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CONTINUOUS EKG RECORDING DURING FREE-FALL PARACHUTING

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ABSTRACT

This study is an attempt to determine heart rate and rhythm of experienced parachutists during free-fall and during the periods immediately before and after the jumps. It includes enough subjects so that statistical inferences can be made regarding a population of experienced parachutists. Continuous EKG recordings were made of 29 experienced parachutists while each participated in free-fall parachuting exercises. A total of 98 individual exits from aircraft in flight were recorded. Mean R-R interval was 0.403 seconds just prior to exit from the aircraft, 0.363 seconds during free-fall, 0.336 seconds immediately after parachute opening, 0.369 at landing, and 0.465 5 minutes after landing. Although there was variation in the R-R interval among individuals, the progressive decrease of R-R interval throughout the exit and free-fall with a nadir at parachute opening, was the common finding. There is marked individual difference in the duration of tachycardia before and after jumps. Over the entire group, mean duration per subject was 19.4 minutes of tachycardia prior to exit, and 30.4 minutes of tachycardia after parachute opening. In the individuals who made at least 2 jumps on any one day, the R-R interval measured on a single individual on the first and second jumps were remarkably similar, and within the group not statistically different. A correlation matrix was computed to show relationships between various parameters studied. The correlation between R-R interval and total number of jumps was opposite in direction to that which was expected, and nearly attained values that were statistically significant.

APPROVED: ROBERT W. BAILEY
LTC, MSC
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CONTINUOUS EKG RECORDING DURING FREE-FALL PARACHUTING

INTRODUCTION

The value of free-fall parachuting, like beauty, lies mainly in the eyes of the beholder. For example, to some 30,000 US sport parachuting enthusiasts who made an estimated one and a half million jumps in 1966[21], sky diving is "the sport of the space age." To the military establishment free-fall parachuting constitutes a promising vehicle for clandestine delivery of fighting units to pin point targets in otherwise inaccessible areas. To a few scientific investigators, however, free-fall parachuting has suggested an interesting tool in the study of man. Some psychological work has been undertaken to study free-fall parachutists[6,7,18], principally using interrogated techniques of various sorts, in an attempt to determine emotional content and intensity during free-fall. Reports in the clinical medical literature have primarily been introductory articles[1,9,23] and reports of death and/or post mortem findings[16,17]. Only scattered information, however, is available regarding the human physiological responses to free-fall and in these instances has been restricted to one or, at most, a few subjects[2,8,10,12,14,22,24,25,26].

The present study is an attempt to determine heart rate and rhythm of experienced parachutists during free-fall and during the periods immediately before and after the jumps. It includes enough subjects so that statistical inferences can be made regarding a population of experienced parachutists.

METHOD

Twenty-nine subjects made a total of 98 individual exits from aircraft in flight. All subjects were experienced free-fall parachutists, with from 175 to 1525 previous jumps. Over the whole group the mean number of jumps per subject was 720. All were trained athletes who participated daily in a physical training program. Their ages ranged from 17 to 47 years (mean age was 30.4 years, with a standard deviation of 5.96 years). They were all free of acute illness, and none had clinical evidence of cardiovascular disease.

One bisternal lead electrocardiogram of each parachutist was continuously recorded from at least 1 hour before the first exit of the day to at least 1 hour after the last exit of the day on 1/4" 0.5 mil Mylar magnetic recording tape by a 3 1/2 lb self-contained tape recorder. The recording equipment and electrodes were attached in the morning for data recording during the day's jumps.

The jumpers then traveled by automobiles to the drop zone, where they donned their parachutes and enplaned. As few as one jump per day or as many as four jumps per day were made, depending upon such variables as weather, aircraft availability, drop zone scheduling, and similar uncontrollable conditions. Most periods of free-fall were twenty seconds in duration, however, there were 3 free-falls recorded that were of ninety seconds duration. When an individual subject made more than one jump in a single day, the jumper would field roll his parachute immediately after landing, then sit quietly until it was time to don another parachute for his next jump. When jumps for the day were completed, the parachutists were taken back to the laboratory where the tape recorder and electrodes were removed.

The tapes were read by each of the following methods:

a. A continuous write-out of rate, expressed as beats per minute, was obtained for each record.

b. Initial scanning was conducted at a 1:60 time ratio to locate periods of interest.

c. A detailed examination on an oscilloscope at 1:1 time ratio was conducted during each of the following periods:

(1) Immediately prior to exit from the aircraft.

(2) Free-fall.

(3) Parachute opening.

(4) Landing.

(5) Five minutes after landing.

(6) Any period of unusual rate or rhythm.

(7) All areas noted upon scanning to be other than totally normal.

d. All periods of interest were recorded on standard EKG paper at a 1:1 time ratio with paper speed of either 25 mm/sec or 50 mm/sec, whichever seemed the more appropriate for thorough evaluation. Excerpts from a typical record are shown in Figure I.

In view of the fact that rates were noted to change rapidly, and frequently would not remain at one level for a minute's duration, the concept of "beats per minute" did not seem appropriate. Therefore, R-R intervals were selected as a more valid measure of rate. When R-R interval was determined from standard EKG paper, a representative group of R-R intervals was selected and measured. When rate was rapidly changing, an R-R interval was considered to be "representative" when three successive R-R intervals within the period of interest were of the same duration. When sustained rates were noted, an R-R interval representative of the group was measured.

CALIBRATION

Each strip of magnetic tape was calibrated at the beginning of the recording day with a 1 millivolt signal at a frequency of 1 signal per second. In addition, the recording tape decks were calibrated weekly with a calibration tape to a tape speed of 7 1/2 inches per 60 seconds. Read-out equipment was calibrated with 60 Hertz oscillation of line voltage and correlated with the 60 signals per minute calibration on the magnetic tape. On the basis of these precautions, plus the manufacturer's specifications for the equipment, it is our opinion that the estimates of heart rate are correct to $\pm 2\%$, and estimates of R-R interval are correct to ± 0.01 seconds.

TECHNIQUES

Some points of technique may be of interest.

a. We regularly shaved the chests of our subjects with a number 40 blade of a standard small animal clipper. Only with shaving were we able to maintain stable electrode contact.

b. We took some effort in the preparation of the skin. After shaving, the skin was cleansed vigorously with technical acetone, and rubbed dry. This effectively de-fatted the skin, which made it possible for our adhesive to hold the electrodes in place for the entire period of study. In addition, the aggressive rubbing produced good skin erythema, and some cutaneous decornification, thereby decreasing skin resistance.

c. As a conductor between the silver electrodes and skin we used bentonite. In preliminary studies we noted lower resistances with silver-silver chloride suspensions, and with sodium chloride in water soluble base, however, these materials were rather fluid, and after activity, the electrode paste tended to pump out of the cup electrodes causing electrode slippage and considerable electrode antifact. Bentonite was more viscid and even after dilution with sweat, did not escape as readily from the electrode cups.

d. Electrodes were held in place using standard 3-inch surgical Elastoplast, reinforced by Blenderm to prevent peeling of the edges. In spite of the activity of the subject, and the perspiration caused by relatively warm temperatures and physical activity, we lost only 1 set of electrodes, which occurred on parachute opening and was repaired within minutes.

e. The electrodes were placed bisternally with the reference electrode over manubrium sterni, and the recording electrode over corpus sterni at the level of the attachment of the 5th costal cartilage. This provided a clear P wave, permitting a better evaluation of rhythm, and a strong signal which was helpful in records in which interference was a problem since it improved our signal to noise ratio.

f. In every subject skin impedance between electrodes was measured with a standard VOM multimeter just after the electrodes were placed, and just before the electrodes were removed. In most instances, initial impedances were in the range of 10K-100K ohms, and final impedances were in the range of 1K-10K ohms.

RESULTS

A. Mean R-R interval, range, and standard deviation among subjects is reported for each of the following:

1. Within the 10-second period prior to exit from the aircraft.
2. During free-fall.
3. Within the 10-second period after parachute opening.
4. At the time of ground contact.
5. Five minutes after landing.

In each of these categories the shortest R-R interval is reported that occurred three times successively. This corresponds to the most rapid heart rate noted in each category.*

TABLE I

SUMMARY OF R-R INTERVALS

N-29	RANGE	MEAN	ST. DEV.
BEFORE EXIT	0.29 - 0.69	0.403	0.069
DURING FREE FALL	0.26 - 0.65	0.363	0.043
AT OPENING	0.25 - 0.48	0.336	0.039
AT LANDING	0.28 - 0.45	0.369	0.045
5 MIN. AFTER LAND.	0.37 - 0.59	0.465	0.056

Directional t test was performed between these mean R-R intervals.

t for R-R interval before exit vs R-R interval during free-fall = +2.83 ($P \leq 0.005$)

t for R-R interval during free-fall vs R-R interval after parachute opening = +1.95 ($P \leq 0.05$)

t for R-R interval after parachute opening vs R-R interval at landing = -2.83 ($P \leq 0.01$)

t for R-R interval at landing vs 5 min. after landing = +6.90 ($P \leq 0.001$)

* Heart Rate in beats/min = $\frac{60}{\text{R-R interval}}$

B. The mean interval between the moment when the pulse rate first exceeded and consistently remained above 100 beats per minute and the time of exit from the aircraft was 19.4 minutes (standard deviation 17.9 minutes). The mean interval between the moment of parachute opening and the time when the pulse rate first fell below and consistently remained below 100 beats per minute was 30.4 minutes (standard deviation of 18.01 minutes). This large standard deviation is the result of marked individual variation.

This data is not considered to be as reliable as the R-R interval data and is weighted on the low side because:

1. In many instances a jumper would land from one jump, and immediately don another parachute and board the aircraft for climb-out for his next jump. In some of these cases, the pulse rate would never fall below 100 beats/minute, and therefore no clear separation could be made within this period between the tachycardia related to the preceding jump and the tachycardia related to the impending jump.

2. In five subjects, the pulse rate never fell below 100 beats/minute between jumps. In four of the five it never fell below 120 beats/minute, and in two, pulse rate held at about 140 beats/minute steadily between jumps. These rates were maintained for the entire period the jumpers were on the drop zone, between four and five hours.

3. On one occasion, just after parachute opening, two parachutists collided, with one parachutist (A) passing through the suspension lines of the other (B), causing both parachutes to collapse. Jumper A jettisoned his main canopy and fell free from the entanglement, which permitted jumper B's main canopy to reinflate; however, jumper A had some difficulty in deploying his reserve parachute, which did not inflate until he was about 300 feet above terrain. Three subjects being monitored observed this sequence from the ground. Their pulse rates remained above 100 beats/minute during and following this incident in spite of the fact that they remained at rest. Jumper B was being monitored during this incident. His R-R interval immediately after opening was 0.41 seconds. This decreased to 0.36 by 30 seconds after opening, and by 60 seconds after opening had returned to 0.41, where it remained for the next 60 seconds, a period which included parachute landing. His R-R interval then rapidly shortened to 0.33, and remained near that figure for the next 5 minutes. Thereafter his pulse rate gradually slowed from 182 beats/minute to 120 beats/minute 22 minutes after parachute opening and to 100 beats/minute 45 minutes after parachute opening.

C. Twenty-four subjects made at least 2 jumps on the same day. In comparing the first two jumps of the day there was in each subject remarkable similarity of the R-R intervals in the periods measured. Analysis of variance shows no significant difference at the 0.05 level in the responses of the group between the first and second jump of the day ($F = 0.59$).

D. A 6 x 6 correlation matrix was computed to determine relationships between various parameters. The matrix is portrayed in Table II. Based upon an n of 29, an r of $|0.37|$ or higher can be considered significantly different from 0.

TABLE II

Correlation Matrix

	NO. OF JUMPS	$\bar{a}$	NADIR	$\bar{p}$	$\bar{a} + \bar{p}$	AGE
NO. OF JUMPS	+1.00	+.29	-.34	+.34	+.33	+.00
$\bar{a}$		+1.00	-.66	+.80	+.94	-.04
NADIR			+1.00	-.72	-.73	+.02
$\bar{p}$				+1.00	+.95	+.07
$\bar{a} + \bar{p}$					+1.00	+.01
AGE						+1.00

$\bar{a}$ = time in minutes of tachycardia before exit

Nadir = shortest R-R interval noted

$\bar{p}$ = time in minutes of tachycardia after parachute opening

$\bar{a} + \bar{p}$ = total time in minutes of tachycardia

Certain of these correlations merit comment.

a. As expected, R-R intervals correlated well and in the expected negative fashion, with both duration of tachycardia before jump and after jump ($r = -0.66$ and $r = -0.72$ respectively).

b. Similarly, the correlation is high ($r = +0.80$) between duration of tachycardia before vs after the jump.

c. The age of the jumper did not correlate with R-R interval ($r = +0.02$).

d. The correlation between R-R interval and total number of jumps is of considerable interest. It is nearly to the level of significance, but is negative ($r = -0.34$) opposite in direction to that which might be expected.

e. Similarly, the correlations between number of jumps, and duration of tachycardia before and after the jump are positive (though still not to a significant level: $r = +0.29$ and $r = +0.34$ respectively) suggesting that the more jumps one has, the longer the period of tachycardia before and after the jump.

ARTIFACTS

A number of artifacts were consistently noted and studied.

a. Differential negative acceleration at the time of parachute opening commonly caused the tape to be lifted away from the recording head for periods up to 2.80 seconds. This was expected, since the tape is held against the recording heads by tension alone. This artifact was not suppressed because it proved to be useful as a positive landmark during a critical period of observation, and was used extensively during tape search and in timing measurements.

b. A similar artifact occurred upon ground contact. This period of signal loss, however, was much shorter in duration and could easily be distinguished from the opening artifact because it was preceded by clean signal.

c. The most troublesome artifact encountered, one which was present on nearly every record, was an irregular 35–45 Hertz signal of from 0.1 to 0.5 millivolts which began upon exit from the aircraft, and cleared immediately upon parachute opening. The cardiac signal could regularly be identified through this inference. Tests were made to identify the source and as a result it was demonstrated that the interference does not originate from the tape, the tape recorder, the lead wires which pass from electrodes to the recorder, or the electrodes themselves. The frequency and amplitude of the interference suggest classical somatic tremor. The results of empirical testing plus this characteristic appearance led us therefore to conclude that this spurious signal is caused by electromyographic potentials. Continuing efforts are being made to positively identify the source of this signal and determine its significance.

DISCUSSION

The consistent tachycardia present during each parachute jump by this highly trained population is worthy of note. Since these men were all trained athletes, in good health and free of clinical heart disease, and since the tachycardia was a constant finding, it is suggested that this response to free-fall parachuting must be considered a normal response and an expected finding in the general parachuting community.

Our data confirms previous reports by Warembourg et al[26], Grandpierre et al[12], and of Goldberg and Foster[10], that significant tachycardia occurs during the parachuting sequence. In our series the levels of tachycardia exceed those reported by Åstrand[3] to have occurred in male subjects performing work equivalent to 1500 Kg-m/min., and approach the levels of tachycardia noted by the same author during six minutes of maximal work by male subjects within the same age range as our jumpers. We do not, however, concur with Warembourg's conclusion[26] that parachuting is not threatening to the cardiac apparatus, and that hemodynamic changes always remain within physiological limits. Sustained tachycardias of the level of 180 beats per minute might well be important. It is known that young men may have a significant degree of coronary artery narrowing that is asymptomatic and is often undetected during ordinary physical examination[5]. It is also entirely possible that a young man presenting himself for training in free-fall parachuting might never in his life have had a pulse rate as high as the ones noted in our subjects, particularly those five subjects with recorded pulse rates above 230 beats/minute. Demands upon the heart of this level, combined with the low grade hypoxia caused by the low pO_2 at jump altitude, and significant narrowing of the coronary arteries, could result in relative myocardial ischemia, and the rate and rhythm aberrations that are known to be associated with it. Four of our subjects demonstrated arrhythmias and/or conduction aberrations during the jump sequence, and 3 showed reversible ST segment depression. We suggest that the period during free-fall is less than an ideal time to conduct stress-testing of the integrity of the myocardium and its perfusion; yet, this is in fact what we are doing every time we train a free-fall parachutist. We are unwilling at this time to attach pathologic significance to these aberrations; however, Kiel reports that 50% of parachuting deaths are attributable to either failure to pull the rip-cord, or failure to activate the reserve parachute when the main parachute malfunctions [16,17]. This indicates that at the time of rip cord pull there are jumpers who are physiologically and/or psychologically beyond their capability to perform one of these simple, life-saving maneuvers.

It is the consensus of experienced parachutists that the physical work required during routine free-fall parachuting is minimal, although to our knowledge this has never been objectively confirmed. Therefore, the tachycardias noted are most likely derived from psychological rather than physiological origins. The 35-45 Hertz interference, previously described as artifact, may also play a part in the tachycardia. If these potentials do represent widespread somatic tremor, then total muscle work during free-fall might be high, but essentially isometric. It is known that continuous fine adjustments of body position are required during free-fall to maintain stability and control. This maintenance of tonus may be the origin of the described interference as well as a contributing factor in the tachycardia.

Parachute opening is clearly the time of greatest tachycardia. This was a universal and consistent finding among all our subjects and the difference between mean R-R interval during free-fall and mean R-R interval just after parachute opening was significant, although in many cases the two measurements were made only a few seconds apart. This confirms observations of Goldberg and Foster on a single parachutist [10], and establishes physiologically what has been postulated from psychological studies [18], that is, that the general level of excitement of parachutists in the jump sequence is highest at the time of rip cord pull. This can be dramatically demonstrated by noting the rate of change of heart rate between the specific points where R-R intervals were measured.

TABLE III

Time	Mean R-R	Equivalent Heart Rate	Approx time Between Measurements	Calculated Rate of Change
Exit	0.403	149		
			15 sec.	+68 beats/min/min
Free-Fall	0.363	166		
			5 sec.	+156 beats/min/min
Opening	0.336	179		
			120 sec.	-8 beats/min/min
Landing	0.369	163		
			300 sec.	-6.8 beats/min/min
5 min after landing	0.465	129		

Twenty-four of our subjects made at least 2 successive jumps on the same morning. Each individual's response pattern for these 2 jumps was remarkably similar, and analysis of variance upon the group shows that there were no significant differences in any of the 5 time periods studied between these 2 jumps ($F = 0.59$). This indicates that an individual's ability to respond can be sustained for at least 2 jumps. Empirical information from experienced parachutists suggests that a jumper can make about 4 jumps in a morning, after which he is subjectively fatigued, and is no longer responsive to instruction. It may be that after this number of jumps, the capability to respond physiologically is diminished. Further studies are now being conducted to test this hypothesis.

The results of correlations performed upon the data deserve some comment. It was expected that as a jumper accumulated experience he would adapt to the threat situation imposed by free-fall parachuting, and that his cardiovascular responses would not be as gross as in less experienced jumpers. The correlations of total number of jumps vs R-R interval at the time of parachute opening and total number of jumps vs total duration of tachycardia do not confirm this expectation, and, if anything, suggest that as one accumulates jumps, both the magnitude and duration of tachycardia increases. This might represent an acquired change in autonomic response. We believe, however, that a more likely explanation is that it reflects selection, rather than adaptation. Parachutists fit nicely into the group having what is called "a stress-seeking personality"[19]. Those individuals who jump and find the experience stimulating (both psychologically and physiologically) continue to jump, and accumulate large numbers of jumps. Those individuals who try parachuting, but find it is not satisfying their needs for psychological (and perhaps as well physiological) stimulation stop jumping, and move to other activities. In this way, the less responsive individuals are selected out, leaving a highly responsive, active jumping population, which is continuing to accumulate "total number of jumps."

UNUSUAL FINDINGS

1. In 5 of our subjects, R-R interval at parachute opening was noted to be 0.25 or 0.26 second, which corresponds to a heart rate of 240 or 230 beats per minute respectively. Rates above 200 beats per minute were maintained for at least two minutes in all 5 subjects. The slowing occurred in a gradual fashion, characteristic of sinus tachycardia.

2. A 22-year-old jumper, with 397 previous jumps, made 3 jumps in one morning. His raw scores are in Table IV.

TABLE IV

	Before Exit	During Free-Fall	After Opening
Jump 1	0.51 (118)	0.44 (136)	0.41 (146)
Jump 2	0.41 (146)	0.65 (92)	0.38 (158)
Jump 3	0.40 (150)	0.37 (162)	0.36 (167)

The numbers in parenthesis are pulse rates per minute equivalent to the measured R-R intervals.

The pulse rate of the second jump during free-fall is definitely unusual, and represents a striking bradycardia as related to the subject's pulse rates prior to exit and after parachute opening. We have noted this on other records as well, and suggest that it is most likely due to breath holding, and the Valsalva maneuver associated with it.

3. ST segment depression was noted during the jump sequence in 3 parachutists. Examples are shown in Figure II.

In a., the J point is lowered, and the ST segment slopes up to an upright T wave. It probably is not abnormal.

In b., the jump tracing shows accentuation of a low ST segment and diphasic T wave noted on the control strip. This also probably is not abnormal.

In c., the ST segment is clearly depressed and the T wave inverted as compared to the control tracing. This change would be considered as abnormal if seen on any ordinary exercise tolerance test.

It would be of interest to know the appearance of the ST segments of our subjects over the left precordium during the jump sequence.

Each of these 3 subjects later performed a standard double-Masters exercise tolerance test, and in each case it was normal.

4. Intermittent changes in rhythm occurred in 4 jumpers. Arrhythmias noted include:

a. Ventricular pre-excitation.

b. Supraventricular premature contractions.

c. Ventricular premature contractions.

d. Irregular rhythm, type undetermined.

Examples are shown in Figure III.

5. In many of our subjects we noted a rash at the site of one electrode. The rash never occurred at the sites of both electrodes, and always occurred only under the electrode, and thus was not associated with the adhesive. This rash was vesicular, pruritic, and its natural course was one of spontaneous clearing over a period of 2-3 weeks. From a clinical standpoint, this looked like dermatitis venenata. If this is the case, it is interesting to speculate why the rash did not appear at the sites of both electrodes. It is conceivable that the subject is sensitive to only part of the molecule of an allergen in bentonite, and that as the bentonite polorizes at the skin-bentonite interface the molecules are aligned under one electrode to place the allergen against the skin, and under the other electrode to direct the allergen away from the skin.

SUMMARY

Continuous EKG recordings were made of 29 experienced parachutists while each participated in free-fall parachuting exercises. A total of 98 individual exits from aircraft in flight were recorded.

1. Mean R-R interval was 0.403 seconds just prior to exit from the aircraft, 0.363 seconds during free-fall, 0.336 seconds immediately after parachute opening, 0.369 at landing, and 0.465 5 minutes after landing.

2. Although there was variation in the R-R interval among individuals, the progressive decrease of R-R interval throughout the exit and free-fall with a nadir at parachute opening, was the common finding.

3. There is marked individual difference in the duration of tachycardia before and after jumps. Over the entire group, mean duration per subject was 19.4 minutes of tachycardia prior to exit, and 30.4 minutes of tachycardia after parachute opening.

4. In the individuals who made at least 2 jumps on any one day, the R-R interval measured on a single individual on the first and second jumps were remarkably similar, and within the group not statistically different.

5. A correlation matrix was computed to show relationships between various parameters studied. The correlation between R-R interval and total number of jumps was opposite in direction to that which was expected, and nearly attained values that were statistically significant.

FIGURES

FIGURE I

TYPICAL JUMP SEQUENCE

a. Climb-out.

b. At exit. The interference reflects actual exit from the aircraft.

c. During free-fall. The described interference is evident.

d. At parachute opening. The interference reflects parachute opening. Note the abrupt disappearance of spurious signal upon opening.

e. During descent under canopy.

f. At ground contact. The interference reflects actual landing.

g. Resting record 5 minutes after landing.

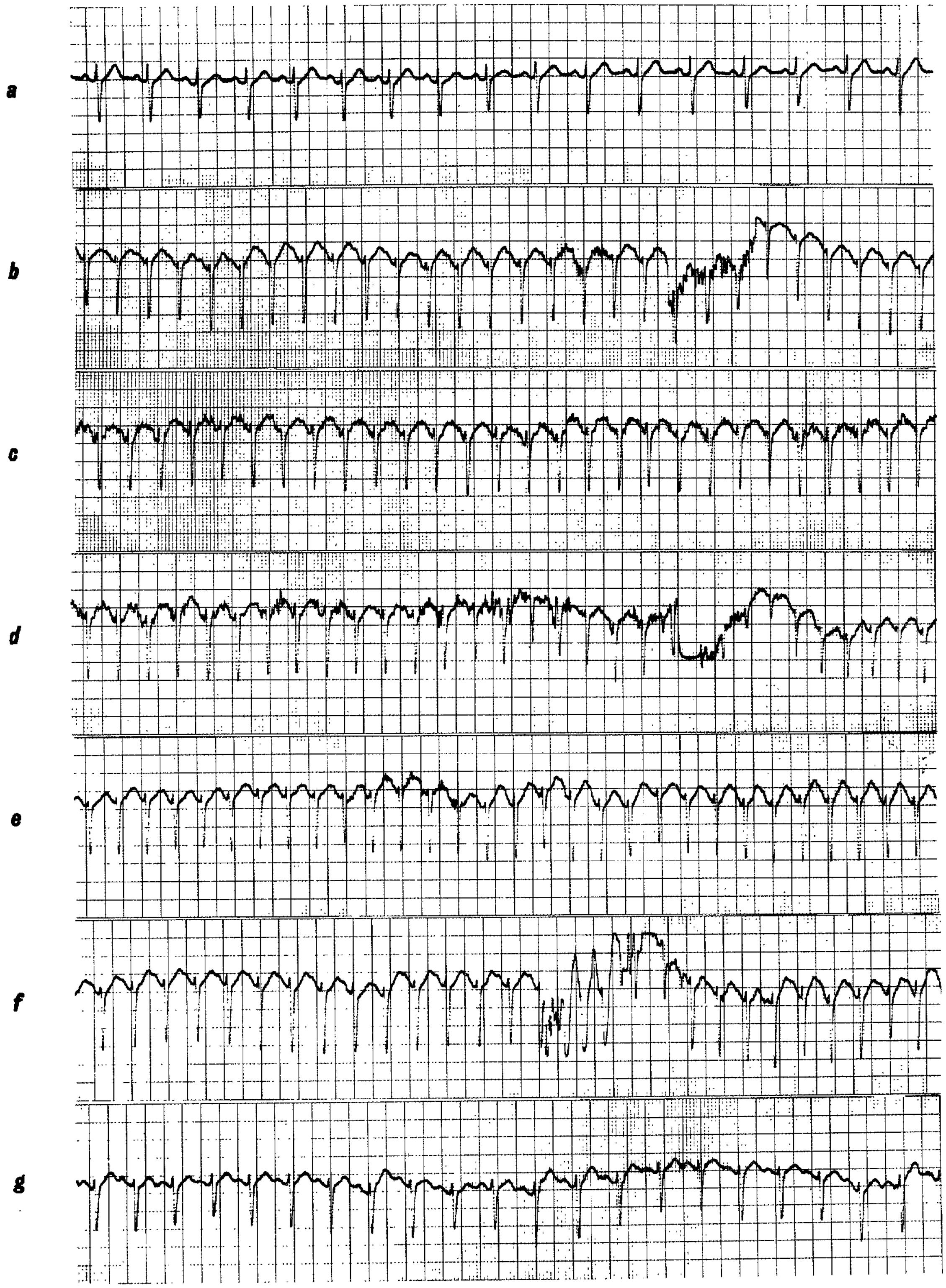

a
b
c
d
e
f
g

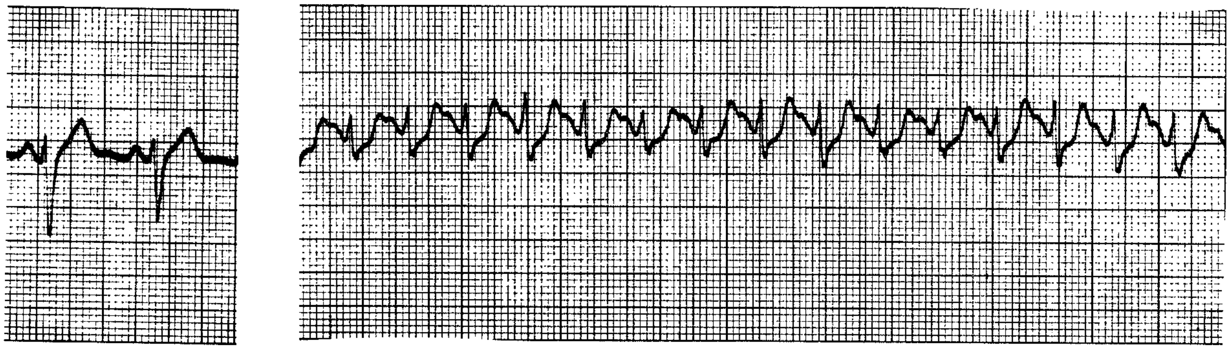
FIGURE II

ST SEGMENT AND T WAVE CHANGES

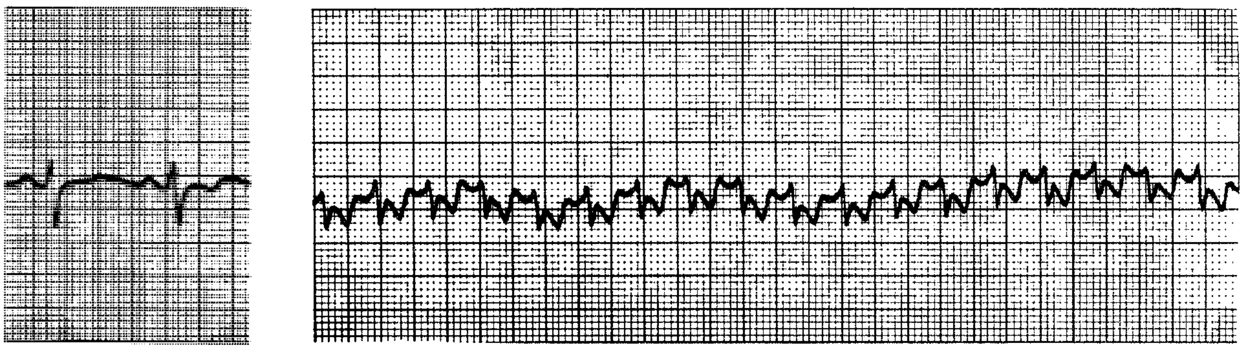
The shorter strip is a resting control from each subject.

The longer strip was taken just after parachute opening in each case.

a



b



c

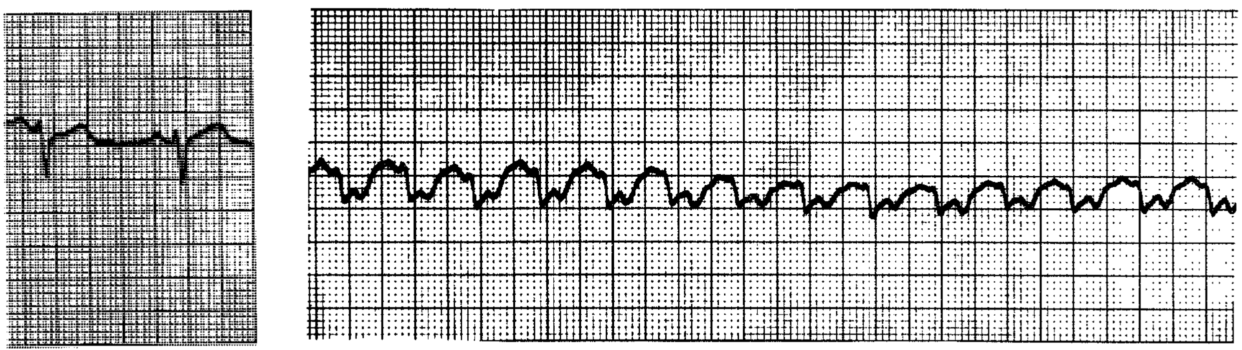


FIGURE III

EXAMPLES OF ABERRATIONS OF RHYTHM OR CONDUCTION

a. Intermittent ventricular pre-excitation during free-fall.

b. This complex is from the same subject as tracing a., but occurred just prior to exit from the aircraft. It clearly shows lengthening of the QRS at the expense of the PR interval.

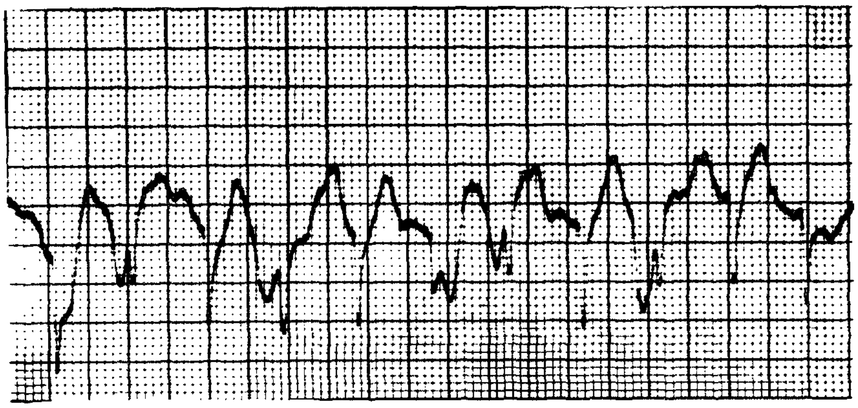
c. A supraventicular premature contraction which occurred during climb-out.

d. and e. Ventricular premature contractions.

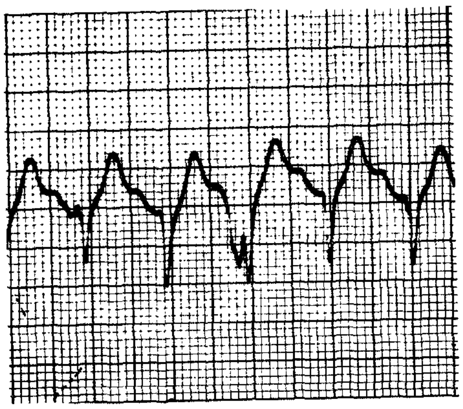
d. occurred during free-fall.

e. occurred during climb-out.

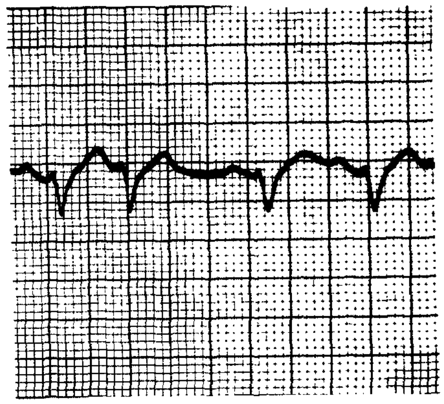
a



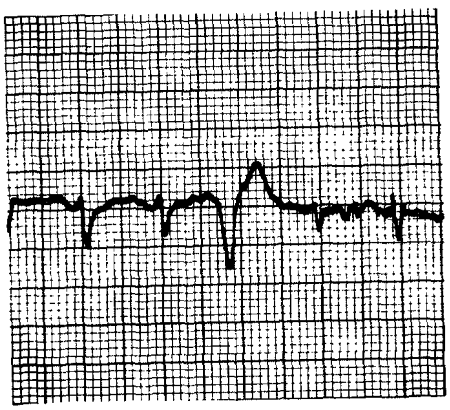
b



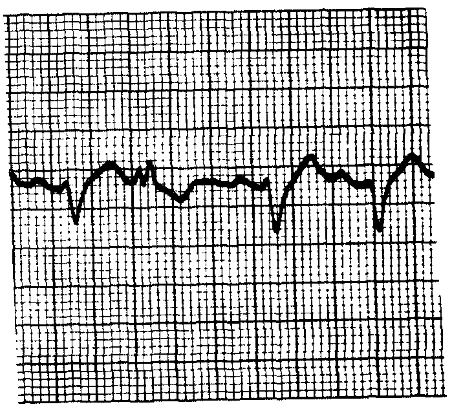
c



d



e



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