

Women's G Tolerance

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G tolerances of 102 women and 139 men subjected to Standard Medical Evaluation (Medeval) G Profiles were compared. Unpaired t-tests revealed no significant difference between the women and men in either relaxed or straining G tolerance. Covariance analysis controlling for differences in tolerance due to age, height, weight, and activity status revealed the women to have marginally lower tolerance; the analysis also identified height as a factor having a strong negative influence on G tolerance, and weight as having a positive influence. When the women were matched only by height to the men in the comparison group, the women's mean G tolerances were significantly lower than the men's. On Standard Training G Profiles 88% of 24 women and 80% of 213 men completed the runs, but this difference was not significant. G tolerances of 47 women were measured on the Medeval Profiles both during and between menses, but no significant differences related to menstruation were found. No important differences between women and men in signs or symptoms of G stress were observed, except for two instances of urinary stress incontinence in women during the Training Profiles. We conclude that women should not categorically be excluded from aircrew duties for reasons of G intolerance.

AS OF APRIL 1982, 227 women were performing aircrew duties in the United States Air Force: 143 pilots, 63 navigators, and 21 flight surgeons. A number of these women are routinely exposed to moderate +G_z stress as instructor pilots in jet trainer

aircraft, and others experience high +G_z stress as rear-seaters in high-performance fighter/attack aircraft.

Although we have assumed that women's +G_z tolerance is not substantially different from men's, there are very few data to support that assumption. Previous determinations of +G_z tolerance distributions for large numbers of subjects have been based on data obtained from male subjects exclusively. Chief among these is the classic work of Cochran *et al.* (3), who reported in 1954 the mean, standard deviation, and range of +G_z tolerance for each of three standard endpoints (peripheral visual loss, blackout, and loss of consciousness) in 1000 subjects. Nearly a quarter century later, Gillingham (9) reported means and standard deviations of +G_z tolerance, using only the peripheral visual loss endpoint, in subgroups of a 415-subject male population. Other studies of +G_z tolerance have generally involved the use of smaller groups of male subjects, and the results of these studies have been comprehensively reviewed (7,23). Notable exceptions, however, are the relatively recent experiments conducted by NASA, in which men and women in several age groups were subjected to +G_z-stress testing before and after simulated weightlessness (bed rest). Newsom *et al.* (19) reported data indicating that the mean durations of pre-bed rest tolerance to +3.0, +3.5, and +4.0 G_z were markedly less in 12 women between ages 24 and 35 than they were in a comparable group of 9 men studied by Shumate *et al.* (16,26). In the same report, however, Newsom *et al.* also compared +3.0-G_z tolerance time of seven of the women in their study with that of another group of seven men: there were no significant differences between these groups in the pre-bed rest and immediately post-bed rest conditions, but the women had a significantly

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The research reported herein was conducted with volunteer subjects in accordance with Air Force Regulation 169-3, 12 Feb 79: Use of Human Subjects in Research, Development, Test and Evaluation.

higher tolerance than that of the men after 5–7 d of recovery. Sandler *et al.* (25) subsequently found the +3.0- G_z pre-bed rest tolerance time of 10 35- to 45-year-old women to be significantly less than that for a group of 6 similarly aged men; additional analysis of Sandler's data reveals that the women also had a significantly ($p < 0.01$) lower post-bed rest tolerance time than did the men. Finally, Goldwater and Sandler (13) reported statistically insignificant differences between tolerance times of nine 55- to 65-year-old women and those of eight men in the same age group, under both pre-bed rest and post-bed rest +1.5- G_z , +2.0- G_z , and +3.0- G_z conditions. Other data presented by Goldwater and Sandler on pre-bed rest and post-bed rest +3.0- G_z tolerance times of 45- to 55-year-old women and those of similarly aged men showed no significant tolerance differences between the women and the men.

Prior experience with female centrifuge subjects at the United States Air Force School of Aerospace Medicine (USAFSAM) consists of 40 women who were exposed to + G_z and + G_x stress on a total of 544 centrifuge runs between 1964 and 1980. No conclusion regarding women's G tolerance can be drawn from this experience because the G-exposure conditions were not consistent; but there was no indication that these women had either better or worse G tolerance than men, or that their symptoms of G intolerance were any different from those experienced by men.

Data on women's + G_z tolerance, obtained from a large sample representative of female aircrew, are needed for at least two reasons: sound advice regarding limitation of women's aircrew duties in the high-G environment must be based on valid G-tolerance data, and G-tolerance norms for aeromedical evaluation of female aircrew are not available. The study reported here was conceived to provide such data.

MATERIALS AND METHODS

In this study, 102 USAF women, either students obtaining professional training at USAFSAM or military personnel permanently assigned to Brooks Air Force Base, underwent + G_z -tolerance testing on the USAFSAM centrifuge. The majority were student flight nurses; medical technicians, student flight surgeons, and miscellaneous others comprised the remainder.

Subjects' ages ranged from 19 to 41 years, with a mean of 27.3 ± 3.9 S.D. Prior to exposure to G stress, all subjects were given a general physical examination and were required to meet USAF Flying Class III standards. In addition, a gynecologist obtained from each subject a gynecologic history and performed a pelvic examination. Women with evidence of reproductive system disease or abnormality, as well as those having positive serum pregnancy tests, were not allowed to participate in the study. Prior to G-tolerance testing, subjects' height, weight, and other anthropometric parameters were measured, and their age and physical activity status were recorded. The activity status was coded 4 if the subject engaged in frequent and regular exercise, 3 if she had only occasional exercise, 2 if she was essentially sedentary, and 1 if she had a recent illness necessitating substantial bed rest. Electrocardiographic recordings (sternal and biaxillary leads) were obtained from all subjects during G-tolerance testing.

G tolerances of the 102 women were determined by means of the USAFSAM Standard Medical Evaluation (Medeval) G Profiles (Fig. 1). The first of these profiles is a gradual-onset run (GOR1), during which the G force rises steadily at $0.067 \text{ G}\cdot\text{s}^{-1}$ until the visual endpoint is reached. This endpoint, which is the same for all runs, is either a bilateral 100% loss of peripheral vision at 25° lateral to the fixation point or a subjectively greater than 50% loss of central vision. A conventional centrifuge light-bar with two peripheral green lights and one central red light is used to determine the visual endpoint in accordance with recommended practice (27).

After the GOR1 profile is completed, a series of rapid-onset runs (RORs) is accomplished. In these, the subject rides relaxed at $1.0 \text{ G}\cdot\text{s}^{-1}$ to a predetermined G level, which is sustained for 15 s or until the visual endpoint is reached. The first ROR is to 2.8 G; if the visual endpoint is not reached during this run, the subject is exposed to another ROR that goes 0.3 G higher, and so on until the endpoint is reached. The highest G level at which the subject goes the full 15 s is called the "ROR-pass" level; the G level at which the run is terminated early because the visual endpoint is reached is called the "ROR-fail" level.

Following the series of RORs, a second GOR (GOR2) is accomplished in the same way as GOR1.

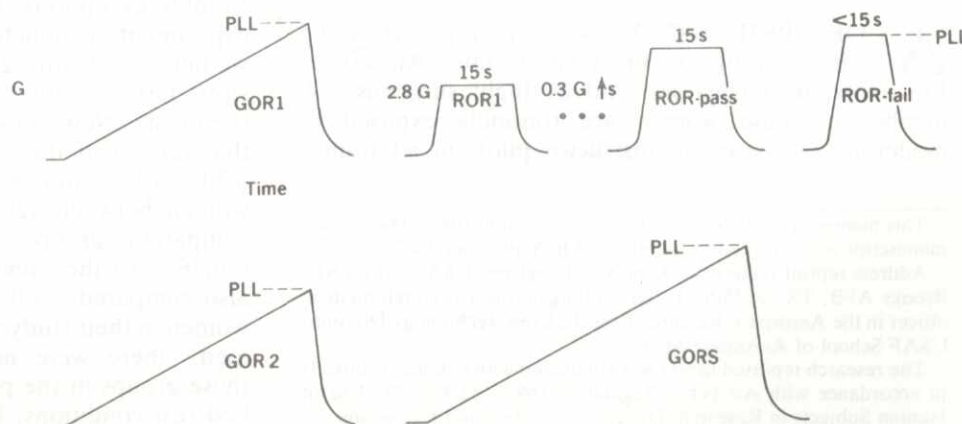


Fig. 1. Standard Medical Evaluation (Medeval) G Profiles used in this study. GOR: gradual-onset run— $0.067 \text{ G}\cdot\text{s}^{-1}$ onset rate. ROR: rapid-onset run— $1.0 \text{ G}\cdot\text{s}^{-1}$ onset rate. PLL: peripheral light loss—the visual G-tolerance endpoint.

The reason for the second GOR is that the first one, which serves to initiate a subject to the procedures and experiences associated with centrifuge exposure, tends to generate G-tolerance data distorted by the subject's initial apprehension.

The last run of the Medeval Profiles is a gradual onset run with straining (GORS), during which the subject performs an anti-G straining maneuver to increase his G tolerance voluntarily to the highest possible level before reaching the visual endpoint. Subjects are instructed on proper performance of the L-1 anti-G straining maneuver (forceful expiratory effort against a completely closed glottis, rapid exhalation/inhalation at approximately 3-s intervals, sustained arm and leg muscle tensing) prior to G exposure, and are coached on the maneuver as necessary during centrifuge runs requiring straining. The GORS run generates the highest G stress of the Medeval Profiles and is terminated at 8.0 G if the subject reaches that level. On all Medeval runs, a seatback angle of 13° is used, the subject's feet are flat on the floor, and no anti-G suit is worn.

In addition to the Medeval Profiles, 24 women were subjected to the USAFSAM Standard Training G Profiles (Fig. 2). This series of rapid-onset runs with straining (RORS) consists of a 3.0-G, 15-s, warmup run; a 5.0-G, 30-s, practice run, during which the subjects' anti-G straining maneuver is critiqued and perfected; and a 7.0-G, 15-s, test run. Subjects completing the 7-G test run without experiencing the visual endpoint or losing consciousness are said to meet the USAFSAM G-tolerance standard. While being exposed to the Standard Training Profiles, subjects wear the conventional USAF CSU-13B/P anti-G suit inflated by means of the standard USAF anti-G valve according to the conventional pressurization schedule. Although the seatback angle is the same for the Training Profiles as it is for the Medeval Profiles, subjects press their feet against simulated rudder pedals during the Training Profiles to help them strain as effectively as possible.

There were 47 women who were tested twice on the Medeval Profiles, once during menses and once intermenstrually. Although no attempt was made to control for order effect by having equal numbers of menstrual and intermenstrual subjects exposed for the first time to the Medeval Profiles, there actually was

a rough balance with respect to order of exposure, as 21 women (45%) were menstruating during their first exposure and 26 (55%) were not.

G tolerance was the main parameter of interest in this study. On the GORS, the peak G level reached was recorded as the subject's G tolerance. On the RORS, the highest G level sustained for 15 s by the subject without his experiencing the visual endpoint (ROR-pass) was considered his G tolerance. In addition to G tolerance, preexposure resting heart rate and maximal heart rate during runs were recorded, as were any unusual symptoms or electrocardiographic abnormalities occurring during or after runs. After each G-tolerance testing session the women answered a list of specific questions about feminine matters: What day of your menstrual cycle is it? Are you menstruating today? What type of brassiere were you wearing during the G-tolerance test (ordinary type, athletic, other, none)? Did you have any breast discomfort during the G stress? Did you have any other problems of a female nature during G stress?

Data analysis supported three main comparisons: 1) the G tolerance of women vs. that of men on the Medeval Profiles; 2) women's G tolerance vs. men's on the Training Profiles; and 3) women's G tolerance during menses vs. that during the intermenstrual period. To compare the women's and men's tolerances on the Medeval Profiles, we compiled the tolerance data from 139 men who were tested in the same manner and over the same testing period (1981-82) as the women. Although in a preliminary report (12) we contrasted the tolerances of 85 women with those of a 434-man comparison group, the concurrently tested 139-man group represents a more valid comparison group, in that the 102 women and the 139 men were served by the same centrifuge crew and therefore were subjected to more nearly identical procedures. The men in the comparison group, like the women, included only those for whom the Medeval Profiles were their first exposure to G stress on a centrifuge. This group consisted of new experimental subject candidates, students in professional courses at USAFSAM who were given centrifuge rides as part of their training, and aircrew undergoing centrifuge testing as part of an aeromedical workup at USAFSAM for relatively minor medical conditions. The age range of this comparison group was 19 to 48 years, with a mean of 31.8 ± 8.6 S. D. To minimize a small bias that might result from including in the male comparison group those patients with conditions that could be construed as G-related, we removed from the group 11 patients undergoing evaluation for an episode of loss of consciousness (4 in flight, probably G-induced; 7 vasovagal). The resulting 128-man group was then used to make the same G-tolerance comparisons between women and men as was the original 139-man group. Two-tailed unpaired *t*-tests were used to determine whether there were significant differences in G tolerance between the 102 women and the 139 or 128 men who underwent the Medeval Profiles. To control for differential effects of variables that could conceivably influence G tolerance, an analysis of covariance was also accomplished: age, height, weight, and physical activity status were chosen

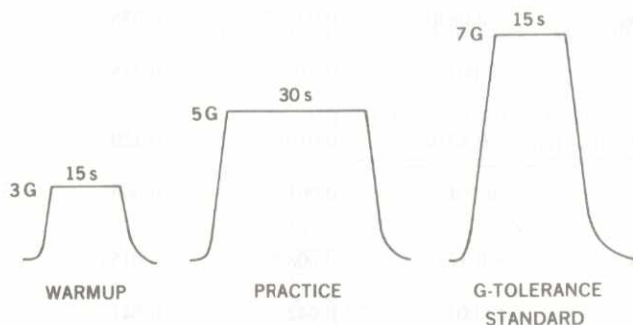


Fig. 2. Standard Training G Profiles used in this study. All are rapid-onset runs with 1.0 G·s⁻¹ onset rate.

as covariates, and the adjusted Medieval G tolerances of the 102 women were compared with those of the 139 men. In addition to the comparisons made between the main groups of women and men, paired comparisons were made between subgroups of subjects matched with respect to age, height, weight, and physical activity status; paired *t*-tests were used in these comparisons.

The 24 women who were subjected to the Training Profiles were categorized as to whether they passed or failed the 7-G, 15-s, RORS G-tolerance standard. As a comparison group, 213 men who had attempted the Training Profiles during the 1981-82 period were identified; they also were categorized as to whether they had passed the G-tolerance standard. An alternate contrast was provided by removing from the 213-man comparison group the 11 patients who were being evaluated for loss of consciousness. Chi-square tests were performed to determine whether a significant difference existed between the 24 women and the 213 or 202 men in their ability to tolerate the 7-G, 15-s run.

For the group of 47 women whose G tolerance was measured on the Medieval Profiles both during menses and intermenstrually, an analysis of variance for a crossover design with unequal numbers of subjects in the treatment orders was performed, the object being to determine whether significant G-tolerance differences were associated with menstruation.

RESULTS

Fig. 3 and Table I contain the results of the G-tolerance testing of the women and the men on the Medieval Profiles. Although the initial run (GOR1) was completed by all subjects, attrition during the test resulted in successively smaller numbers of subjects completing successive portions of the test. Motion sickness was the usual reason for a subject's not

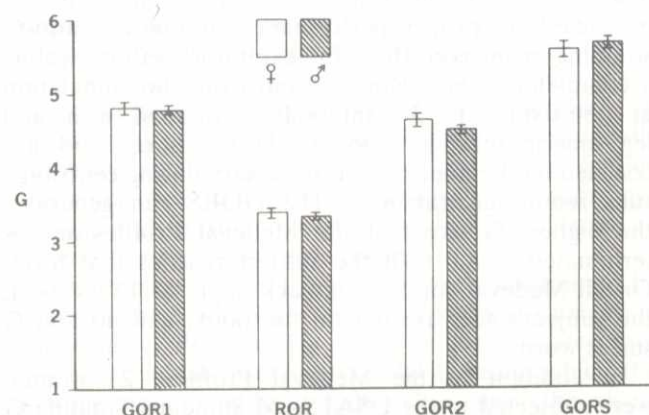


Fig. 3. G tolerances of women and men on Medieval Profiles. Means and standard errors of the mean (indicated by brackets) were obtained from data in Table I.

TABLE I. G TOLERANCES OF WOMEN AND MEN ON MEDICAL EVALUATION (MEDEVAL) PROFILES.

Profile	Women		Men		Men w/o LOC*		Women vs. Men	Women vs. Men w/o LOC
	N	$\bar{X} \pm S.D.$	N	$\bar{X} \pm S.D.$	N	$\bar{X} \pm S.D.$	p (t-test)	p (t-test)
GOR1	102	4.81 ± 0.79	139	4.79 ± 0.75	128	4.82 ± 0.73	0.806	0.906
ROR-pass	92	3.39 ± 0.55	136	3.35 ± 0.49	125	3.37 ± 0.49	0.598	0.787
GOR2	83	4.64 ± 0.83	129	4.52 ± 0.72	118	4.55 ± 0.71	0.278	0.443
GORS	79	5.59 ± 0.92	114	5.67 ± 0.81	103	5.68 ± 0.79	0.532	0.506

*LOC: Loss of consciousness as a symptom for which medical evaluation was performed.

TABLE II. RESULTS OF COVARIANCE ANALYSIS OF WOMEN'S AND MEN'S G TOLERANCES ON MEDEVAL PROFILES [MODEL: G tolerance = a + b (age) + c (height) + d (weight) + e (activity)].

Profile		Intercept	Age Coefficient	Height Coefficient	Weight Coefficient	Activity Coefficient
GOR1	women	12.41				
	men	12.65	0.00792	-0.146	0.0113	0.103
	p* (2-tail)	0.087	0.319	<0.001	<0.001	0.085
ROR-pass	women	7.84				
	men	8.00	0.00666	-0.0830	0.00547	0.0365
	p	0.117	0.241	<0.001	0.012	0.395
GOR2	women	11.55				
	men	11.69	0.0113	-0.137	0.0107	0.120
	p	0.333	0.186	<0.001	0.001	0.066
GORS	women	12.46				
	men	12.76	0.0108	-0.125	0.00820	0.0158
	p	0.099	0.306	<0.001	0.042	0.841

*Ho for p values in first column is that women's and men's intercepts are equal to each other, Ho for remaining p values in that respective coefficients are equal to zero.

completing all the profiles; apprehension, discomfort, and cardiac dysrhythmias were other common reasons. The percentage of female subjects who completed all the Medieval Profiles was slightly lower than that for the male subjects (77% vs. 82%, respectively). Of importance in this study, however, is that the women's and men's mean G tolerances on the Medieval Profiles were very similar—essentially the same, as evidenced by the lack of any differences even approaching statistical significance.

The analysis of covariance yielded the results presented in Table II. When the women's and men's G tolerances were adjusted so as to negate the effects of age, height, weight, and physical activity, the women's tolerances were marginally lower than the men's: *p* values around 0.10 were obtained for the differences in GOR1, ROR-pass, and GORS tolerances (*p* = 0.087, 0.117, and 0.099, respectively). We interpret these differences as being due to sex and to other factors not identified. The most striking result of the analysis, however, was the extremely significant effect of height on G tolerance when the effects of all other factors were controlled. The probability of observing height coefficients as great as those found, if they were in fact zero, was less than 0.001 for all profiles. The negative sign of the coefficients indicates that G tolerance was inversely proportional to height. Weight also influenced G tolerance, as shown by probabilities of less than 0.05 associated with the weight coefficients for all profiles. The positive sign of these coefficients means that, other factors being equal, heavier subjects tended to have higher G tolerances. Age had no effect on G tolerance. Greater physical activity was associated with higher tolerances, at the *p* < 0.10 level of significance, for the GOR1 and GOR2 profiles—suggesting that relaxed tolerance to gradual-onset G stress might be influenced by physical condition.

The matched-pair contrasts revealed no major differences between the women's and men's G tolerances for the groups matched by age (70 pairs), weight (26 pairs), and activity status (84 pairs), although the weight-matched and activity-matched women had GOR2 tolerances slightly greater than those of the men (*p* < 0.10). The G tolerances of the height-matched women, on the other hand, were considerably lower than those of the height-matched men, as summarized in Table III. In this comparison the significance of the differences reached the *p* < 0.05 level for all but the GOR2 G profile.

Of the 24 women who attempted the Training

TABLE IV. PERFORMANCE OF WOMEN AND MEN ON 7-G, 15-S, G-TOLERANCE STANDARD.

	Women	Men	Men w/o LOC
Failed	3	43	39
Passed	21	170	163
Total	24	213	202
Success Rate	0.88*	0.80	0.81

*Differences between success rate of women and that of either group of men are not significant at *p* < 0.05 level (chi-square).

Profiles, 21 passed the 7-G, 15-s, G-tolerance standard: the women thus had a success rate of 88% (Table IV). Of all 213 men attempting the Training Profiles, 170 completed the 7-G run: their success rate was thus 80%. When the 11 men with a history of loss of consciousness were excluded from the analysis, the rate was 81%. The small number of women who failed the 7-G run admittedly compromised the utility of the chi-square test used in the analysis, but we were unable to show that the success rate for the women was significantly different from either success rate for the men.

The G tolerances of the 47 women exposed twice to the Medieval Profiles—once during menses and once intermenstrually—were essentially the same under the two conditions (Table V). Interestingly, the analysis of variance used to compare the women's menstrual and intermenstrual G tolerances revealed that G tolerance was significantly higher on the second exposure to G stress than it was on the first (*p* < 0.01 for all profiles). The magnitude of this order effect is revealed in Table V.

The common symptoms of exposure to high-G stress on the centrifuge—including disequilibrium, motion sickness, uncomfortable feelings of distension in arms and legs, leg cramping, neck and back pain, numbness and tingling, fear, loss of consciousness, and various others—were reported at about the same overall rate for both women and men: 47% of the 102 women and 49% of the 139 men reported symptoms. When categories of symptoms were compared, only the category of emotional/psychosomatic symptoms showed a significant difference between the women and men (women 15%, men 6%; *p* < 0.05, chi-square test). Manifestations of apprehension contributed the major portion of this

TABLE III. G-TOLERANCE DIFFERENCES BETWEEN HEIGHT-MATCHED WOMEN AND MEN ON MEDIEVAL PROFILES.

Profile	N	Difference, Women - Men w/o LOC*	
		$\bar{X} \pm \text{S.D.}$	<i>p</i> (paired <i>t</i> -test)
GOR1	33	-0.55 ± 0.94	0.002
ROR-pass	30	-0.31 ± 0.59	0.007
GOR2	27	-0.30 ± 0.96	0.119
GORS	24	-0.50 ± 1.12	0.041

*Height-matched group did not include any men with history of LOC.

TABLE V. G-TOLERANCE DIFFERENCES ASSOCIATED WITH MENSTRUATION.

Profile	Difference, Menstrual - Intermenstrual						
	First Run Menstrual		First Run Intermenstrual		Unweighted \bar{X}	Pooled S.D.	p
	N	$\bar{X} \pm \text{S.D.}$	N	$\bar{X} \pm \text{S.D.}$			
GOR1	21	-0.19 ± 0.89	26	0.44 ± 0.59	0.12	0.74	0.26
ROR-pass	16	-0.26 ± 0.59	24	0.20 ± 0.32	-0.03	0.45	0.70
GOR2	15	-0.48 ± 0.64	23	0.25 ± 0.45	-0.12	0.53	0.20
GORS	15	-0.77 ± 0.76	22	0.63 ± 0.65	-0.07	0.70	0.57

difference, suggesting that the women either were more fearful than the men or were less reticent to express their fears in the testing situation. Motion sickness occurred in 35% of the women and 45% of the men (with symptoms progressing to emesis in 7% and 12%, respectively), musculoskeletal symptoms were reported by 11% of the women and by the same percentage of the men, and loss of consciousness occurred in 4% of the women as compared to 10% of the men; but none of these differences between the women and the men was significant at the $p < 0.05$ level.

The women's maximal heart rates during all the Medeval Profiles, as well as their mean resting heart rate immediately prior to the Medeval runs, were significantly higher than the comparable heart rates for the men (Table VI). During the Training Profiles and the associated prerun period, however, there were no significant differences between the women's and men's heart rates. The total incidence of cardiac dysrhythmias occurring in the 102 women during G-tolerance testing (53%) was similar to that occurring in the 139 men (56%). When the observed dysrhythmias were grouped into broad categories for contrasting incidences between the women and men, the following results were obtained: tachydysrhythmias—women 58%, men 50%; bradydysrhythmias—women 9%, men 14%; ST-T segment changes—women 2%, men 5%. None of these differences was significant, nor were any significant differences found when the dysrhythmias were grouped into less broad categories (e.g., ventricular tachydysrhythmias).

Of particular interest was whether high-G stress would cause the women to have any peculiarly feminine symptoms, such as breast or pelvic discomfort.

Although 82% of the women's runs were accomplished with subjects wearing either a conventional bra or no bra (18% were with athletic or extra-support bras), none of the women reported symptoms of any sort relating to their breasts. One subject reported that menstruation with uterine cramping began during the Medeval Profiles; she believed the G stress precipitated the menstrual flow. Two women experienced urinary incontinence during the Training Profiles. Both were parous, had failed to urinate immediately prior to their centrifuge exposure, and observed that the pressure of the inflated abdominal bladder of the anti-G suit had made it impossible for them to hold their urine. Another woman, while fully conscious, allowed her head to fall forward at +5.6 G_z during a GORS profile and was unable to raise it, thus causing the run to be terminated. The rare prior occasions on which this has happened on the USAFSAM centrifuge occurred at +7.0 G_z or greater and involved male subjects wearing flight helmets.

The only potentially serious symptoms reported by the women in conjunction with the centrifuge testing were one case of calf and popliteal fossa pain and one case of headache with photophobia and nausea. In the former case, the subject was taking an oral contraceptive and was a habitual smoker; so we were concerned about the possibility of G-induced deep-vein thrombosis when, 3 d after the exposure to a maximum of +5.6 G_z on the Medeval Profiles, she complained of throbbing left calf pain and difficulty in walking. Our initial clinical impression was deep venous thrombophlebitis, so the subject was hospitalized. Subsequent examination and clinical tests, including venography, failed to confirm that impression; and the patient was released from

TABLE VI. PEAK HEART RATES OF WOMEN AND MEN, AT REST AND DURING G STRESS.

Profile	Women		Men		Men w/o LOC		Women vs. Men	Women vs. Men w/o LOC
	N	$\bar{X} \pm \text{S.D.}$	N	$\bar{X} \pm \text{S.D.}$	N	$\bar{X} \pm \text{S.D.}$	p (t-test)	p (t-test)
<u>Medeval</u>								
Prerun	101	104 \pm 23	139	90 \pm 20	128	90 \pm 21	<0.001	<0.001
GOR1	101	158 \pm 21	138	143 \pm 23	127	143 \pm 23	<0.001	<0.001
ROR-pass	88	134 \pm 21	129	121 \pm 20	119	121 \pm 20	<0.001	<0.001
GOR2	82	142 \pm 22	129	128 \pm 21	118	128 \pm 22	<0.001	<0.001
GORS	77	168 \pm 18	114	162 \pm 22	103	161 \pm 23	0.049	0.028
<u>Training</u>								
Prerun	24	99 \pm 17	213	100 \pm 19	202	100 \pm 19	0.805	0.806
3 G, 15 s	24	132 \pm 18	213	134 \pm 25	202	134 \pm 25	0.704	0.704
5 G, 30 s	24	166 \pm 11	206	161 \pm 22	197	161 \pm 22	0.274	0.275
7 G, 15 s	22	173 \pm 10	170	168 \pm 19	163	168 \pm 19	0.228	0.228

the hospital with a diagnosis of stress myositis. The other subject developed a basal headache, photophobia, and nausea 6 h after being exposed to a maximum of +6.6 G_z on the Medeval Profiles. Concerned that the symptoms might be those of an intracranial vascular accident resulting from high intravascular pressures associated with the anti-G straining maneuver, we arranged to have her examined immediately at a major medical center. The benign course of her illness and the appearance of similar symptoms in her uncentrifuged associates resulted in a final diagnosis of viral gastroenteritis. None of the men in the comparison group required more than momentary medical attention for any symptom.

DISCUSSION

The inherent G tolerances of women and men, as measured by centrifuge testing with standardized G profiles and tolerance endpoints, are essentially the same.

The results of the covariance analysis reveal a strong negative influence of height on G tolerance, a less strong positive influence of weight, and a weak negative influence of female sex and unspecified factors. One could reasonably infer from these results that the women gained a tremendous advantage in G tolerance by their being shorter than the men, on the average, but that the advantage was considerably diminished by their weighing less and, to a lesser extent, by their sex and other factors. The net effect was thus one of G-tolerance parity between the women and the men. Moreover, when the G tolerances of height-matched women and men were compared, the women had significantly lower tolerances; tolerances of weight-matched pairs were not significantly different, however. These results attest to the important effect of height on G tolerance, and suggest that if the height difference between women and men as a group were eliminated, women's G tolerance would be lower than men's.

This suggestion is supported by a simple calculation of the theoretical G protection afforded by the women's shorter stature. The 102 women in our sample had a mean height of 166.5 ± 7.3 cm ($\bar{X} \pm S.D.$). Height data were available for 138 of the 139 men in the comparison group, and their mean height was 180.3 ± 6.9 cm. The women were thus 13.8 cm (7.7%) shorter than the men. If this difference can be applied proportionally to the approximately 30-cm vertical heart-to-eye distance of males reported by Rushmer (24), then the women in our study had a 2.3-cm shorter heart-to-eye distance than the men. Since a 1.29-cm vertical column of blood is associated with a 1-mm Hg blood-pressure drop per G, the 2.3-cm hydrostatic-column height difference resulted in a 1.78-mm Hg per G eye-level blood-pressure conserving factor enjoyed by the women as a result of their shorter heart-to-eye distance. At 4.8 G (the GOR1 mean tolerance level for both the women and the men) the women on the average had 8.54 mm Hg less eye-level blood-pressure drop than did the men. Because the total eye-level blood-pressure drop for men is approximately 23.26 mm Hg per G ($30 \text{ cm} \div 1.29 \text{ cm/mm Hg per G}$), an 8.54-mm Hg difference in blood-pressure drop translates into about a 0.37-G difference

in G tolerance ($8.54 \text{ mm Hg} \div 23.26 \text{ mm Hg per G}$; or more directly, 7.7% of 4.8 G). This result is less than, but comparable to, the 0.55-G GOR1 mean tolerance difference observed between the height-matched women and men. At 3.4 G (the ROR-pass mean tolerance level for both the women and the men) the women had an estimated 6.05 mm Hg less eye-level blood-pressure drop due to the hydrostatic column effect than did the men; and this is equivalent to about a 0.26-G difference in G tolerance. The actual mean ROR-pass G-tolerance difference between the height-matched women and men, 0.31 G, is certainly comparable to the 0.26-G theoretical difference. Similar calculations for the GOR2 and GORS G-tolerance levels yield similar results. The relation between height and G tolerance, as measured in males and reported by Gillingham (10), can also be applied to the present study. The described regression equation for GORS tolerance, T_G , as a function of height, h , is:

$$T_G = 11.77 - 0.035 h$$

If we let h have the value of the height difference between the women and men in the present study, 13.8 cm, then the G-tolerance difference given by the slope term of the equation is 0.48 G. The actual difference between the height-matched women and men in GORS G tolerance was 0.50 G—remarkably close to the 0.48-G improvement in tolerance predicted, by the regression equation, for men reduced in stature by the mean male-female height difference. The point to be illustrated by the above calculations is that women's shorter stature helps prevent their manifesting lower +G_z tolerances than those of men.

The performance of the women on the 7-G, 15-s, RORS G-tolerance standard indicates that they were certainly no less capable of tolerating moderately high levels of sustained G stress—levels requiring anti-G suit and straining maneuver—than were the comparable group of men. Although the process by which the women were selected to attempt the Training Profiles could conceivably have biased the outcome of the comparison (all the women completing the Medeval Profiles were asked if they wanted to try the Training Profiles), unpaired *t*-tests revealed no significant differences in G tolerance on the Medeval Profiles between the women who tried the Training Profiles and those who did not. In this study we did not determine whether women can tolerate the very high, sustained G loads that some men can tolerate after appropriate training—+9 G_z for up to 45 s (20). Our experience with the women in this study leads us to believe that women with similar training should be able to tolerate very high G loads as well as men, unless their relative lack of muscle mass and strength compromises their ability to perform an effective anti-G straining maneuver. Evidence that physical strength is an important factor in the ability to tolerate high G loads for prolonged periods has been published (6,28); and one might use such evidence to suggest that women, not having as much muscle strength as men, would be less tolerant of sustained G loads at the +8 and +9 G_z level. Whether or not this is true must be determined by further experimentation.

Menstruation had no observable effect on G

tolerance, even though one might expect physiologic changes associated with menstruation to alter G tolerance. While premenstrual retention of fluid seems well-founded empirically and is documented in the literature (29), important variations in cardiovascular parameters with respect to time in the menstrual cycle are neither directly obvious nor consistently observed experimentally. Döring reported that resting heart rate is at a maximum premenstrually and falls during menses to a postmenstrual minimum (4), and others have found slight variations in heart rate over the menstrual cycle (8,18); but the preponderance of evidence indicates that heart rate, blood pressure, and other measures of cardiovascular function do not vary significantly with menstrual phase (1,15,17,21,22). As relaxed +G_z tolerance is so dependent on cardiovascular effectiveness, our inability to demonstrate an effect of menstruation on G tolerance may reflect the fact that cardiovascular changes associated with menstruation are minimal. A more rigorous study than ours would be needed, however, to demonstrate any cyclic variation in relaxed G tolerance associated with menstrual phase, if such a variation does in fact exist.

Straining G tolerance, being dependent on skeletal muscular strength and endurance, could be affected by phase of the menstrual cycle if women exhibit cyclic variations in muscular strength and endurance. Petrofsky (21) reported that isometric handgrip endurance of women not taking oral contraceptives varied with the phase of their menstrual cycle, although their isometric handgrip strength did not vary. Moreover, the President's Council on Physical Fitness and Sports, in its study of physical activity during menstruation (1), cited evidence from several sources that muscular strength, particularly abdominal strength, is reduced during the premenstrual and menstrual phases. These data suggest that women's straining G tolerance could be lower at some points in their menstrual cycle than at others, especially because of the importance of vigorous abdominal muscular effort in performing the anti-G straining maneuver. The results of our comparison of menstrual and intermenstrual straining G tolerance do not reveal any difference in tolerance; but to demonstrate conclusively any important effect of cyclic muscular weakness on women's straining G tolerance, an experimental study of their responses to sustained +7 to +9 G_z stress during the various menstrual phases would be needed.

The women's heart rates associated with the Medieval Profiles, both resting before the runs and maximal during the runs, were significantly higher than the men's; yet their heart rates before and during the Training Profiles were not significantly different from the men's. In a clinical setting, women's resting heart rates are generally assumed to be higher than men's, and resting heart-rate data taken prior to treadmill stress testing indicate that such is actually the case (5). Women's and men's maximal heart rates during vigorous exercise, on the other hand, are approximately equal (2,5). It would be tempting, therefore, to explain our heart-rate results by asserting that the Medieval Profiles are for the most part analogous to a resting

condition, whereas the Training Profiles are a form of exercise stress; but such an explanation would be an oversimplification. We feel the heart-rate differences observed with the Medieval Profiles occurred as a result of an additional factor: the women in general were more apprehensive in the novel testing environment than were the men, as many of the men were aircrew and were therefore not threatened by the prospect of increased G forces. By the time the women underwent the Training Profiles, however, they had lost much of their apprehension and were reacting to physiologic rather than emotional stimuli.

Although breast discomfort commonly occurs in women—especially those with large breasts—during athletic activities such as running and playing basketball (14), the 102 women who rode the centrifuge in this study reported no breast-related symptoms. The main reason for breast discomfort during sports is excessive oscillatory motion of the breasts, and this discomfort is substantially attenuated by the wearing of a properly supporting bra (14). Casual observations reveal that the human breast exhibits the dynamic characteristics of a second-order mechanical (mass-spring-damper) system having a resonant frequency above about 1 Hz. As virtually all the mechanical power of the USAFSAM centrifuge at the time of the women's G tolerance study was below 0.1 Hz (11), the production of any significant amount of G-induced breast oscillation and consequent discomfort was highly unlikely. Furthermore, the amplitude of breast motion on the centrifuge was no doubt greatly attenuated by the high damping provided by the shoulder restraint straps. The lack of breast-related symptoms in a dynamic G environment can thus be explained theoretically in terms of frequency response and damping, and the fact that no breast discomfort occurs even during relatively static high-G loading is evidenced empirically by the results of this study.

The urinary stress incontinence that occurred in 2 of the 24 women exposed to the Training Profiles raises the possibility that women are predisposed to such occurrences. Urinary stress incontinence is a common problem in parous women and the intra-abdominal pressures that result from anti-G suit inflation and anti-G straining maneuvers no doubt recreate the mechanical conditions that precipitate incontinence in susceptible women. No other occurrences of urinary incontinence have been reported in 20 years of centrifuge operations at USAFSAM with nearly all male subjects. One of us (K.G.) recalls several anecdotal reports of urinary incontinence in women aircrew during G stress in flight, but he also knows at least one male fighter pilot who has admitted to urinary incontinence during high-G maneuvering in flight. At this point we can only suggest that women may be more likely than men to suffer urinary incontinence when exposed to high-G stress requiring use of an anti-G suit and straining maneuver.

CONCLUSION

Women's +G_z tolerance is essentially the same as men's for G stress up to and including +7 G_z for 15 s. Menstruation appears to have no effect on

women's relaxed G tolerance or on their straining tolerance to gradual-onset G stress without an anti-G suit. Urinary stress incontinence is the only important G-induced symptom that women may be more likely to experience than men. As we have demonstrated no G-tolerance deficiency in women, we believe it is sound practice not to exclude women categorically, for reasons of G intolerance, from assuming aircrew duties in the high-G environment.

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