and mixed-training groups

Variable		Endurance-trained group (n = 9)	Group of individuals with mixed training status (n = 24)	t
Physical attributes				
Age (yr)		31 ± 4	26 ± 5	2.26*
Ht (cm)		170 ± 5	170 ± 7	0.20
Wt (kg)		65 ± 6	72 ± 15	1.34
BSA (sq m)		1.76 ± 0.11	1.82 ± 0.20	0.87
PFI		124.6 ± 13.6	130.9 ± 22.6	0.78
Resting supine and orthostatic cardiovascular data				
HR (bpm)	Pretilt	64 ± 7	61 ± 10	1.07
	Average HUT	83 ± 7	80 ± 9	0.85
	Max. HUT	88 ± 8	86 ± 9	0.53
	Avg. change	18 ± 4	19 ± 6	0.44
	Max. change	23 ± 5	25 ± 7	0.76
SBP (mmHg)	Pretilt	122 ± 13	128 ± 8	1.69
	Average HUT	121 ± 14	130 ± 9	1.93
	Min. HUT	114 ± 16	123 ± 11	1.95
	Avg. change	0 ± 5	2 ± 8	0.62
	Max. change	−8 ± 8	−4 ± 10	1.13
DBP (mmHg)	Pretilt	81 ± 7	90 ± 8	3.10**
	Average HUT	96 ± 9	104 ± 8	2.26*
	Max. HUT	103 ± 10	110 ± 10	1.91
	Avg. change	16 ± 3	14 ± 6	1.01
	Max. change	22 ± 4	20 ± 8	0.80
PP (mmHg)	Pretilt	41 ± 11	38 ± 7	1.05
	Average HUT	25 ± 10	26 ± 6	0.21
	Min. HUT	16 ± 10	20 ± 7	1.28
	Avg. change	−16 ± 6	−10 ± 10	1.45
	Max. change	−25 ± 7	−17 ± 11	1.94
MAP (mmHg)	Pretilt	94 ± 8	103 ± 7	2.90*
	Average HUT	106 ± 10	112 ± 8	1.91
	Max. HUT	110 ± 10	118 ± 9	2.18*
	Avg. change	10 ± 2	10 ± 6	0.20*
	Max. change	16 ± 3	16 ± 7	0.11

*p < 0.05, **p < 0.01.

Table 3. Correlation of PFI with orthostatic data ($n = 33$)[1]

	HR	SBP	DBP	PP	MAP
Resting supine values	−0.56*	−0.28	−0.25	0.06	0.39
Average values on HUT	−0.63*	−0.23	−0.24	0.05	0.24
Average change on HUT	−0.09	0.01	0.01	0.06	0.04
Extreme values on HUT	−0.51*	−0.24	−0.19	0.13	0.22
Maximum change on HUT	0.08	−0.05	0.04	−0.07	0.04
Variability (SD) during HT	0.20	0.10	0.07	0.10	0.09

[1]Fainters excluded. *$p < 0.01$.

Table 4. Comparison of orthostatic data between the group with PFI score classified as 'good' and the trained group as a whole

Variable		Group with PFI score classified as 'good' ($n = 4$)	Trained group as a whole ($n = 33$)	t
Physical attributes				
Age (yr)		23 ± 3	27 ± 5	1.58
Ht (cm)		162 ± 7	170 ± 6	2.16*
Wt (kg)		58 ± 12	70 ± 13	1.73
BSA (sq m)		1.61 ± 0.19	1.80 ± 0.18	1.97
PFI		166.2 ± 4.1	129.3 ± 20.5	3.55**
Resting supine and orthostatic cardiovascular data				
HR (bpm)	Pretilt	51 ± 6	62 ± 9	2.23*
	Average HUT	70 ± 5	81 ± 9	2.51*
	Max. HUT	79 ± 11	86 ± 9	1.55
	Avg. change	18 ± 4	18 ± 5	0.31
	Max. change	28 ± 8	25 ± 6	0.85
SBP (mmHg)	Pretilt	127 ± 10	126 ± 10	0.18
	Average HUT	128 ± 10	127 ± 11	0.12
	Min. HUT	122 ± 11	120 ± 13	0.15
	Avg. change	1 ± 6	1 ± 7	0.05
	Max. change	−6 ± 6	−5 ± 10	0.17
DBP (mmHg)	Pretilt	88 ± 5	88 ± 9	0.02
	Average HUT	101 ± 2	102 ± 9	0.09
	Max. HUT	110 ± 2	108 ± 10	0.32
	Avg. change	14 ± 5	14 ± 6	0.21
	Max. change	23 ± 4	21 ± 7	0.46
PP (mmHg)	Pretilt	40 ± 8	38 ± 8	0.24
	Average HUT	27 ± 8	26 ± 7	0.32
	Min. HUT	20 ± 7	19 ± 8	0.11
	Avg. change	−13 ± 7	−11 ± 10	0.24
	Max. change	−20 ± 2	−19 ± 10	0.14
MAP (mmHg)	Pretilt	101 ± 6	100 ± 8	0.06
	Average HUT	110 ± 5	110 ± 9	0.04
	Max. HUT	117 ± 3	116 ± 10	0.12
	Avg. change	10 ± 5	10 ± 5	0.03
	Max. change	16 ± 5	16 ± 6	0.13

*$p < 0.05$, **$p < 0.01$.

test was used for determining the significance of difference between two proportions.

Results

In the subjects of the present study, PFI ranged from 92.6 to 170.4 with a mean value of 129.3 ± 20.5, a score of '(high) average'. Four subjects attained substantially higher values of PFI (above 160), exhibiting fitness levels representative of elite athletes. Three subjects (two in the endurance-trained group and one in the group of individuals with a mixed-training status) suffered from vasodepressor syncope between 8 and 14 min of HUT and, subsequently, were excluded from the analysis. Fainters were found to possess physical attributes, PFI scores and pretilt resting supine cardiovascular parameters which were not different from those of nonfainters.

Table 1 presents the pooled orthostatic data of the nonfainters ($n = 33$) during resting supine and HUT. All orthostatic changes (except for average change in SBP) were found to be statistically significant.

When comparisons were made between orthostatic responses of the endurance-trained group and the mixed-training group (Table 2), it was noted that the latter had significantly higher values of DBP and MAP, both pretilt and on HUT, while other cardiovascular parameters were not statistically different.

Highly significant correlations, were exhibited between PFI and HR (both resting supine and orthostatic HUT). However, it was more significant with the average value of HR on HUT than with either resting supine or maximal values attained during the 20 min period of HUT. The correlation between PFI and all other parameters (including heart rate changes following HUT) was poor (Table 3).

In an attempt to analyse the data amongst those having attained a 'good' score (>160) of PFI, it was noted that these individuals ($n = 4$) possessed significantly lower values of HR, resting supine HR of 51 and mean orthostatic HR of 70 bpm, as compared to 62 and 81 bpm, respectively, for the group as a whole. Other orthostatic data, including changes in HR from resting supine values following HUT, did not differ significantly from the trained group as a whole (Table 4).

Discussion

Endurance training has variously been implicated to affect adversely the orthostatic reactions of an individual due to (1) an enhanced parasympathetic activity [10, 11], (2) a decreased sympatho-oadrenal/other neurohumoural responses [12–14], (3) a diminished baroreflex sensitivity [2, 3, 15], (4) an increased compliance of the leg veins [16, 17], and (5) an inadequacy of veno/vasoconstrictor responses [18].

Three subjects out of a total of 36 participating in this study suffered from vasodepressor syncope on HUT. This incidence (8.3%) is not significant (SE = 6.43) compared to the incidence of fainting in a much wider study ($n = 166$, fainters = 0) of normal healthy Indian men [7].

The present study was conducted with the intention of evaluating the eventual influence of aerobic conditioning on the orthostatic responses without examining the mechanisms, *per se*, involved in mediating these influences. Only non-fainters' data were considered for further analysis.

Our subjects attained PFI scores which ranged from 92.6 to 170.4, with a mean value of 129.3 ± 20.5, a (high) average score which conforms to a reasonably fair status of physical fitness. Four subjects were in possession of substantially higher values (above 160) of PFI, exhibiting fitness levels representative of elite athletes [8].

On HUT, the subjects exhibited significant changes, from resting supine, in the cardiovascular parameters in the form of an average increase of 19 ± 5 bpm in HR, 14 ± 6 mmHg in DBP and 10 ± 5 mmHg in MAP and an average decline of 10 ± 10 mmHg in PP. There was an

Table 5. Changes in cardiovascular parameters on HUT (present study compared with those on untrained Indian population)

Change on HUT		Present (n = 33)	Banerjee[19] (n = 30)	Banerjee[20] (n = 27)	Dixit* (n = 166)	Tripathi* (n = 8)
HR	Average	19 ± 5	16	16	16	17 ± 3
(bpm)	Maximum	25 ± 6	22	23	21	21 ± 4
SBP	Average	1 ± 7	0	3	1	3 ± 8
(mmHg)	Maximum	5 ± 10	−6	−4	−4	14 ± 5†
DBP	Average	14 ± 6	11	11	9	15 ± 5
(mmHg)	Maximum	21 ± 7			14	20 ± 5
PP	Average	−11 ± 10	11	8	−10	18 ± 8
(mmHg)	Maximum	−20 ± 10	−18	16	−16	−26 ± 6
MAP	Average	10 ± 5	8	8	6	10 ± 7
(mmHg)	Maximum	16 ± 6				14 ± 7

*Unpublished study by the authors.
†Significantly different ($p < 0.05$) from the corresponding value in the present study.

insignificant increase of 1 ± 7 mmHg in SBP. However, the maximal changes (all significant statistically) were in the form of a rise of 25 ± 6 bpm in HR, 21 ± 7 mmHg in DBP and 16 + 6 mmHg in MAP and a fall of 5 ± 10 mmHg in SBP and 20 ± 10 mmHg in PP.

The subjects in our study were noticed to have significantly lower values of resting supine HR and higher values of PFI compared to a group of untrained individuals (an unpublished study by the authors) in whom no history of exercise training was discernible for the last one year. Average (and maximal) orthostatic HR values were also significantly lower in the group of subjects compared to those in the untrained. This is an observation which has been reported consistently by many [7, 10, 11]. Other cardiovascular variables (both resting supine values as well as following HUT) were not different statistically.

Table 5 presents the changes (from resting supine) observed in this study in the cardiovascular parameters following HUT in comparison with certain others conducted on untrained Indian population. In most of these studies, the changes are seemingly not different.

With the exception of heart rate, no significant correlation was observed between the endurance status (expressed as PFI) and the entire orthostatic data (Table 3).

It appears from the study that the cardiovascular responses to central hypovolaemia induced by HUT are not modified to any appreciable extent by moderate intensities of endurance training. Responses to an orthostatic challenge contemplated in the form of a 70° HUT are not found to be significantly different in the trained and the untrained. Neither does such responsiveness bear a simple and straightforward relation with the endurance status.

References

1. Klein KE, Wegmann H, Brunner H, *et al.* Physical fitness and tolerance to environmental extremes. *Aerospace Med* 1969;**40**:998–1001.
2. Stegemann J, Busert A, Brock D. Influence of fitness on the blood pressure control system in man. *Aerospace Med* 1974;**45**:45–48.
3. Charles JB, Richardson J. Differences in responses to central blood volume shift between aerobic-conditioned and unconditioned subjects. Reprints of the Annual Scientific Meeting of the Aerospace Medical Association, Washington DC, 1981;317–318.
4. Shvartz E, Meyerstein D. Relationship of tilt tolerance to acrobic capacity and physical characteristics. *Aerospace Med* 1972;**43**:278–280.
5. Convertino VA, Montogomery LD, Greenleaf JE. Cardiovascular responses during orthostasis. Effects of an increase in VO_{2max}. *Aviat Space Environ Med* 1984;**55**:702–708.
6. Forster EM, Whinnery JC. Dynamic cardiovascular response to +Gz stress in aerobically-trained individuals. *Aviat Space Environ Med* 1990;**61**:303–306.

7. Dikshit MB, Banerjee PK, Rao PLN. Orthostatic tolerance of normal Indians and those with suspected abnormal cardiovascular reflex status. *Aviat Space Environ Med* 1986;**57**:168–173.
8. Bandyopadhyay B, Chattopadhyay H. Assessment of physical fitness of sedentary and physically active male college students by a modified Harvard Step Test. *Ergonomics* 1981;**24**:15–20.
9. Bandyopadhyay B, Chattopadhyay H. A comparative study of two modified Harvard Step Test in Indians. *Proc Indian Sci Congr Physiol* 1980;**67**:177–178.
10. Scheuer J, Tipton CM. Cardiovascular adaptations to physical training. *Ann Rev Physiol* 1977;**39**:221–251.
11. Booth FW, Thomason DB. Molecular and cellular adaptation of muscle in response to exercise: Perspectives of various models. *Physiol Rev* 1991;**71**:541–585.
12. Hartley LH, Mason JW, Hogan RP, *et al*. Multiple hormonal responses to graded exercise in relation to physical training. *J Appl Physiol* 1972;**33**:602–606.
13. Goldwater DJ, Lada MD, Polese A, *et al*. Effect of athletic conditioning on orthostatic tolerance after prolonged bed rest. *Circulation* (Suppl) 1980;**65**:287.
14. Svedenhag J, Martinsson A, Ekblom B, *et al*. Altered cardiovascular responsiveness to adrenoceptor agonists in endurance-trained men. *J Appl Physiol* 1991;**70**:531–538.
15. Raven PB, Rohm-Young D, Blomquist CG. Physical fitness and cardiovascular responses to LBNP. *J Appl Physiol* 1984;**56**:138–144.
16. Klein KE, Wegman HM, Kuklinski. Athletic endurance training advantage for space flight: The significance of physical fitness for selection and training of space lab crew. *Aviat Space Environ Med* 1977;**48**:215–227.
17. Luft VC, Myrhe LG, Leoppky JA, *et al*. A study of factors affecting tolerance of gravitational stress by lower body negative pressure. Albuquerque NM: Lovelace Simulated Found 1976 contract NAS9-14472, 2-60.
18. Samueloff SL, Brouse NL, Shepherd JT. Response of capacitance vessels in human limbs to head uptilt and suction on lower body. *J Appl Physiol* 1966;**21**:47–54.
19. Banerjee PK, Dikshit MB, Iyer EM. Cardiovascular responses to cold pressor test and orthostasis – a comparative study. Report 117/10/80, IAM, IAF, Bangalore 1983.
20. Banerjee PK. Results of tilt table test and maximal exercise test in candidates for payload specialists. IAM, IAF, Bangalore, 1985 (unpublished).