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RELATIONSHIP OF CARDIOPULMONARY FITNESS TO FLIGHT PERFORMANCE IN TACTICAL AVIATION

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This report describes current endeavors to identify whether cardiopulmonary fitness can positively influence flight performance in a tactical fighter community. Population analyses of 111 subjects consisting of experienced aviators and student naval aviators present evidence that the U. S. naval aviation pilot community is in an above average state of physical fitness with less than average coronary heart disease potential. Correlations found in this study between cardiopulmonary fitness and psychophysiological responses that occur during simulated and/or actual flight operations present strong evidence that flight performance could be favorably affected.

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SUMMARY PAGE

THE PROBLEM

Coronary heart disease has always been of concern in aviation medicine because of the possibility for sudden incapacitation in flight. Studies are now being directed at the quantitative assessment of cardiopulmonary function in clinically normal subjects. These measures are then correlated with performance on specific aviation tasks and with other physiological functions that are known to be important for aviation. The purpose of this research is to determine whether cardiopulmonary fitness within the normal range has value for predicting performance on aviation tasks. Cardiopulmonary fitness of a group of student aviators and a group of older experienced pilots was quantitatively assessed. These data were analyzed to determine whether cardiopulmonary fitness correlated with some aspect of performance on other biomedical tests that are relevant to aviation such as vision, motion, and spatial orientation. In addition to these laboratory studies, cardiopulmonary fitness was correlated with heart rates monitored during inflight air combat training maneuvers.

FINDINGS

Cardiopulmonary fitness of the students was excellent while that of the older pilots was somewhat less but still very good. Correlating these data with other biomedical parameters indicated that a high level of cardiopulmonary fitness may improve dynamic visual acuity, but it also enhances susceptibility to motion sickness. A comparison of cardiopulmonary fitness and heart rates during air combat training flights revealed an inverse correlation. The criterion measures of aviation performance during these flights were not sufficient to do the necessary statistical correlations with cardiopulmonary fitness; therefore, it was not determined definitively that good cardiopulmonary fitness will improve an aviator's performance. Correlations that were found, however, present strong evidence that flight performance could be favorably affected.

ACKNOWLEDGMENTS

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INTRODUCTION

Numerous studies have shown a direct relationship of cardiopulmonary (aerobic) fitness to work performance (1,2,3,4,5); one with good cardiopulmonary fitness uses a lower percent of his aerobic power for any given workload. There is an improvement in cardiovascular function, reduction in overall physical/mental fatigue, and there has been suggestion of enhanced cognitive function. Additionally, the onset of cardiovascular disease seems to be less in a population of physically fit individuals. The incidence of coronary heart disease (CHD) and its impact on the U. S. Navy and naval aviation is a growing concern (6,7). Discussion of risk factors such as hypertension, body fat, smoking, cholesterol levels, and lack of exercise are ever increasing in the literature. Sudden incapacitation due to cardiopulmonary disorder is a serious, but rare, event among aviators. Cardiopulmonary disease, however, to include coronary disease, hypertension, arrhythmias, and chronic obstructive/restrictive diseases, produces a significant loss of highly skilled and expensive aviators usually at the midpoint of their flying career (8,9).

Two concerns are presented: (1) What is the cardiopulmonary makeup of young incoming aviators currently being trained to fly Navy high performance aircraft (HPA)? How do they relate to the general population?; and (2) What is the cardiopulmonary makeup of experienced, yet older, aviators presently flying HPA in the fleet? How do they compare to the incoming students?

Assessment of cardiopulmonary capacity or fitness in a clinical setting is not new. Monitoring of laboratory physiological responses, principally, heart rate, temperature, and muscle tension during flight, has been previously reported (10,11,12,13). The relationship of aerobic fitness to flight performance in aircrew flying simulated or actual HPA when exposed to frequent and repeated environmental/operational tasks (such as excessive ±G loading, high pulmonary demands, disorientation, extreme visual tracking requirements, multiple cognitive function demands, etc.) is not well known. The purpose of this study was to determine whether cardiopulmonary fitness (aerobic fitness) influences selected physiological responses during flight and/or simulated flight and what that may mean in regards to flight performance in naval aviation fighter communities.

METHODS

One hundred and eleven male students and designated naval aviators in the age range of 21-40 were evaluated. Eighty-four of the subjects were student naval aviators in various stages of training at the Naval Air Station, Pensacola, Florida. Twenty-seven were HPA-designated naval aviators assigned to fighter aircraft squadrons at the Naval Air Station Oceana, Virginia Beach, Virginia. Test protocols were devised to assess cardiopulmonary efficiency in both laboratory and field (squadron spaces) environments. The test batteries consisted of: (a) pulmonary function testing to assess lung capacity and rule out obstructive/restrictive disease; (b) cardiovascular, pulmonary, and metabolic responses during maximum treadmill exercise (Bruce protocol) to assess aerobic fitness; (c) body composition (percentage fat and muscular strength as identified by grip strength); and (d) blood chemistries pre- and post-exercise to assess coronary risk factors.

Following comparison analyses between groups, correlation analyses were conducted between cardiopulmonary fitness and additional psychophysiological variables identified to be significantly associated with flight performance:

COMPARISON OF CARDIOPULMONARY FITNESS AND MOTION SICKNESS SUSCEPTIBILITY. Twenty-nine student naval aviators participated as subjects. Motion sickness susceptibility was determined by using a Stille-Werner Rotator during a modified Brief Vestibular Disorientation Test (BVDT) (14). The test consisted of a constant clockwise rotation at 18 rpm with eyes closed and head tilts relative to the plane of rotation every 30 sec for a total of 10 min or until the subject requested to abort due to symptoms of motion sickness. Spin time, heart rate, respiratory rate, and skin temperature responses were then analyzed in relation to levels of cardiopulmonary fitness.

COMPARISON OF CARDIOPULMONARY FITNESS AND VISUAL ACUITY. Thirty-four student naval aviators were used as subjects. An automated vision test battery was used to assess central and peripheral (static) acuity and peripheral movement detection. A Dynamic Visual Acuity testing device designed by Burg in the 1960s (15) and modified with Landolt-C targets was used to assess decrement in visual acuity with increasing target velocities. Velocities selected were 20^{o}/sec, 50^{o}/sec, and 110^{o}/sec, which were representative of dynamic visual envelopes of operational flight such as target tracking and midair collision avoidance.

COMPARISON OF CARDIOPULMONARY FITNESS AND HEART RATE RESPONSE DURING AIR COMBAT MANEUVERS (ACM) TRAINING FLIGHTS. Eleven highly experienced naval aviators flying 23 ACM training flights on a Tactical Air Combat Training System (TACTS) range were used as subjects. Each aviator was a member of an adversary squadron designated to fly ACM on the TACTS range during training of fleet squadrons. Aircraft flown were the A-4, F-5, and the T-38. Training flights monitored in this study were classified as high speed with low to moderate G loading. Using a three-lead electrocardiogram, heart rate response was collected with an in-flight solid state recording device ("Vitalog") every 2.5 sec from pre-flight to post-flight. For each ACM event (dog fight), G loading was continuously monitored and recorded using TACTS. Both the Vitalog and TACTS were timed sequences. Correlations and differences of heart rate response were assessed for: pre-flight (includes time to put on flight gear and walk to the aircraft), takeoff, transit, ACM, landing, and post-flight (includes return to squadron spaces and removal of flight gear).

RESULTS AND DISCUSSION

Mean exercise histories, naval physical fitness test results, treadmill duration, and recovery time (Table 1) placed the student naval aviator population in the "outstanding" category of overall fitness. Metabolic efficiency during progressive absolute work, including maximum oxygen uptake ($\dot{V}O_2$ max), relative aerobic capacity per absolute work ratio, anaerobic threshold, and functional aerobic impairment (16), demonstrated an above-average group. Pulmonary function revealed average efficiency and lack of any obstructive or restrictive disease. Body composition revealed average strength, yet lower than national average percentage body fat (17). Coronary risk factors utilizing the U. S. Air Force Coronary Artery Risk Evaluation (CARE)* (18) demonstrated a relative risk of 1.4 times for developing coronary heart disease as compared to a population of equal age with baseline values. This value is substantially less than that found in the general population with a relative risk of 3.0.

For a population close to 10 years older (mean age 31.7 years vs 23.9 years for students), the designated aviator group was not drastically different in overall fitness from the student aviators. Mean exercise histories, naval physical fitness test results, metabolic efficiency, treadmill duration, and recovery time placed the designated naval aviator population in the "good" to "excellent" category of overall fitness. The most prominent differences were found in coronary risk factors (principally smoking history and age), which expressed evidence of a greater trend toward future coronary heart disease. The Coronary Risk Factor (CRF) of the designated aviators of this study could not be determined because the blood samples were destroyed in transit to the main laboratory.

Motion Sickness Susceptibility

Results of the BVDT indicated that spin abort time and cardiopulmonary fitness are inversely related, $r = -.506$, $p < 0.01$ (Fig. 1). The physiological and psychophysiological basis of this finding is a matter of speculation. Enhancement of vagal tone has been suggested as a potentiator of motion sickness susceptibility (19), but this is open to question (20). Alteration of levels of stress hormones may also be involved, possibly depending upon how aerobic fitness is acquired. The majority of our aerobically fit subjects identified running as their exercise of choice. Running may train the individual to be highly conscious of deviations from expected body motion, yet, because it is natural voluntary movement, running would provide little experience with conflicting sensory inputs about body motion. Consequently, the heightened reactions of our aerobically fit group to the sensory conflicts produced by cross-coupled stimuli may have been caused by (1) altered physiological states related to aerobic fitness, e.g., enhanced vagal tone or altered levels of stress hormones; (2) conditioned alertness to sensory inputs indicating deviations from expected body motions; and/or (3) aerobic fitness acquired without habituation to a range of nauseogenic motion stimuli.

Visual Acuity

Statistical review of the relationships of cardiopulmonary fitness with static visual acuity parameters did not reveal any significant correlations in the student naval aviator age range population. Mean dynamic visual acuity threshold values (minutes of arc) increased from $1.22 \pm .24$

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*CARE assesses the risk factors of age, smoking history, systolic blood pressure, and total cholesterol in comparison to a similar population with no risk factors. Any number greater than 1.0 represents a degree of risk that potentially could be reduced.

at 20°/sec to 4.01 ± 1.69 at 110°/sec representing an equivalent visual acuity of 20/24 - 20/80. Dynamic visual acuity at angular velocities of 20°/sec and 50°/sec were not correlated with fitness; however, fitness was correlated with dynamic visual acuity at angular velocity of 110°/sec ($r = -0.58$, $p < 0.01$) (Fig. 2).

Visual acuity has been shown to deteriorate as the angular velocity of an object increases (21). The variation in ability to discriminate detail in moving objects initially seems of little concern except in the conditions of high speed, low-level flight, air-to-air combat, and potential mid-air collisions. Frequent use of dynamic visual acuity at higher angular velocities during simulator tests has shown substantial improvement (22). The possibility that cardiopulmonary fitness may also enhance dynamic visual acuity warrants further study.

Heart Rate Response During Air Combat Maneuvers (ACM) Training Flights

Increases in heart rate during takeoff, flight, and landing were reported as early as the 1930s when heart rate, systolic blood pressure, and respiratory rate data were collected on aviators during aerial acrobatics (11). Table 2 and Figure 3 describe similar heart rate increases of the designated naval aviators of this study during monitored ACM training flights. Heart rate increased significantly ($p < 0.05$) from starting heart rate* during pre-flight, takeoff, transit flight, ACM, landing, and post-flight. Each flight usually had two ACM events while on the TACTS range. The mean max G loading during these events neared +5.0 G; the mean G remained near +2.0 G.

Cardiac response is compromised during high G, which leads to a reduced or delayed cerebral blood flow and thereby reduces G tolerance. A heart rate lag (delay in heart rate decrease) was usually seen following the G loading in this study, which was found to be correlated with mean G. This lag was most significant ($p < 0.01$) the first 60 sec following each ACM flight. One might expect that immediately following G (lag time), magnitude of heart rate would be greater and possibly longer to compensate (rebound affect) for the insufficient cerebral blood flow. A sympathetic response to increase vascular tone to maintain cerebral blood flow following the rapid G onset is most likely the causative agent. Centrifuge studies have identified similar findings (23).

Smith (24) observed that heart rate response appeared to be similar in magnitude during takeoffs and landings. These results prompted his conclusion that "...for the same amount of stress, the percentage increase in heart rate is independent of subject variability." In our study, flight experience was common, and type of ACM flights and environmental conditions were similar; therefore, we could assume a similar amount of stress was present. We found, however, that the magnitude of heart rate response was extremely variable among the aviators in all phases of flight. We also identified a physiological variable that was different among the group and

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*Starting heart rate is defined as the heart rate at time of activation of the monitoring device during flight gear donning.

that appeared to significantly influence the heart rate response. That variable was cardiopulmonary fitness, as defined by maximum oxygen uptake ($\dot{V}O_2$ max). Heart rate response was found to be inversely correlated with cardiopulmonary fitness (Fig. 4). This was true for pre-flight, r = -.595; takeoff, r = -.616; transit to the ACM range, r = -.601; ACM, r = -.565; return transit to base, r = -.604; landing, r = -.559; and post-flight, r = -.601 (all $p < 0.05$). The amount of heart rate lag response to ACM though, was not correlated with cardiopulmonary fitness.

CONCLUSION

Based on our results, the fitness profile (cardiopulmonary, capacity, and low coronary risk) of our incoming student naval aviators is of high caliber. Although maintenance of a similar level of fitness is somewhat less in the designated aviators 10 years older, the consistency of maintaining a "good" fitness level appears to still be an important consideration.

It is apparent that cardiopulmonary fitness can demonstrate an influence on physiological demands and responses that may occur during HPA operational flights. In fact, this influence could involve a number of physiological and psychological responses. To determine whether this relationship with cardiopulmonary fitness means anything in regard to aircraft performance is difficult. In other words, we cannot say absolutely that an increase in cardiopulmonary fitness will help an aviator fly better. If enhanced performance capability in flight is demonstrated, it may actually be a sense of well-being or self-confidence derived from individual fitness. Interestingly, self-confidence and/or well-being have been identified as prominent results of fitness training and have shown to be positive factors in enhanced work productivity (2).

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TABLE I
POPULATION COMPARISONS

	Student Naval Aviators	Designated Naval Aviators	General Population
Resting Heart Rate (BPM)	63.3 ± 11.5	63.5 ± 11.7	72.0 (25)
Resting Blood Pressure (mm Hg)	119.1 ± 9.9 / 76.1 ± 7.7	121.1 ± 9.3 / 73.4 ± 5.7	120/80 (25)
Age (Years)	23.9 ± 5.6	31.7 ± 3.6	20-44 (26)
Height (cm)	179.9 ± 6.9	181.7 ± 6.5	176.8 (26)
Weight (kg)	77.7 ± 8.5	81.2 ± 9.1	78.6 (26)
Body Fat (%)	12.0 ± 4.7	12.8 ± 4.4	15.0 (17)
* Exercise History	73%	54%	Not Available
Coronary Heart Disease (CHD) History	0.2%	11%	Not Available
Grip Strength (kg)	50.7 ± 6.8	53.1 ± 7.8	49.0 (26)
Smoking History	0.08%	16%	35% (27)
FVC (L)	5.9 ± 0.8	6.0 ± 1.0	5.57 (28)
FEV_1 (L)	4.7 ± 0.6	4.5 ± 0.7	4.49 (28)
FEV (25-[illegible] (L/SEC)	4.8 ± 1.1	4.5 ± 1.3	4.87 (28)
Total Cholesterol (mg/dl)	180.9 ± 48.9	Not Available	220 (27)
HDL Cholesterol (mg/dl)	48.8 ± 11.0	Not Available	44.0 (29)
TC/HDL Ratio	4.0 ± 1.4	Not Available	5.0
Triglycerides (mg/dl)	81.0 ± 38.0	Not Available	104.0 (29)
Coronary Risk Factor (CRF)	1.4 ± 1.2	Not Available	3.0 (18)
1.5 Mile Run (min)	9.5 ± 1.0	10.2 ± 1.2	11.0 (30)
Situps (within 2 mins)	76.5 ± 13.6	75.0 ± 23.6	Not Available
Sit and Reach (in.)	4.6 ± 2.5	2.5 ± 1.1	Not Available
$\dot{V}O_2$ Max ($ml \cdot kg^{-1} min^{-1}$)	53.7 ± 6.5	48.7 ± 7.4	45.4 (16)
Treadmill Time (min)	15.9 ± 1.7	14.6 ± 1.4	11.8 (16)
Anaerobic Threshold (%)	61.7 ± 9.8	62.7 ± 5.8	Not Available
Recovery Time (min)	30.3 ± 12.9	32.2 ± 13.3	Not Available
** Relative Aerobic Capacity (%)	0.65 ± 0.7	0.77 ± 0.08	Not Available
*** Functional Aerobic Impairment (FAI) (%)	8.0 ± 7.7	7.1 ± 9.5	Not Available

*Exercise history described as routine exercise 2-3 times per week for 20-30 minutes each.

**Relative aerobic capacity is the percent of maximal oxygen uptake ($\dot{V}O_2$ max) utilized at Stage 4 of the treadmill stress test.

***Functional Aerobic Impairment (FAI) is defined as the percent deviation between the observed and predicted values for $\dot{V}O_2$ max.

TABLE II

MEAN HEART RATE AND FLIGHT PROFILES DURING AIR COMBAT MANEUVER TRAINING FLIGHTS

	START	PRE FLT	TAKE OFF	$TRANSIT_1$	ACM_1	ACM_2	$TRANSIT_2$	LAND	POST FLT
HR (BPM)	78.5	94.9	100.5	91.1	95.7	99.3	92.8	106.2	98.0
SD	±9.5	±11.4	±26.2	±23.8	±20.5	±17.7	±20.5	±22.6	±15.8
TIME (MIN)		25.3	2.0	11.8	4.8	4.4	12.7	2.0	15.1
MAX + G_z					4.62	4.78			
SD					±1.3	±1.6			
MEAN + G_z					1.81	1.98			
SD					±0.4	±0.4			

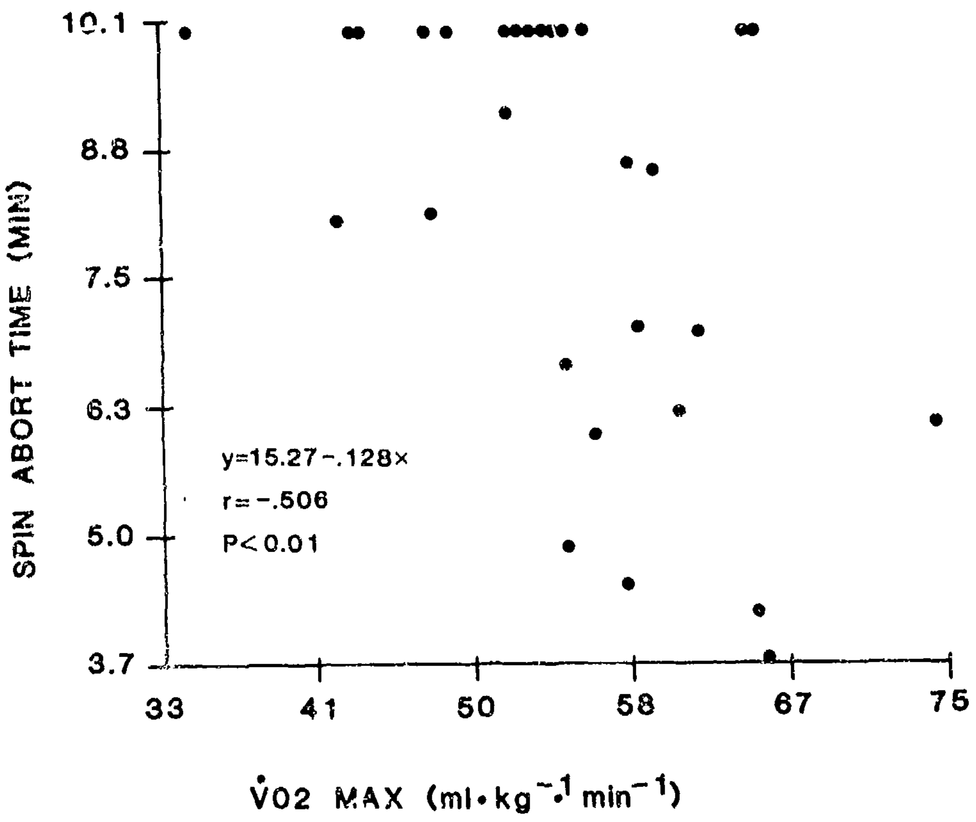

Figure 1

Correlation ($r = -0.56$, $p < 0.01$) of spin abort time (min) and cardiopulmonary fitness as measured by $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$).

DYNAMIC VISUAL ACUITY vs AEROBIC CAPACITY

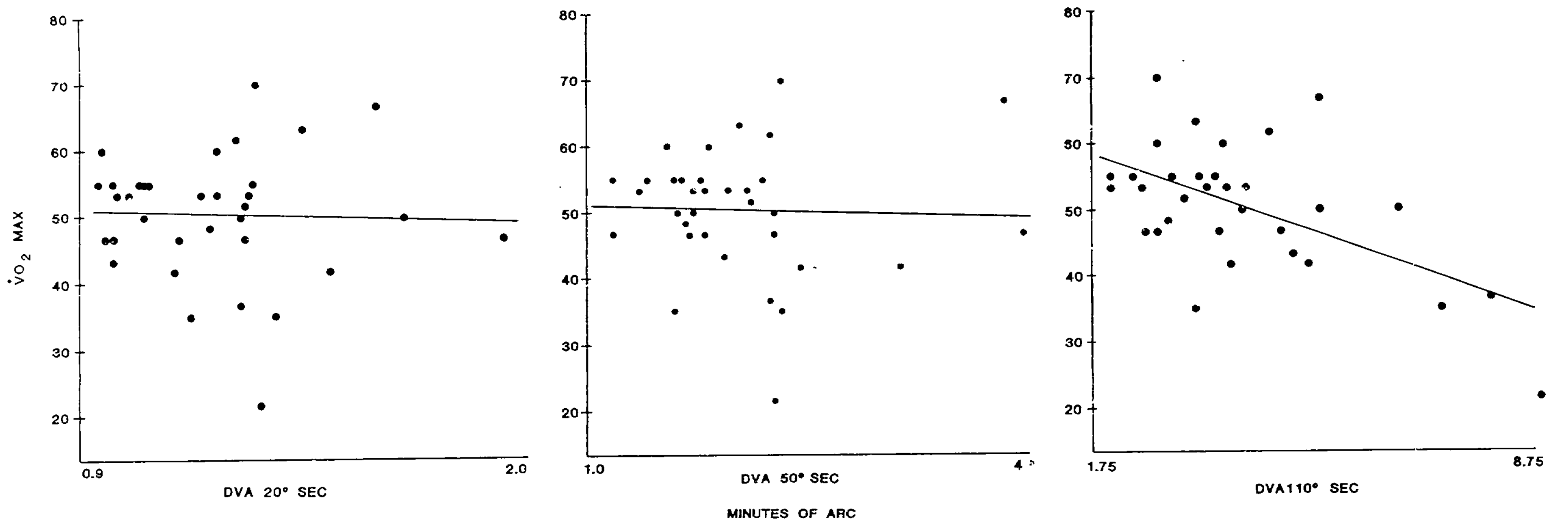

Figure 2

Correlations of cardiopulmonary fitness as measured by $\dot{V}O_2$ max ($ml \cdot kg^{-1} \cdot min^{-1}$) and Dynamic Visual Acuity (minutes of arc) at 20°/sec ($r = -0.04$, $p > 0.05$), 50°/sec ($r = -0.02$, $p > 0.05$), and 110°/sec ($r = -0.58$, $p < 0.01$).

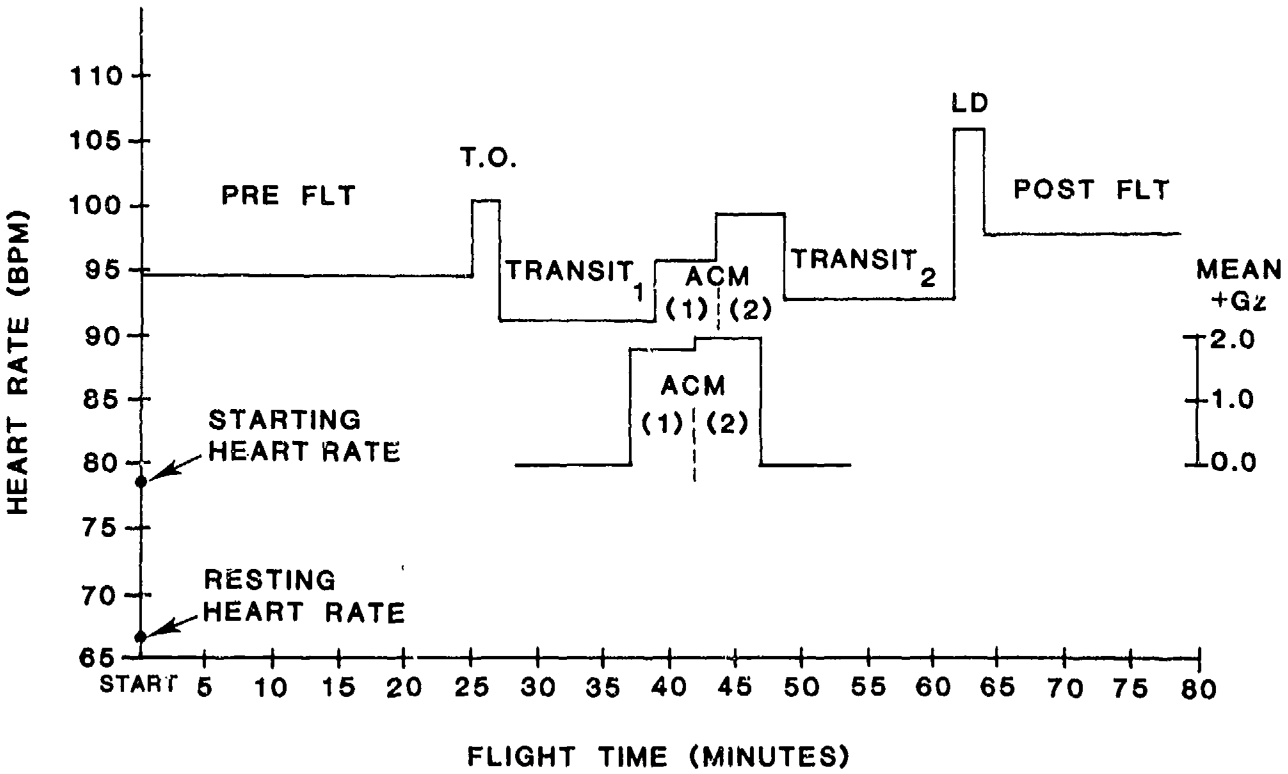

Figure 3

Mean heart rate and $+G_z$ response during Tactical Air Combat Training System (TACTS) Range ACM flights for 11 aviators during 23 flights. PRE FLT = preflight, T. O. = take off, Transit = flight to TACTS range. ACM 1 and 2 = individual ACM events (flights), $Transit_2$ = return flight to base, LD = landing, Post FLT = post flight.

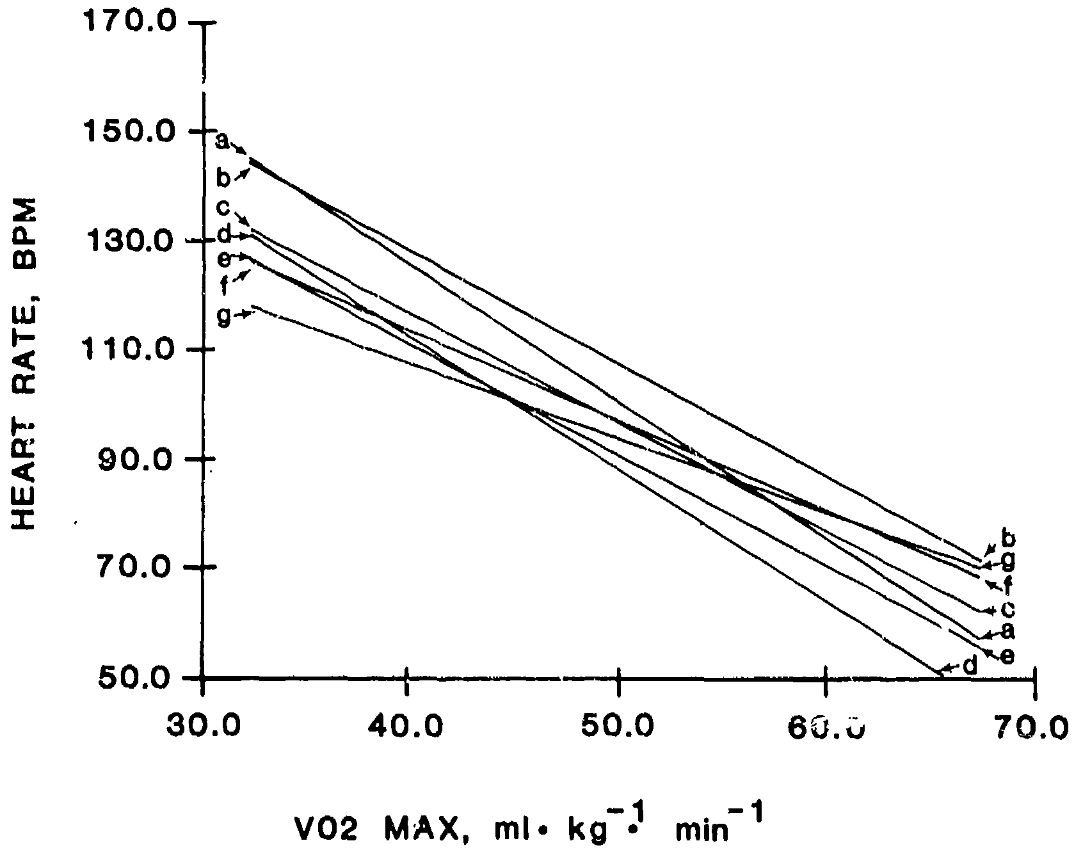

Figure 4

Best fit correlation lines for mean heart rate response during each flight phase and cardiopulmonary fitness ($\dot{V}O_2$ max) for 11 aviators during 23 ACM flights. a = take off, b = landing, c = ACM, d = $TRANSIT_1$ (flight to ACM range), e = $TRANSIT_2$ (return flight to base), f = post-flight, g = pre-flight.

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