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Effect of age and flying experience on heart rate response of fighter aircrew during high-G exposure in the high-performance human centrifuge

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ABSTRACT

Objectives: Institute of Aerospace Medicine Indian Air Force regularly conducts high-G training in the human rated high-performance human centrifuge (HPHC) for fighter aircrew. It was hypothesized that the cardiovascular response of young and inexperienced pilots who undergo training in the HPHC may be different from the elder and experienced pilots as age and flying experience may have some effect on the CVS response to high-G exposure.

Material and Methods: A retrospective analysis of the heart rate data from the data bank of the department of acceleration physiology and spatial orientation was done to understand differences in heart rate response between young and older fighter aircrew.

Results: A total of 624 successful HPHC runs were evaluated for the baseline heart rate (before high-G exposure), peak heart rate (PHR) (during the exposure), and heart rate after the exposure of the run. The mean age, height, and weight of the subjects were 27.62 ± 5.5 years, 175.31 ± 4.8 cm, and 72.81 ± 8.4 kg, respectively. Student's *t*-test revealed that there was a significant difference in the basal heart rate and PHR during the high-G exposure between young, inexperienced, and older experienced pilots. Higher basal heart rate and PHR during high-G exposure among younger pilots could be explained by anxiety due to inexperience and a tendency to pull harder in comparison to other pilots who with experience tend to be more adjusted and pull slower to meet the desired G-level during the high-G training.

Conclusion: The cardiovascular response during exposure to a high-G environment is significantly different between young, inexperienced pilots, and other senior pilots.

Keywords: Heart rate, High-G, Human centrifuge, Fighter aircrew, Flying experience

INTRODUCTION

The fighter aircrew is regularly exposed to sustained high +Gz acceleration of varying magnitude and durations. Exposure to sustained high Gz acceleration has a significant effect on the cardiovascular system which manifests as a spectrum of symptoms, namely, peripheral light loss and central light loss to G-induced loss of consciousness.[1] These manifestations are due to circulatory disturbance which is the result of simple Newtonian physics applied to the fluid compartments within the body. Exposure to high +Gz acceleration produces immediate changes in the distribution of pressure in the arterial and venous systems, which, in turn, induces shift of blood toward the more dependent parts. These initial disturbances evoke reflex compensatory responses involving the arterial baroreceptors and possibly also the low pressure cardiopulmonary receptors and arterial chemoreceptors. In addition, exposure to acceleration may modify activity in skeletal muscle mechanoreceptors and metaboreceptors, lung-stretch receptors, and vestibular receptors, leading to modulation of cardiovascular function.[2] These responses may be affected by age just like all other physiological functions. Cardiovascular response in terms of heart rate is the most commonly and easily monitored parameter which may reflect the cardiovascular changes under high +Gz conditions.[3]

On exposure to a sustained high +Gz environment, the cardiovascular response of younger pilots and other experienced pilots may differ due to a variety of factors, namely, age (the resting vagal tone is higher with age), anxiety, and handling of the aircraft (younger pilots are likely to be more aggressive). Understanding the differences in cardiovascular responses between younger and other experienced pilots would allow better monitoring of parameters and development of safety protocol during training in the high-performance human centrifuge (HPHC).

MATERIAL AND METHODS

The Institute of Aerospace Medicine Indian Air Force (IAM IAF) regularly conducts training of fighter aircrew in an 8 m arm human rated HPHC. Heart rate (in beats per minute) is the basic parameter that is continuously monitored during such training. The details of high-G training at IAM IAF are published elsewhere.[4] For the purpose of this study, the pilots of the age group 20–25 years were considered “young pilots” and the rest were considered “elder pilots.” Although experience comes with age, it also corresponds to rank and flying hours. Hence, these aspects were studied separately. The under trainee (U/T) and UT operational pilots (U/T Ops) were considered “inexperienced pilots” and the rest (Fully operational or Fully Ops, Supervisors, and Senior Supervisors) were considered “experienced pilots.” The attributes were also studied among pilots with flying hours <250 h and others having more than 250 h. These pilots were exposed to all the high-G conditions in the HPHC, while wearing five bladder cut-away type anti-G suits (AGS) and performing AGSM (L-1 maneuver) except during the GOR run, where their relaxed G-tolerance was measured without AGS. Statistical analysis was done using SPSS 20 with a confidence interval of 95% and significance value set at $P < 0.05$.

RESULTS

A total of 624 HPHC runs were analyzed from the database for base-line heart rate (BHR) (heart rate at 1.4 Gz which is the baseline for the HPHC), peak heart rate (PHR) during the exposure to the G-profile, and post exposure heart rate (HR_PR). The descriptive data for the same have been shown in Table 1.

Age and heart rate response

Mean age, height, weight, flying hours, G-onset rate, baseline, peak, and post-run heart rates of the young pilots and elder pilots are shown in [Table 2]. The mean heart rate was higher in younger pilots in comparison to elder pilots. Age-wise distribution of the pilots in the study is shown in [Figure 1]. [Figure 2] shows age-wise distribution of heart rates and G onset rate.

ANOVA and Bonferroni *post hoc* analysis revealed that there was a significant difference in PHR among the pilots of the age-group 20–25 years and 31–35 years ($P = 0.001$) and 26–30 years and 31–35 years ($P = 0.006$). Young pilots pulled significantly faster (G-onset rate higher) than the elder pilots; t (156.8) = 6.72; $P = 0.000$.

Rank and heart rate response

The rank-wise distribution of the pilots in the study is shown in [Figure 3].

The mean age of inexperienced pilots was 24.5 ± 2.7 years and the experienced pilot was 34 ± 4.3 years. Independent samples t-test revealed that experienced pilots were taller and heavier than the inexperienced pilots and pulled G slower than the inexperienced pilots. Heart rate responses were higher among the inexperienced pilots. However, a statistically significant difference was observed only in BHR and PHR ($P < 0.01$).

Flying hours and heart rate response

The total number of pilots whose data were analyzed based on flying hours in the study is shown in [Figure 4]. The

Table 1: Descriptive statistics of parameters in the study.

Attributes	N	Mean	Standard deviation	Nature of parameters
Age (years)	624	27.62	5.545	Physical
Height (cm)	554	175.31	4.834	Physical
Weight (kg)	554	72.81	8.384	Physical
G_onset_ROR (G/sec)	532	1.4524	1.64113	Operational
Flg_Hrs	533	802.59	821.749	Operational
Baseline_HR	614	107.10	21.731	Physiological
Peak_HR	624	207.12	27.173	Physiological
HR_Post_Run	595	124.08	27.247	Physiological
Peak_HR_GOR	68	166.8088	34.77143	Physiological
Peak_HR_ROR	556	212.0468	21.43579	Physiological
Post_run_HR_GOR	67	105.0149	23.96556	Physiological
Post_run_HR_ROR	528	126.4962	26.69833	Physiological

Table 2: The mean, standard deviation (SD), and standard error of the mean of all the measured parameters for young pilots (≤ 25 years) and experienced pilots (>25 years).

Attributes	Young_Elder Pilots	N	Mean	Std. deviation	Std. error mean
Age (years)	Young Pilots	258	22.78	1.367	0.085
	Elder Pilots	365	31.02	4.777	0.250
Height (cm)	Young Pilots	191	174.22	5.033	0.364
	Elder Pilots	362	175.88	4.637	0.244
Weight (kg)	Young Pilots	191	67.26	5.911	0.428
	Elder Pilots	362	75.72	8.017	0.421
Flg_Hrs	Young Pilots	192	243.46	85.275	6.154
	Elder Pilots	347	1089.15	881.029	47.296
G_Onset_Rate (G/sec)	Young Pilots	244	1.6021	1.84290	0.11798
	Elder Pilots	355	1.0939	1.38249	0.07337
Baseline_HR (beats/min)	Young Pilots	252	109.73	25.478	1.605
	Elder Pilots	361	105.23	18.507	0.974
Peak_HR	Young Pilots	258	210.18	24.123	1.502
	Elder Pilots	365	204.92	29.000	1.518
HR_Post_Run	Young Pilots	244	126.23	29.067	1.861
	Elder Pilots	350	122.57	25.880	1.383
Peak_HR_GOR	Young Pilots	58	167.8621	35.68992	4.68632
	Elder Pilots	10	160.7000	29.74727	9.40691
Peak_HR_ROR	Young Pilots	224	213.2723	21.19061	1.41586
	Elder Pilots	331	211.2205	21.62482	1.18861

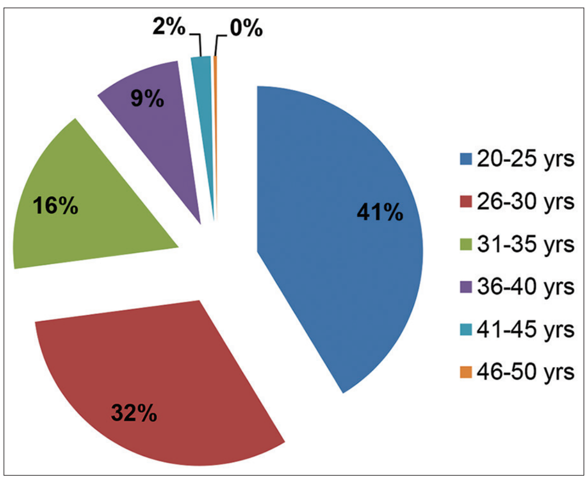

Figure 1: Age-groups and number of pilots in the study.

mean age of the pilots with flying experience of 250 h and less was 23.43 ± 2.7 years and 30.06 ± 5.17 years for others. The heart rate responses (BHR, PHR, and heart rate post-run) were significantly higher among the pilots having flying experience of 250 h or less ($P < 0.01$).

HPHC runs and heart rate response

[Figure 5] shows the various HPHC runs that were analyzed in the study.

The G-onset rate and heart rate response during various G-levels in the HPHC are shown in [Figure 6].

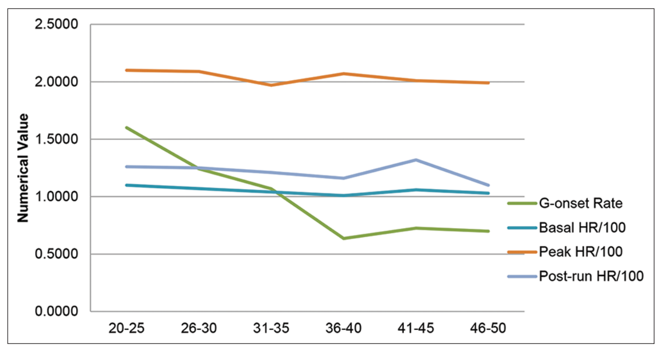

Figure 2: Age-wise (in years; X-axis) G-onset rate (G/sec) and heart rates (in beats per min) of the pilots in the study.

Spearman's correlation [Table 3] showed statistically significant negative correlation of heart rate responses with age and flying hours.

The mean maximum target heart rate (often used in exercise testing) for age (i.e., 220-age) during GOR and ROR would be 192 ± 6 bpm and 193 ± 6 bpm, respectively. The mean PHR attained during GOR was significantly lower (87% of mean maximum heart rate) than the mean of maximum target heart rate for age ($P < 0.001$) and the mean PHR attained during ROR ($P < 0.001$) was significantly higher (110%) than the mean of maximum target heart rate for the age. PHR was significantly higher for young and inexperienced pilots as well as Ab Initio and other pilots in comparison to the expected target heart rate ($P < 0.05$). However, this rise in the

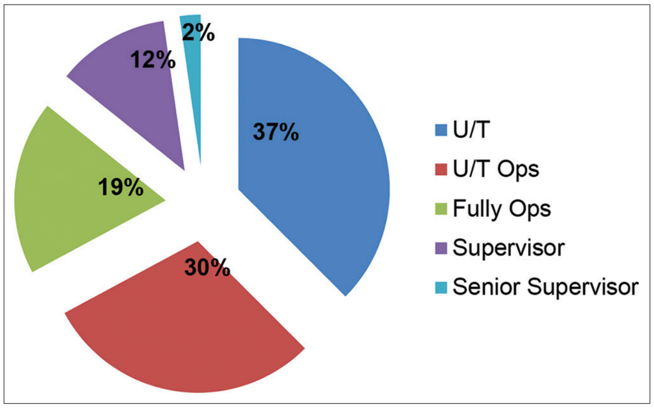

Figure 3: Rank-wise distribution of the pilots in the study.

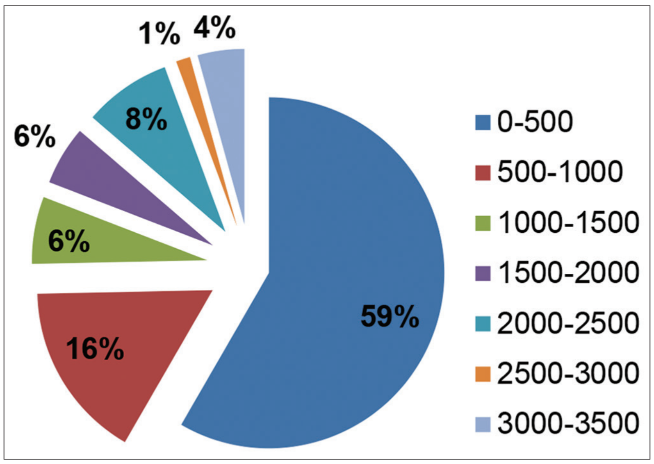

Figure 4: Flying hours and number of pilots in the study.

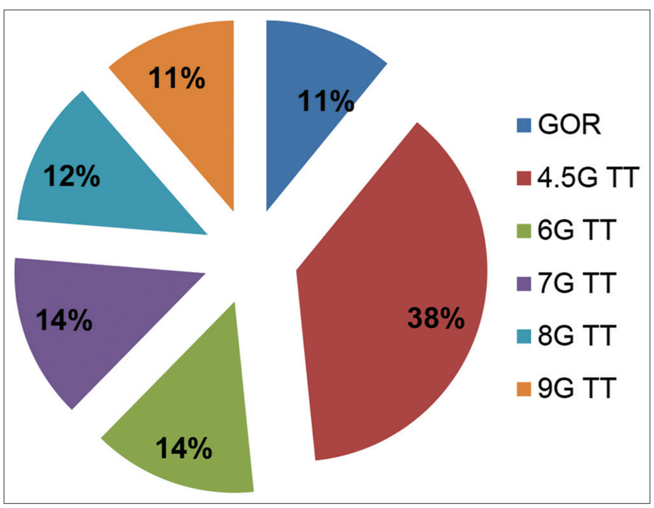

Figure 5: G-levels exposed to the pilots during the HPHC runs. HPHC: High-performance human centrifuge.

heart rate was not significantly different between young and inexperienced pilots as well as Ab Initio and other pilots in the study ($P > 0.05$).

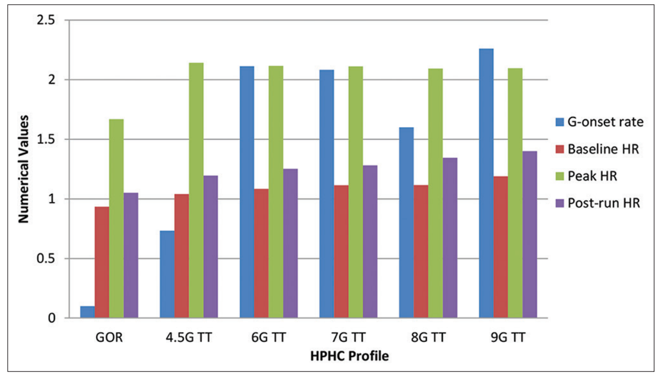

Figure 6: G-onset rate and mean heart rate (HR/100) during exposure to HPHC runs in the study (TT is target tracking controlled by pilots). HPHC: High-performance human centrifuge.

DISCUSSION

The cardiovascular system has evolved to be extremely dynamic and responsive to the stress of orthostasis in the human body. If the orthostatic stress is magnified in the form of sustained exposure to a high +Gz environment (>2 s), the cardiovascular system's dynamism and responsiveness are stretched to their limits. Rowell has concluded that the performance of the heart under G stress is determined primarily by peripheral circulation.[5] The compensatory changes under such conditions are mediated through a closed loop baroreceptor reflex based on autonomic nervous system (ANS) response. The baroreceptor sensitivity (gain) is modified by various factors including advancing age and arterial wall distensibility (which also becomes less distensible with advancing age).[1] This results in a significant reduction in heart rate response with age as aging itself could disrupt ANS through reduction and increase in the input of parasympathetic and sympathetic nervous systems, respectively.[6,7] The ANS controls cardiac functions by activating its efferent sympathetic nerves to increase heart rate and contractility.[8] In addition, the parasympathetic nerves exert control over heart functions through a direct vagal mediated reduction in heart rate (bradycardia).[9] The ANS promotes rapid adjustments of the cardiovascular system during orthostasis and high-G stress. The age-related disruption in ANS may affect this adjustment. However, the course of normal aging could be altered by physiological conditioning.[10] Aerobic conditioning is also known to reduce heart rate. Hence, the age-related cardiac response may also get modified by the aerobic fitness of aircrew which may get pronounced with age.

The heart rate responses during ROR runs were significantly higher than GOR runs. The raised BHR could be attributed to the higher baseline G level (1.4 G) as well as excitement in anticipation of the immediate G-exposure (psychogenic) as reported by Parkhurst *et al*. and Leverett *et al*.[3,11] There

Table 3: Pearson's correlation coefficient (Corr Coefficient) for age (in years), G onset rate (in G/sec), and heart rates (BHR-baseline heart rate, PHR-peak heart rate, and HR_PR – post run heart rate in beats per min) in the study.

Attributes	Flg_H	G_onset	BHR	PHR	HR_ PR	PHR GOR	PHR ROR	Age
Flg_H								
CC	1	−0.172**	−0.146*	−0.19**	−0.145**	−0.336**	−0.162**	0.860**
Sig	533	0.000	0.000	0.000	0.001	0.006	0.000	0.000
N		523	524	533	509	56	477	533
G_onset (G/sec)								
CC	−0.17**	1.000	0.276**	0.081*	0.229**	Constant GOR	−0.083*	−0.187**
Sig	0.000	.	0.000	0.024	0.000		0.028	0.000
N	523	600	590	600	571		532	600
BHR								
CC	−0.15**	0.276**	1.000	0.214**	0.526**	0.139	0.116**	−0.146**
Sig	0.000	0.000	.	0.000	0.000	0.129	0.003	0.000
N	524	590	614	614	587	68	546	614
PHR								
CC	−0.19**	0.081*	0.214**	1.000	0.307**	1.000**	1.000**	−0.154**
Sig	0.000	0.024	0.000	.	0.000	0.000	0.000	0.000
N	533	600	614	624	595	68	556	624
HR_ PR								
CC	−0.15**	0.229**	0.526**	0.307**	1.000	−0.089	0.087*	−0.093**
Sig	0.001	0.000	0.000	0.000	.	0.247	0.023	0.012
N	509	571	587	595	595	61	530	595
PHR GOR								
CC	−0.34**	Constant GOR	0.139	1.00**	−0.089	1.000		−0.292**
Sig	0.006		0.129	0.000	0.247	.		0.008
N	56		68	68	61	68		68
PHR ROR								
CC	−0.16**	−0.083*	0.116**	1.00**	0.087*		1.000	−0.134**
Sig	0.000	0.028	0.003	0.000	0.023		.	0.001
N	477	532	546	556	530		556	556
Age (years)								
CC	0.860**	−0.187**	−0.146*	−0.15**	−0.093**	−0.292**	−0.134**	1.000
Sig	0.000	0.000	0.000	0.000	0.012	0.008	0.001	.
N	533	600	524	624	595	68	556	624

**: Correlation is significant at the 0.01 level, *: Correlation is significant at the 0.05 level (2 tailed)

was a significant rise in heart rate during exposure to high-G which remained elevated post-run. It was significantly higher among the young and inexperienced pilots who are probably due to the tendency to pull harder in comparison to other pilots who with experience tends to be more adjusted and pull slower to meet the desired G-level during the high-G training.

Age and experience (flying hours) had a significant negative correlation with baseline, peak, and post-run heart rate responses [Table 3]. Although there were a significant difference in PHR and post-run heart rate responses between pilots of 20–30 years and 31–35 years, this relationship was not consistent among elder pilots. This could be due to the insufficient no of subjects in the higher age groups (41–45 years had 12 and 46–50 years had only two pilots). The PHR response appears to be the result of the combined effect of G onset rate, G level, duration of G exposure, the intensity of AGSM, use of AGS, age, and flying experience of the pilot which, in turn, also affects the recovery heart rate post-run.[3] These factors may not be significant in isolation as revealed by low to negligible correlation, which, however, may affect cardiovascular response significantly if acted together in combination.[12] Furthermore, the PHR was not significantly different during various ROR runs (4.5G TT–9G TT). This could be due to the effective anti-G straining maneuver (AGSM) performed during such runs with similar intensity despite the differing G-levels.

The mean PHR during the ROR run was much higher (110%) than the maximum target heart rate calculated by the formula 220-age given by Fox *et al.* to indicate exercise intensity.[13] At the same time, the PHR attained was 87% of the maximum target heart rate during the GOR runs as subjects were relaxed and no AGSM was performed during such runs. This heart rate response appears to be independent of the age and experience of pilots as the rise in heart rate was not significantly different between young and experienced and Ab Initio and other pilots. The heart rate response gives a glimpse of the intensity of stress the cardiovascular system has to undergo to endure a high-G environment.[14] The cardiovascular system of even a relaxed sitting subject during a GOR run is stressed to a workload akin to Zone 4, that is, a hardcore anaerobic training zone. This stress reaches a maximum effort zone when the subject performs AGSM in the high-G environment. This could be because lung compliance reduces due to increased abdominal pressure during sustained exposure to high-G. The AGS and AGSM, further, aggravate the reduction in lung compliance. The reduced compliance and increased weight of the chest wall structures increase the work of breathing in proportion to increased +Gz. Glaister reported that a total increase of 55% in the work of breathing occurs at +3Gz.[15] This could alone explain the cardiovascular stress imposed on a relaxed seated subject akin to a hardcore anaerobic training zone during GOR runs. This observation re-emphasizes the need for anaerobic physical conditioning for fighter pilots.

CONCLUSION

The heart rate responses of younger and inexperienced pilots were significantly higher than the elder and experienced pilots. The higher BHR among younger pilots could be psychogenic due to inexperience and higher baseline G level. The higher PHR among younger pilots could be due to inexperience and a tendency to pull harder during high-G training.

Declaration of patient consent

Patient consent is not required as patients identity not disclosed or compromised.

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Nil.

Conflicts of interest

There are no conflicts of interest.

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