Physical work capacity and tolerance to +Gz stress in fighter pilots

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The relationship between aerobic work capacity and tolerance to +Gz stress is controversial. This paper presents the results of a study of physical work capacity (PWC, predicted maximal heart rate) by cycle ergometry and +Gz tolerance by human centrifuge on 42 normal healthy high-performance fighter pilots. PWC per kg body weight was found to have positive correlations with relaxed +Gz tolerance values on gradual onset rate (GOR, $r = 0.25$) and rapid onset rate (ROR, $r = 0.26$), and a significant positive correlation with simulated aerial combat manœuvre (SACM) duration ($r = 0.41$, $p < 0.01$). Pilots with PWC > 2.5 W/kg body weight had higher mean values of relaxed GOR, ROR tolerance and SACM tolerance (4.97 ± 0.53 G, 4.50 ± 0.44 G and 191 ± 57 s, respectively) than those (4.65 ± 0.61 G, 4.24 ± 0.53 G and 148 ± 45 s, respectively) recorded in pilots with PWC < 2.5 W/kg. Within the observed range of physical work capacity status, a higher score may thus be considered a positive attribute in relation to +Gz stress tolerance.

Keywords: Aerobic work capacity; +Gz stress

Aerobic physical exercise is being increasingly recognized as the primary method of intervention in the health promotion programmes. However, in the subpopulation of high-performance fighter pilots the role of aerobic conditioning programme has remained controversial, primarily due to its interference with their performance in respect of tolerance to +Gz stress. Two issues of potential concern related to aerobic fitness involve (i) increased incidences of cardiac rate and rhythm disturbances during +Gz exposure [1, 2] and (ii) increased susceptibility to motion sickness [1, 3]. On the other hand, the available data on +Gz tolerance score, in the form of peak tolerance on gradual onset rate or duration of tolerance to simulated aerial combat manœuvre (SACM), had neither brought out any inverse relationship with aerobic score in cross-sectional studies [4] nor indicated any significant reduction following aerobic training [5]. Nevertheless, the observations of incidences of dysrhythmia and motion sickness during centrifuge run and reduced tolerances to orthostatic stress by lower-body negative pressure in highly trained individuals [6] have certainly created an uncertainty in implementation of the exercise prescription as a part of the programme for the fighter pilots [7]. Furthermore, actual data available on the physical work capacity profiles of fighter pilots and its association with the measures of +Gz tolerance are relatively few in comparison with the number of critical reviews available in the subject area.

At the Institute of Aerospace Medicine, Indian Air Force, fighter pilots of high-performance aircraft are given high-G training in the human centrifuge. Assessment of various measures of +Gz tolerance is a standard feature in this programme. Forty-two pilots randomly selected from these trainees were assessed on cycle ergometric exercise for the evaluation of physical work capacity status, recorded as the maximal wattage corresponding to the predicted maximal heart rate. This article presents the observed relationship between work capacity and +Gz tolerance values in them.

Material and methods

Subjects. Forty-two healthy male fighter pilots randomly selected from those who reported for high-G training at this Institute were the subjects of the study. They were explained the experimental protocol in detail and had voluntarily consented to take part in the study.

Acceleration tolerance test. Subjects were given gradual onset rate (GOR) and rapid onset rate (ROR) runs to determine their relaxed and straining tolerances in the microprocessor-controlled human centrifuge, using peripheral light loss (PLL) as the end point. The rates of onset employed for GOR and ROR runs were 0.1 and 1.0 G/s, respectively. Relaxed GOR and straining GOR (GOR-S) and relaxed ROR runs were determined without G suit inflation. Simulated aerial combat manœuvering (SACM) profile consisted of a ROR with onset rate of 1 G/s to a peak of 4 G for 15 s, followed by another build-up at 1 G/s up to 8 g for 10 s, and then deceleration at the rate of 1 G/s to a level of 4 G/s. This profile continued till the subjects felt fatigued and gave a call to terminate the run or sustained a PLL or G-LOC. Pilots performed anti-G straining manœuvre (AGSM) while accelerating from 4 G to 8 G and back to 4 G. Anti-G suit was kept inflated throughout SACM. SACM tolerance was taken as the total duration in seconds from the start of the run till its termination. Further details of the test and features of the human centrifuge have been reported earlier [8].

Assessment of physical work capacity. The test was conducted on an automated cycle ergometric test system developed in this laboratory for the assessment of the maximal work rate corresponding to individual's predicted maximal heart rate while performing on a graded test loading protocol [9]. A Lanooy-type cycle ergometer (Lode, Holland) was interfaced with a PC through a load controller unit (ADE, Bangalore). Subjects' ECG signal on lead CM5 was fed to a PC add-on board (Numag Data System, Bangalore) through an amplifier (Cardiart 308, BPL India) for online-monitoring of ECG and registering heart rate (HR) count at every 15 s of exercise. The test mode of this automated system starts with a load of 50 W with an automatic increase by 25 W every 3 min until completion of 3 min at 150 W or reaching the predicted maximal HR (220 – age in yr, entered as subject data), whichever was earlier. Physical work capacity (PWC), as maximal wattage corresponding to the predicted maximal HR, was evaluated from the regression of work rate in watts versus heart rate in bpm (last 15 s) for each incremental load, and maximal W/kg body weight for the subjects' predicted maximal HR were logged and displayed on the monitor.

Statistical analysis. Pearson's product moment correlation test was employed to find out the correlation coefficients of age, height, weight, PWC in W and in W/kg body weight with GOR, GOR-S, ROR and SACM values.

Results

Table 1 presents the mean values with standard deviation and range of age, height, weight, $PWC_{pred\ max\ HR}$ values and +Gz tolerance values of 42 fighter pilots.

Correlation coefficients of age, height, body weight and PWC values of the pilots with their +Gz tolerance parameters are presented in Table 2. Age showed positive correlations with all +Gz tolerance measures, the r values being significant between age and GOR. Height showed negative correlations, thought not significant, with all +Gz tolerance measures. PWC,

Table 1. Age, physical characteristics and physical work capacity values and +Gz tolerance values of fighter pilots ($n = 42$)

	Mean	± SD	Range
Age (year)	27.3	3.6	22–36
Height (cm)	173.6	5.3	164–190
Weight (kg)	67.5	6.2	58–80
PWC (W)	161	32	112–250
(W/kg BW)	2.41	0.42	1.65–3.52
GOR-R (G)	4.77	0.60	3.4–6.1
GOR-S (G)	7.62	0.89	5.6–9.0
ROR (G)	4.34	0.51	3.0–5.2
SACM (s)	165	54	63–300

Table 2. Correlation coefficients between physical characteristics and +Gz tolerance measures in fighter pilots ($n = 42$)

Age and physical characteristics	+Gz tolerance measures			
	GOR	GOR-S	ROR	SACM
Age (yr)	0.370*	0.162	0.175	0.201
Height (cm)	−0.274	−0.243	0.278	−0.140
Weight (kg)	0.017	−0.022	0.072	−0.011
PWC (W)	0.209	0.148	0.184	0.356*
(W/kg BW)	0.252	0.177	0.255	0.406**

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

Table 3. Comparison of + Gz tolerance measures between high-PWC and low-PWC groups of pilots (mean ± SD)

	High-PWC ($n = 16$)	Low-PWC ($n = 26$)	t value
Age (yr)	26.6 ± 3.7	27.4 ± 3.5	0.70
Height (cm)	173.7 ± 5.9	173.6 ± 5.5	0.56
Weight (kg)	67.3 ± 6.4	66.7 ± 6.0	0.31
PWC (W)	192 ± 28	142 ± 45	7.54***
(W/kg)	2.85 ± 0.28	2.13 ± 0.20	9.71***
GOR (G)	4.97 ± 0.53	4.64 ± 0.61	1.73
GOR-S (G)	7.86 ± 0.81	7.48 ± 0.90	1.59
ROR (G)	4.50 ± 0.44	4.24 ± 0.53	1.95
SACM (s)	191 ± 57	148 ± 45	2.71**

**$p < 0.01$, ***$p < 0.001$.

both in absolute and per kg body weight, were found positively associated with +Gz tolerance measures. However, correlation coefficients were significant only in respect of SACM tolerance (0.356 with PWC and 0.406 with PWC/kg body weight).

Dividing the total sample of these pilot volunteers into two groups of (i) high PWC and (ii) low PWC, with the observed PWC values above or below 2.5 W/kg body weight, respectively, as the demarcating criterion, their +Gz tolerance values are compared in Table 3. The two groups were not significantly different in respect of their age, height and body weight. By virtue of their grouping on the basis of PWC, the two groups had highly significant differences in their PWC values, both in absolute and per unit body weight scores. The mean values of GOR, GOR-S, ROR and SACM tolerance were found to be higher in the high-PWC group (4.97, 7.86, 4.50 G and 191 s, respectively) as compared to those in the low-PWC group (4.65, 7.48, 4.24 G and 148 s, respectively).

Discussion

The best single laboratory measure of physical fitness has been the aerobic work capacity, the most valid and reliable measure of which is the maximal oxygen uptake capacity (VO_2 max), i.e. the highest oxygen uptake an individual can attain during dynamic physical work [10]. Aerobic work capacity per kg body weight is generally considered as a reliable indicator of the cardiovascular activity developed so as to predict the aerobic capacity/physical work capacity from the submaximal cardiovascular responses. These tests are based mainly on the fact that heart rate increases linearly with work rate during progressive exercise. Decrement in maximal heart rate with advancing age is also considered for such prediction [10]. In the present study, evaluation of the physical work capacity was made by way of assessing the maximal work capacity commensurating with individual's predicted maximal heart rate while performing on an automated progressive step-loading cycle ergometric exercise protocol.

PWC values of the fighter pilots in the present study are indicative of a nominally healthy but poorly physically trained sample. The observation of Nunneley *et al.* [11] on 10 pilots of high-performance aircraft observed similar fitness status that they considered typical of professional pilots.

The level of physical work capacity varies from one individual to another and is influenced by several factors such as age, sex, body dimensions, environmental factors and aerobic training status of the individual [10].

Aerobic training involves large mass of the skeletal muscle in a rhythmic exercise of relatively low resistance so that whole-body oxygen uptake is increased manyfold over the resting level [10]. The training improves the functional status of cardiorespiratory system, including increases in maximal oxygen uptake capacity, stroke volume, cardiac output and systemic vascular conductance [12]. Training-induced modulation of the autonomic input to the heart and increase in skeletal muscle capillary density favour cardiac performance and oxygen extraction capacity by the working muscles, respectively. An improved efficiency of the cardiovascular system is reflected in decreased heart rate and increased stroke volume in resting and submaximal exercising states. All the above changes have distinct advantages in improving the performance of high-intensity work [10]. Further, there is a strong evidence suggesting that aerobic exercise programme provides definite benefits in terms of health and well-being [13].

However, within the aeromedical community, some have expressed concerns regarding the effects of aerobic training on autonomic modulation of the heart and increased vascular compliance in the leg muscles *vis-à-vis* effective cardiovascular adaptation to gravitational stresses [1, 2, 6, 7]. The observations of Whinnery and Parnell [1] on low +Gz tolerance and occurrence of premature ventricular contractions in a few cases of avid endurance runners raised the question of a negative role of aerobic exercise training on +Gz tolerance. Also, observations of increased incidence of motion sickness in a few highly trained runners on centrifuge runs [1] and on vestibular stimulation [2] created further controversy on the issue. The belief of an inverse relation between aerobic fitness and tolerance to +Gz stress is considered widespread in aeromedical community.

It is, however, noteworthy that no study, either cross-sectional or longitudinal, has so far reported any adverse association between aerobic fitness score or aerobic training with +Gz tolerance measures *per se*. Cooper and Leveret [14] and Epperson *et al.* [15] reported no significant differences in +Gz tolerance with endurance running. Klein *et al.* [4] compared untrained and highly trained subjects and observed no differences in their orthostatic and +Gz tolerance (GOR). The longitudinal study of Epperson *et al* [15] indicated that SACM tolerance of aerobically trained group was not significantly different compared to that of the control group [15]. Dynamic heart rate response to a series of G profiles also has not shown any reduced dynamic heart rate response to +Gz stress in aerobically trained sample as compared to controls [16].

The observed correlation coefficients between physical work capacity and +Gz tolerance measures in the fighter pilots of the present study are indicative of positive associations between them (Table 2). Though in most of the circumstances the correlations were low and not significant, the direction of association is noteworthy. As reported in an earlier study [4], total body height showed negative correlations with +Gz tolerance measures and age showed positive correlations in the present sample. In respect of SACM tolerance, PWC showed significant positive correlations, both in its absolute and per kg body weight scores.

On comparison of the +Gz measures of the two groups made out of the present sample above and below the PWC score of 2.5 W/kg body weight, the group with higher physical work capacity scores was found to have higher mean values of all +Gz tolerance measures than those in the relatively less fit group of subjects (GOR: 4.97 vs. 4.65, GOR-S: 7.86 vs. 7.48, ROR: 4.50 vs. 4.24 G, SACM: 191 vs. 148 s, respectively), the difference in SACM tolerance score being significantly higher in the high-PWC group ($p < 0.01$). Whinnery and Parnell [1] also reported higher mean +Gz values in a group of aerobically trained sample (VO_2 max: 43–71 ml/kg/min) compared to data gathered on all healthy subjects (no mention of VO_2 max) in Armstrong Laboratory (GOR: 4.81 vs. 4.65 G, ROR: 3.40 vs. 3.34 G, respectively).

From the observations of the present study, a higher score of physical work capacity appears to be a positive attribute towards +Gz tolerance. Though the present sample did not represent or include a highly aerobically trained group, it seems likely that the observed level and distribution of physical fitness status is representative of the fighter pilot population (somewhat similar levels being quoted elsewhere [11]). Observations of the present study call for an unreserved encouragement of the aerobic training programme in the sample population.

The specificity of strength training exercises in improving sustained high-G tolerance is well established [15] and the programmes based on emphasis on strength training workouts as recommended by many [17, 18] need effective implementation. Nevertheless, the benefit of the aerobic form of exercise, which is rapidly becoming the primary method of intervention in comprehensive health promotion programme and is also more popular in most of the population, including the fighter pilots, need not be denied to the high-performance pilots on the basis of a not-so well-founded suspicion that it may interfere with their flight performance in terms of tolerance to +Gz stress, a controversy that has all the possibility of impeding the personal pursuit of exercise conditioning in them.

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