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ALTITUDE TOLERANCE OF GENERAL AVIATION PILOTS WITH NORMAL OR PARTIALLY IMPAIRED SPIROMETRIC FUNCTION

I. Introduction.

Recent studies indicate that the prevalence of chronic obstructive pulmonary disease (COPD) is increasing in the United States population (1,12), and the risk of its incurrence is estimated at 5 to 10 times greater in men than in women (3). Several variations of COPD of "sufficient degree to be symptomatic" and/or "to interfere with pulmonary function" are among the conditions for which medical certification of airmen is denied or deferred (5). Unless clinically indicated, quantitative spirometric evaluation is not a mandatory part of the aeromedical examination. Quantitative spirometry in a recent study of 257 commercial airline pilots (40-59 yr of age) showed that minor-to-moderate spirometric impairment existed in 12 percent of this population sample and was highly correlated with age and cigarette smoking (3). Substantial degrees of spirometric impairment could adversely affect safe flight by the general aviation pilot breathing only ambient air at cabin altitudes approaching 12,500 ft.

Because commensurate spirometric data from general aviation pilots did not appear to exist in the published medical literature, a parallel study was made. The forced vital capacity (FVC), the 1-s forced expired volume (FEV_1), the forced midexpiratory flow ($FEF_{25-75\%}$), the FEV_1/FVC x 100 ($FEV_1\%$), and the maximum ventilatory volume were quantitatively assessed in 181 male general aviation pilots. This population sample included nonsmokers, smokers, and ex-smokers in approximately equal numbers. Based on the combined data for $FEV_1\%$ and $FEF_{25-75\%}$, minor or greater degrees of spirometric impairment were manifested by 25.4 percent of the pilots and moderate or greater degrees by 12.7 percent. Most of the impairment was manifested in the smokers and ex-smokers. The first sharp rise in moderate impairment for these two subgroups occurred in the fourth decade of age. Details of this study have been published in a previous report (9).

Whether the quantitated minor-to-moderate spirometric impairment observed in the previous study (9) compromises safe flight to any degree can be ascertained only by testing such spirometrically impaired pilots in critical aspects of flight safety, such as altitude, fatigue, and orthostatic tolerances. This present study deals with the assessment of altitude tolerance in a sample from this same group of pilots.

II. Materials and Methods.

Selection of Subjects. Volunteer males were recruited from subjects of a recently completed study on spirometric assessment (9). Each volunteer was currently a medically certified general aviation pilot. For the purpose of this study, spirometric impairment was defined as an $FEF_{25-75\%}$ value of less than 80 percent of the predicted normal value. The predicted normal values for this parameter are based on the study of Morris et al. (11). Ten pilots having an average $FEF_{25-75\%}$ value of 65.1 percent composed the spirometrically impaired (SI) group. All their other spirometric parameters were grossly normal. The altitude tolerance of this group was compared to a group of spirometrically normal (SN) pilots. Spirometric normality is defined here as a value of 80 or more percent of the predicted normal value for all five spirometric parameters assessed in the preceding study (9). The $FEF_{25-75\%}$ values of the SN pilots covered a range of 102.0-140.2 percent of their predicted normal values. These two groups were age-matched as closely as possible. Each group contained eight smokers, one ex-smoker, and one nonsmoker. The vital statistics of both groups are presented in Table 1.

Protocol and Parameters. Cardiorespiratory functions were assessed in each pilot seated comfortably while breathing only ambient air in an altitude chamber during consecutive periods of 10 min at ground level (GL), 15 min at 8,000 ft, and 30 min at 12,500 ft. The interaltitude excursion rate was controlled at approximately 1,000 ft/s. The average altitude-chamber temperature for all 20 experiments was 23.5° C.

All specific parameters were assessed at the end of the GL period, the end (A_1) of the 8,000-ft altitude period, and both

TABLE 1. Summary of Age, Height, Weight, and Smoking Data

		Age (yr)	Ht (cm)	Wt (kg)	FRW (%)	Amount Smoked (pack-yr)
SN	$\bar{x}$	46.5	70.9	84.9	104.8	32.4
	SEM	3.0	0.9	3.8	3.8	6.5
SI	$\bar{x}$	47.6	69.3	83.6	106.6	32.2
	SEM	2.5	0.8	3.3	3.6	7.6

midway (A_2) and the end (A_3) of the 12,500-ft altitude period. Each parameter was assessed during steady-state conditions as the mean value of a 2-min sampling period. Systolic (SBP) and diastolic (DBP) blood pressures were measured by automatically cycled auscultative sphygmomanometry and expressed in mm Hg. Pulse pressure (PP) and mean arterial pressure (AP) (8) were calculated from the SBP and DBP data. Pulmonary ventilation ($\dot{V}E$) was measured by a precalibrated mass flowmeter (10). An oral breathing valve and nose clip allowed the continuous flow-by measurement of each exhalation. To normalize differences in body size, we expressed all VE measurements as ml/min/kg body weight at body temperature and pressure, saturated (BTPS) conditions. Arterial oxyhemoglobin saturation, expressed in percentage (% HbO_2), was measured with an ear oximeter (14). Temporal artery blood-flow velocity (TAFV) was measured with an externally positioned Doppler device and expressed in cm/s (7). This device senses the direction as well as the velocity of flow (7). Electrocardiographic function was monitored with the CM_5 single-lead electrocardiogram (ECG) (2). The electrical signal from this ECG lead was fed simultaneously to: (i) an oscilloscope for continual visual monitoring of the signal for ischemia and/or arrhythmia; (ii) a cardiotachometer for continual indication of heart rate (HR); and (iii) a standard ECG recorder for scheduled periodic recording and opportunistic recording of any substantial ECG changes as observed simultaneously on the oscilloscope. Steady-state HR measurements in beats/minute (bpm) were obtained from either the pulsatile mode of the TAFV recording or that of the single-lead ECG.

Each subject was given a comprehensive equipment and procedure orientation preceding the day of the experimental run. All the subjects had had at least one prior training experience in an altitude chamber. All altitude exposures were monitored by a staff physician.

III. Results.

The cardiorespiratory parameters assessed for altitude tolerance in both the SN and SI pilot groups are summarized in Tables 2 and 3. In general, only small quantitative differences between the SN and SI pilots emerged from these data, and none of these differences was statistically significant at the probability level of 0.05 or less. At altitude,

TABLE 2. Summary of Blood Pressure Data

		SBP(mm Hg) GL	A_1	A_2	A_3
SN	$\bar{x}$	122.1	121.1	119.9	118.5
	SEM	4.7	4.5	2.9	4.4
SI	$\bar{x}$	122.2	123.4	121.3	122.1
	SEM	3.8	3.2	3.6	4.1
		DBP(mm Hg) GL	A_1	A_2	A_3
SN	$\bar{x}$	77.8	77.1	76.5	74.2
	SEM	2.3	3.1	2.8	2.5
SI	$\bar{x}$	78.9	76.8	74.0	73.2
	SEM	2.2	1.9	2.1	2.4
		PP(mm Hg) GL	A_1	A_2	A_3
SN	$\bar{x}$	44.3	44.0	43.4	44.3
	SEM	2.8	2.3	2.1	3.0
SI	$\bar{x}$	45.3	46.7	47.3	48.9
	SEM	2.6	2.2	2.4	2.6
		AP(mm Hg) GL	A_1	A_2	A_3
SN	$\bar{x}$	92.6	91.8	91.0	89.0
	SEM	3.0	3.4	3.1	2.9
SI	$\bar{x}$	92.0	92.3	89.8	89.5
	SEM	2.6	2.2	2.4	2.8

TABLE 3. Summary of Heart Rate, Pulmonary Ventilation, Arterial Oxyhemoglobin Saturation, and Temporal Artery Blood Flow Velocity Data

		HR(bpm) GL	A_1	A_2	A_3
SN	$\bar{x}$	70.2	70.9	73.7	72.1
	SEM	2.9	2.9	2.7	3.4
SI	$\bar{x}$	73.1	74.0	77.8	74.4
	SEM	2.2	2.3	2.8	3.1
		$\dot{V}E$(ml/min/kg body weight) GL	A_1	A_2	A_3
SN	$\bar{x}$	106.9	105.3	108.6	104.6
	SEM	11.0	7.7	4.8	6.0
SI	$\bar{x}$	99.9	102.9	112.1	108.6
	SEM	5.9	6.1	6.2	6.0
		$\%HbO_2$ GL	A_1	A_2	A_3
SN	$\bar{x}$	95.4	92.4	85.6	85.8
	SEM	0.4	0.7	1.1	1.1
SI	$\bar{x}$	95.1	91.9	85.1	84.4
	SEM	0.3	0.3	1.1	1.1
		TAFV(cm/s) GL	A_1	A_2	A_3
SN	$\bar{x}$	4.5	4.1	3.9	3.5
	SEM	0.4	0.5	0.4	0.5
SI	$\bar{x}$	6.0	5.5	5.2	4.4
	SEM	0.9	0.9	1.0	0.8

blood pressure functions appeared to be maintained quite well in both groups. Although statistically nonsignificant, the altitude hypoxia appears to have displaced the SI group more than the SN group. This displacement is indicated in the relatively higher SBP, PP, HR, and TAFV values at altitude. The % HbO_2 of the SI group was maintained quite well at the higher of the two altitudes at the apparent cost of a slightly greater $\dot{V}E$ than that of the SN group.

None of the 20 pilots who took part in this study manifested any ischemic ECG changes at GL or at either altitude. Two of the SN and one of the SI pilots manifested unifocal premature ventricular contractions (PVC) in their respective ECG recordings at GL. The PVC frequency in all three cases was quite low. Because the PVC frequency did not increase, and the otherwise normal character of the three ECG tracings did not deteriorate at both altitudes, this condition was medically judged to be benign. It may be a random coincidence, but all three of these pilots are chronic cigarette smokers.

IV. Discussion and Summary.

As previously reported (9), spirometric assessment of 181 male general aviation pilots revealed moderate degrees of impairment in 12.7 percent of this population sample. This moderate impairment was manifested mainly in the two spirometric parameters (FEV_1% and $FEF_{25-75\%}$) usually deemed most sensitive in the detection of functional decrements in the peripheral airways. All the other assessed spirometric parameters were found to be grossly normal. Peripheral airway impairment is considered to be one of the earliest manifestations of COPD (6).

Because the altitude tolerance of the 10 SI pilots appeared to be generally equal to that of the 10 SN pilots, the detection of a pilot having any possibility of spirometrically related intolerance to the sedentary altitude profile used in this study would have to be reflected by a greater spirometric degradation than just an $FEF_{25-75\%}$ value of 65.1 percent. Conversely, any smaller spirometric decrement should be predictive of normal tolerance to the same altitude profile. Therefore, one distinct value of this study is the delineation of an objective $FEF_{25-75\%}$ spirometric

screening norm for acceptable tolerance to general aviation altitudes.

The moderate degree of $FEF_{25-75\%}$ impairment (65.1 percent of predicted normal values) did not appear to diminish normal tolerance to an altitude-exposure profile somewhat representative of average maxima encountered in general aviation flights under ambient air breathing conditions. Whether this same degree of spirometric impairment constitutes an incursion to any degree on other critical aspects of flight safety, such as fatigue and orthostatic tolerances, remains to be ascertained empirically. Such studies are currently under consideration.

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