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Medical Evaluation of Cosmonauts : Physiological Stress Testing

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The Physiological stress testing in the medical evaluation of Cosmonauts, requires assessment of overall physical fitness and the ability of the body to withstand the unusual environment of zero G, as well as recovery to normal on return to earth. The overall physical fitness is assessed by measuring the VO_2 max of the individual, alongwith other cardio pulmonary parameters, while performing on bicycle ergometer. Other stress tests like orthostatic tolerance, cold pressortest and heat tolerance studies, help to establish the physiological normalcy of a potential cosmonaut.

Introduction

From a few minutes of orbital flight in the late 50s, technology has enabled man to foresee a very prolonged space sojourn by the turn of this century. During the early days of space exploration, scientists were not sure that man could thrive in space and thus it was then most difficult to foresee the physiological requirements of the would be astronauts. However, in the last 2 decades or so, with multiple space missions having been successfully accomplished, a more rational approach to this aspect has appeared.

The physiological testing for cosmonaut selection though is made, all the more diffficult, because of the peculiarity of the space environment—the most important from the physiological aspect being the zero gravity state. That physiological alterations occur on exposure to zero g flight for short or long durations, has been amply documented. (Berry 1976, Bergman et al 1976, Winter DL 1977) and therefore some guideline is now available for preselection of the type of human subjects who would be exposed to this environment. Even then, the very fact that simulation of zero g condition is almost impossible on the ground, (Adey 1973) except for producing subgravity analogues by upto neck water immersion or prolonged bed rest (Graybiel and Clarke 1961 Hood et al 1968), makes this task less exacting and more difficult. This paper, thus, is meant to outline the current concepts of what is physiologically required, of a potential cosmonaut as well as some of the experiences

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this Institute has had in this aspect in the recent past.

The physiological preselection of cosmonauts requires to be done from two main aspects :

(a) Overall physical fitness.

(b) Ability of the body physiology to withstand the unusual environment of zero G as well as to recover its equanimity to normal on return to earth.

The former assessment can best be done by measuring the VO_2 max of an individual alongwith other cardiopulmonary parameters. Treadmill running as well as bicycle ergometry have been used for the purpose alongwith lung function testing.

Exposure to the zero g environment induces a number of physiological adaptations especially in the cardiovascular and renal mechanisms which are governed by autonomic balance. Certain reflex mechanisms such as orthostatic tolerance have been seen to be particularly affected during weightlessness and for a short period, after return to earth. It has been the consensus of opinion therefore, to preselect cosmonauts on the basis of their responses to physiological stress tests which ensure normal autonomic balance on the ground, with the assumption that such individuals will not suffer badly from physiological maladaptation when exposed to zero g situations.

We had recently some experience in evaluating Air Force Pilots for selection as cosmonauts in this laboratory. The following physiological stress testing was carried out on subjects (physical characteristics table I) who had already undergone a thorough medical and ECG examination.

Table I

Physical characteristics of Pilots (N=12)

	Age Yrs	Ht Cms	Wt Kg
$\bar{X}$	35.7	173.2	69.8
SD X	2.9	6.2	±7.2

Spirometry : This was done on the vitalograph on which was obtained an expirogram from which the following lung function parameters were assessed

FORCED VITAL CAPACITY (FVC) ml

FEVI/FVC%

MAX VOL VENT

FORCED EXPIRATORY FLOW (25%-75%)—Sm airways air flow

FORCED EXPIRATORY FLOW (200-1200)—lar airways flows

A typical expirograph record is shown in fig. 1

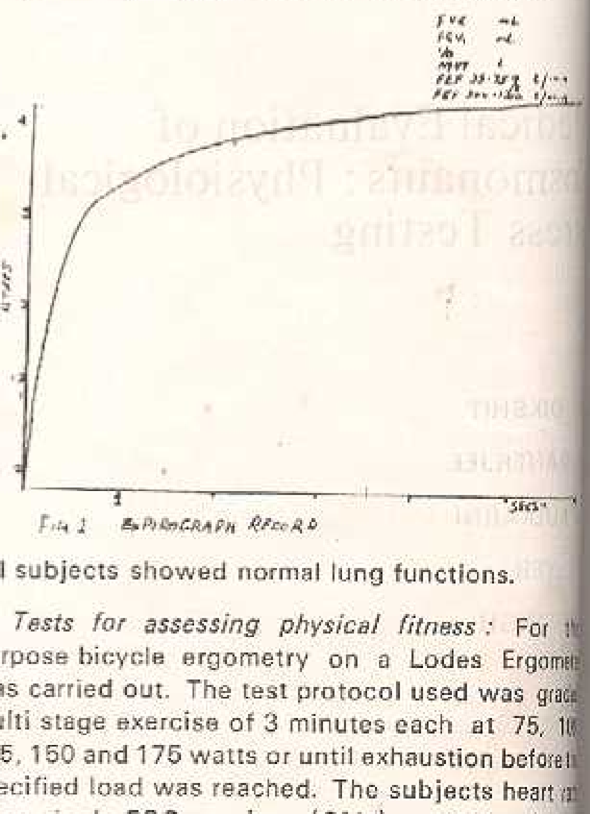


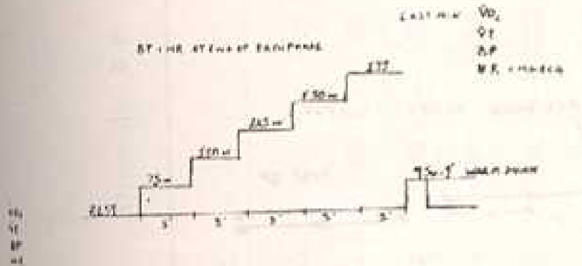
Fig 1 EXPIROGRAPH RECORD

All subjects showed normal lung functions.

Tests for assessing physical fitness : For th purpose bicycle ergometry on a Lodes Ergome was carried out. The test protocol used was grad multi stage exercise of 3 minutes each at 75, 10 125, 150 and 175 watts or until exhaustion before t specified load was reached. The subjects heart r using single ECG monitor (CM_5) and blood pre sure were recorded at rest and thereafter in the la ½ minute of each exercise load. Recovery values i these parameters were also taken at 3 minute Inte val for 15 minutes. The protocol is displayed i fig. 2.

Minute ventilation and VO_2 were taken at re prior to exercise and there after in the last minute exercise to assess the VO_2 max and VE. From th data collected, VO_2 ml/kg, O_2 pulse/beat and venti lation equivalent for every litre of O_2 consum were found out. The findings are depicted in fig 3

Twelve subjects completed the 175 watts load 3' which was also their max exercise. The average for VO_2 value of 2.416 ± .173 litres/min or 35 ± 8 ml/kg/min concides well with the value reported for the given exercise load. The Vent equivalent of around 38 lit/1 litre of VO'' consumed both at rest and during exercise also denotes a normal efficiency of the ventilatory system (fig. 3).



N=12	$\dot{V}O_2$ L/min STPD	VO_2 ml/kg	O_2 pulse ml/beat	$\dot{V}E$ (L) BTPS	V. equiv.
REST	·258 ±·033	—	3·7 ±1·3	9·81 ±1·91	32.6 ±8·7
EXERCISE	2·416 ±·173	35 ±8	12.6 ±1·2	92·6 ±12.48	38·3 ±3·7

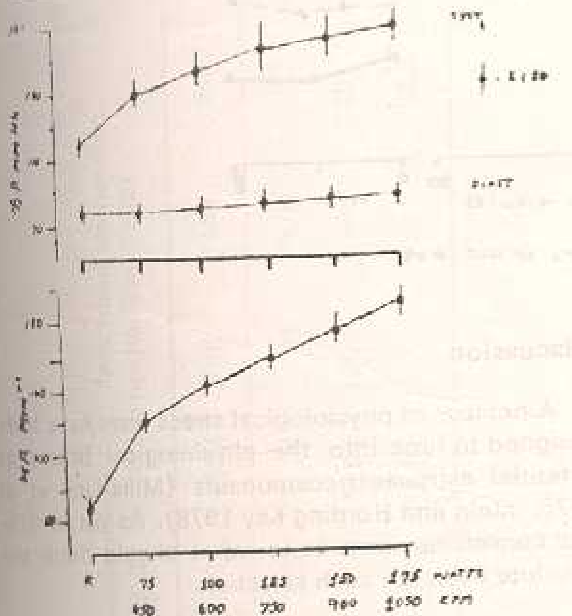


Fig: 3 GRADED VENTILATORY RESPONSE TO CYCLE LOAD
N=12 at REST (R) and at 175 WATTS, N=9 AT OTHER LOADS

The systolic blood pressure increased to 188 ± 11.2 mmHg from a control value of 118 ± 7.1 mm Hg while the diastolic pressure rise was minimal from 79 ± 5.9 mm Hg to 83 ± 8.2 mmHg at max exercise. A heart rate of 191 ± 10.1 beats at 175 watts also indicated that maximum exercise level had been reached.

The following criterion were considered for termination of exercise and declaring the candidate unfit.

(a) A sudden fall in systolic BP by 10mm or more

(b) A sudden bradycardia of 10 beats or more

(c) A rise in diastolic BP of more than 15 mm Hg from resting

(d) Abnormal ECG

(e) Unusual breathlessness.

The values compared are for 12 pilots who showed a normal response in all physiological stress tests. In the exercise test two pilots failed because.[1] one developed abnormal ST/T waves as he was undergoing 150 watts exercise.[2] The other candidate demonstrated an increase in diastolic pressure from 68 mm Hg at rest to 104 mm Hg by 1 minute of 175 watts exercise. This was an increase in diastolic pressure by 36 mmHg which is considered grossly abnormal (Sheps et al 1979).

One subject had a VO_2 max of 26.8 ml/kg/min, which was below the mean normal value of 35 ml by more than one standard deviation. This subject also had lesser ventilatory efficiency as his ventilation at max exercise of 51.8 lit was well below the expected 92.6 lit ± 12.8 lit/min. These two factors were, though not considered absolute rejection criterion in this subject as some degree of endurance training is likely to improve upon them.

Tests for orthostatic tolerance to gauage the stability of cardiovascular reflex responses

This department has been consistently engaged in evaluation of cardiovascular reflex status by 70° head up tilt table test which has also been used by others to evaluate potential astronauts (Klein and Hordinsky 1979, Mills-Link et al 1975). The classical response to 70° head up tilt consists of a rise in HR of around 10 beats per minute a rise in diastolic pressure of 6-8 mmHg and slight changes in systolic pressure usually demonstrating a fall (Lind et al 1968, Bartok et al 1968 Dikshit et al 1980, Banerjee et al 1982, Dikshit et al 1982). Abnormal orthostatic response is indicated by very high heart rate (in excess of 120 beats/min) and a narrowing of pulse pressure to less than 20 mmHg (Vogt 1966). The findings of tilt table tests are being reported for 9 of our subjects (fig. 4) who demonstrated classical normal responses. One subject was disqualified in

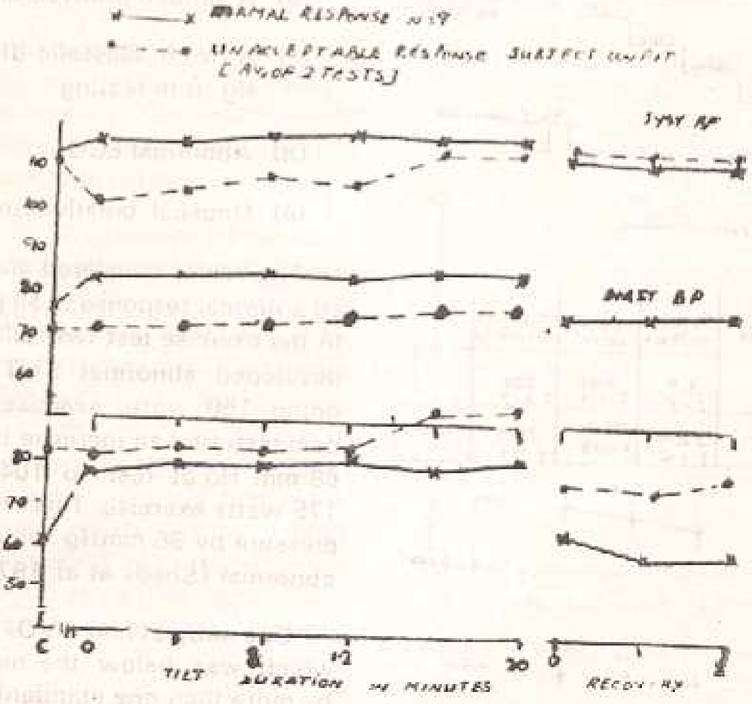


Fig 4 CVS RESPONSE TO 70° TILT N=9

this test as he did not show the expected rise in HR and diastolic BP on tilting (fig 4). Another subject showed normal heart rate and blood pressure response but developed a frank preexcitation syndrome pattern during 70° tilt. Yet another subject showed flat inverted T waves during orthostasis. Even though this does not signify a major anomaly, he developed frank ECG abnormality at 150 watts of exercise load and was as such disqualified.

Cold pressure test by hand immersion in water at 4°C is being used by us to evaluate cardiovascular reflex status (Banerjee et al 1982) mainly from the aim of assessing effector sympathetic drive. The classifical normal response is outlined in table II as seen by us here. Even though this test was not in the protocol, 5 of the cosmonaut candidates volun teered to undergo it. They all responded normall They also had normal 70° tilt and exercise te responses.

The reasons for rejection of four candidates wh deviated grossly from what are considered norm responses for our laboratory data are given table III.

Discussion

A number of physiological stress tests have bee designed to look into the physiological fitness o potential astronauts/cosmonauts (Mills-Link et 1975, Klein and Hording Key 1979). As yet no defi nite consensus exists as to what should form th absolute basis for such selection.

The most controversial, has been the selectio on the basis of physical fitness. As yet no defini correlation has been found between aerobic physio fitness and some aviation stresses such as accelera tions (Cooper and Leverett 1966, Whinnery 1979 Klein et al (1977) have in fact suggested that hig

Table II

C V Response to cold pressor test

Normal response to C.P. Test hand immersion at 4°C : N=30 (Banerjee Etal 1982)

	C	½mt	1mt	1½mt	2mt
HR MIN	71.8	84	84	82.3	78.7
SYST BP	115.4	129.6	136.3	144.4	140
DIAST BP	77.1	91.8	97.1	99	98.8

Diastolic B P

Sl No	Subject No	C	½'	1'	1½'	2'
1	6	80	94	104	106	110
2	2	74	88	90	90	84
3	1	74	90	96	100	100
4	9	74	90	98	100	98
5	11	84	108	108	110	110
	$\bar{X}$	77	94	99	101	100

Heart rate

H R	Subject No.	C	½'	1'	1½'	2'
1	6	72	84	78	78	66
2	2	64	90	90	72	66
3	1	84	84	84	78	80
4	9	64	72	72	70	62
5	11	64	84	88	88	80
$\bar{X}$		70	83	82	77	71

Systolic B P

Sl No	Subject No	C	½'	1'	1½'	2'
1	6	120	130	150	154	150
2	2	110	120	130	134	128
3	1	118	130	136	150	150
4	9	110	120	140	140	138
5	11	122	140	146	150	148
$\bar{X}$		116	128	140	146	143

Table III

Altered/Abnormal responses to stress testing

** Causes for absolute rejection for cosmonaut training

* Cause for rejection—but could be reconsidered if performance improves

	HR	SYST	DIAST	VO_2	VO_2 Pulse	VE	VEEQV	Tilt Table	Lung Function	Cold Pressor
Subject No. 13										
Exercise Testing										
Rest	68	122	80	.239	3.5	7.4	31			
Exercise Load : 175 watts	—	210	104 **	2.233	—	89.8	40.2 *	Normal	Normal	N A
Subject No. 14										
Rest	56	118	70	0.179	3.2	5.3	29.6			
Exercise 150 watts	** 190 ECG Abn-ormal	190	80	1.922	10.1	106.2	55.6	Normal Reflex But T wave inverse during tilt	Normal	N A
Subject No. 15										
Rest	79	118	74	—	—	—	—	Unacceptable ** NO HR, NO DP Changes	Normal	N A
Exercise	175	170	80	1.874	10.7*	10	51.8 *			
Subject No. 16										
Not Done								Reflex response normal but ** Pre-excitation syndrome on tilting	FEF Just below * normal	N A

endurance physical capacity is a disadvantage in tolerance of orthostatic stress given after simulated weightlessness (upto neck water immersion) or during actual space flight, where they showed, that the highly physically trained astronaut in one of the Skylab missions developed gross orthostatic intolerance during inflight LBNP, testing. The authors attribute this to the large muscle mass of lower limbs which develops considerably due to aerobic training. The exact physiological or biochemical characteristics developed by the trained muscle which induce such responses are as yet unknown, (Klein et al 1977). As to whether only arm exercise training will improve the situation is not known, but could be attempted. It has also been reported that even-though orthostatic tolerance in highly trained athletes after upto neck water immersion is poor, it certainly seems to improve with some degree of physical training in untrained individuals (Saiki et al 1979).

Healthy Indian subjects as such have lesser max aerobic power as compared to other ethnic groups (Bandopadhyay and Chattopadhyay 1980). The average VO_2 max we have seen in representative sample of healthy Air Force Pilots in 35 ml/kg. If one considers the above arguments, then this degree of max aerobic function in otherwise healthy subjects may in fact prove to be a boon for cosmonaut activities and one may now hypothize that such subjects may infact show better adaptation to the zero g situation as compared to the physically very fit astronauts/cosmonauts who have had the experience.

We have had some experience with yoga (Wadhawan et al 1981), which is expected to improve overall cardiovascular fitness. Whether such training should be considered for selection of cosmonauts is as yet only a conjecture.

There is no doubt that orthostatic stability is an important criterion for a successful adaptation to the space environment and is generally accepted by all (Berry 1976, Mills-Link et al 1975, Klein and Hordinskey 1979). Our subjects have shown a normal response, data for which is adequately available. Any variation from the accepted normal response would therefore be considered a liability. A fall in blood pressure from normal to 100/55 mm Hg during orthostasis has been designated by some to be a rejection criterion (Mills Link et al 1975). This amounts to a mean arterial pressure (MAP) of 70 mm Hg below which brain perfusion falls. This is an acceptable criterion as long as the subject does not have presyncopal symtoms if his MAP drops from his resting value (normally around 85 mm Hg) to a value which may be higher than the stipulated lower limit of 70 mm Hg.

Cold pressure test has been used sparingly as an astronaut stress test. We have been using it to study cardiovascular reflex mechanisms and feel that the sympathetic drive can be assessed successfully with this test, which we have been able to correlate to 70° headup tilt, and thus consider it a useful adjunct to orthostatic tests in order to assess the overall cardiovascular reflex status.

Heat balance studies have not been carried out in space to any significant depth, though there have been pointers from the Kosmos 936 experiments that some disruption may occur (Novak et al 1980) and understandably so as heat control mechanisms are an integral part of the CNS vegetative functions which are known to be affected during weightlessness. Chermjakov (1975) has estimated heat accumulation of 60-63 Kilo cal/m²/hr. as tolerable in space environment while during work schedules this may go up to 86 Kilo cal/m²/hr. Even though tropicalized subjects have comparatively high heat tolerance (Verghese et al 1969, Dikshit et al 1980) it would be worthwhile to assess potential cosmonauts for their heat tolerance, norms for which are available with us (fig 5).

The task of laying down selection criterion for cosmonauts has been an onerous one because interpretation of these tests in terms of pass/fail is difficult mainly because there is lack of test values encountered in a normal healthy population of the type that is likely to volunteer for space missions and also because the range of normality of physiological responses is very wide. With this in mind we have put forward some of our more recent findings and suggest that the lower limit of values in exercise orthostatic tests should be restricted to 1 standard deviation for selection purposes. Heat tolerance tests ought to be introduced. The aim thus is to try and find an individual who is likely to

1. HEAT STORAGE = Δ MBT × Kg × 0.83 / m^2 BSA

2. MOD CRAIGS IND = $\frac{HR}{100}$ + Δ T RECT. + SWEAT LOSS KG/HR

3. ACCUMULATIVE CIRC. STRAIN = 85 × ORIGINAL HR Log $\frac{85}{85 - \Delta HR}$

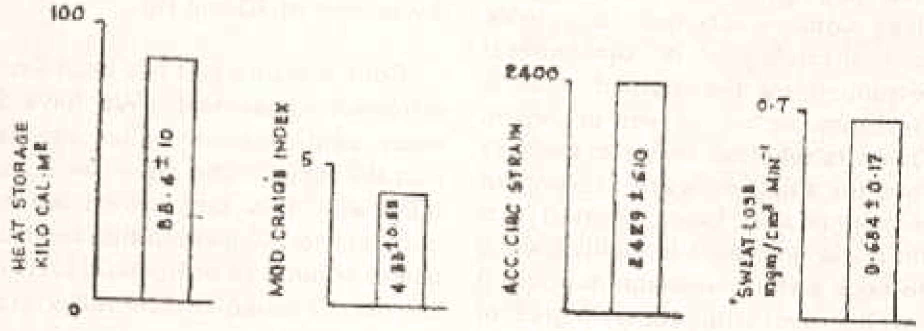


FIG. 5 INDICES FOR EVALUATING HEAT STRAIN
(MODIFIED FROM DIKSHIT ET AL 1980)

be nearest to the expected normal. It must however be borne in mind that the physiological status considered as a pre-requirement for astronaut selection is likely to undergo various changes with progress of time and what holds good today may infact be considered as irrelevant tomorrow.

Conclusion

1. In light of the present knowledge of the art, certain physiological stress tests like orthostatic tolerance cold pressor test and heat tolerance studies could be done for establishing the physiological normalcy of a potential cosmonaut.
2. The relevance of extreme physical fitness as a prerequirement has been questioned.
3. It is suggested that the lower limit of acceptability for various criterion discussed should not exceed 1 standard deviation for that parameter, in order to obtain an individual who falls as closely as possible within the expected normal mean response.

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