PHYSIOLOGICAL CONDITIONING FOR MINIMIZING CREW FATIGUE AND HUMAN ERROR

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Introduction

Would aircrews be less susceptible to operational fatigue if they were always maintained near the peak of physiological conditioning? This question was investigated under Douglas Aircraft Company's (DAC) Independent Research and Development (IRAD) program during the early Nineteen Seventies. The investigation and development of this program consisted of two phases. Phase I, Task 1 entailed the development of a safe method for rapid, physiological conditioning for fatigue prevention or reduction. Phase I, Task 2 was the development of a simpler and safer method for the determination of the initial physical loads. In Phase II the Phase I methods were applied to DAC pilot subjects, which concluded the program as a biophysical procedure to delay or prevent fatigue, and to improve the air crewman's workload capacities.

Materials and Methods

The apparatus used for the program (Figure 1) were: (1) a Quinton Motorized Treadmill (TM) Model QI-601 with cardiotachometer operable in several modes, including heart-rate feedback to regulate TM speed automatically; (2) a Corbin Farnsworth Scopette for heart-rate (HR) and electrocardiogram (ECG); (3) an X-Y Plotter for recording HR and TM speed throughout the session; and (4) blood pressure and skin-fold measuring instruments and scale for weight.

The first step was to develop a submaximal TM stress test that would indicate a reasonably accurate initial level of conditioning. After reviewing the literature and conducting some preliminary experiments, it was determined that the following TM program would provide the required information: TM elevation 0%; TM speed and time -- 3 miles per hour (mph) for three minutes, 5 mph for two minutes, 6 mph for 2 minutes, and 3 mph for two minutes,then sit quietly until the HR returned to 90 beats per minute (bpm). Figures 2 and 3 show the variation in the responses of two S's to the standard base test (SBT).

Procedure

Using the data obtained in the initial TM test to determine the individualized conditioning program, four subjects (S's) were started on the program. The starting TM speed was the individual's choice - i.e. - that which was a comfortable pace, but faster than a walk. This was held constant

throughout the exercise phase. In all S's the maximum HR was not permitted to exceed 170 bpm, which was based on data derived from prior programs of a similar nature conducted by the author.

During the daily experiment, the subject's weight and BP were recorded pre- and post-exercise. Heart rate was recorded after sitting quietly for 5 minutes, again standing quietly on the TM and was monitored and recorded continuously during exercise until 170 bpm was reached.

When 170 was reached the S slowed to a walk, which again was the subject's choice, but was always the same for that S regardless of the exercise speed. The parameters observed during the experiment were: resting HR, standing HR, HR increase as a function of time at constant speed, time to 170 HR, time to 120 HR during walking, and time to a HR of 90 upon sitting. All this is plotted during the run by the X-Y Plotter, and each day's result is compared with earlier runs to visualize the progress. The exercise period was finally limited to 20 minutes from beginning of exercise to sitting. When the S began to exceed this time without going over the maximum allowable HR, the TM speed was increased to a higher level.

Phase I - Results

The rate of progress in improving cardiovascular and pulmonary function was faster than anticipated. In less than a month, all S's had improved considerably in the subjective evaluation of their well-being. In two to three months, both subjective and objective improvements were quite obvious. Improvement in tolerance to stress of all types was the most noticeable subjective change, whereas, the most striking objective improvements were significant reduction in blood pressure and improvement in cardiac function, evidenced by reduction in resting HR of as much as 20 bpm. Table 1 illustrates the beneficial effects noted and Table 2 shows the changes in BP for each subject.

In short, a highly workable method was developed for rapid physiological conditioning to improve a crewman's tolerance to stress and to delay the onset of fatigue. The key to rapid conditioning appears to be the control of the stress level as indicated by the maximum allowable HR, and to not exceed the predetermined maximum.

At this point, it became obvious that a better means of estimating the initial stress level was in order. Therefore, Phase I, Task 2 was initiated. The Karvonen formula has been most commonly used as a guide in establishing a safe maximum HR during exercise, for each individual. The Karvonen formula is bases on an age-adjusted recommended maximum HR calculated as shown:

maximum age-adjusted heart rate	−	resting heart rate	x 70% +	resting heart rate	=	safe exercising heart rate

The Subject's maximun heart rate can be determined individually by giving him a maximal effort test or one can take the average age-adjusted rate from this table:

Age:	30-49	40-49	50-59	60-69
Maximum Heart Rate:	183	178	167	164

This method appears to have an obvious deficiency. For example, the maximum allowable heart rate during exercise $(MAHR)_X$ is based on the chronological age rather than the physiological age of the individual. These two may be quite different. It has long been known that many older individuals who have continued adequate physical activities are usually much younger than their chronological ages would indicate. Conversely, many sedentary younger individuals are physiologically older than their actual years would indicate, and often develop metabolic diseases (hypertension, obesity, diabetes, and collagen), some of which might be prevented by an adequate exercise program.

In this context, physiological age, or condition, can be considered to be reflected by the resting HR (RHR) - i.e. - the slower the RHR the better the condition of the cardiovascular system. A well-conditioned athlete may have a RHR in the lower 50's or even in the 40's (it has been recorded to be in the upper 30's during sleep), whereas an obese, poorly conditioned invdividual may have a RHR in the 90's or higher. Hence, it would seem logical to base the $(MAHR)_X$ on RHR rather than on chronological age.

This new method for estimating the safe starting exercise stress for those about to begin a conditioning program is shown in Table 3. In conjunction with this table, the previously described method of heart rate monitoring must be used.

From Table 3, an equation can be derived:

$(AHR)_S$ = Actual Heart Rate (sitting quietly for 5 minutes)

$(DHR)_S$ = Desired Heart Rate (sitting quietly for 5 minutes)

$(CHR)_X$ = Ceiling Heart Rate during exercise (for any subject)

$(MAHR)_X$ = Maximum Allowable Heart Rate during exercise

The equation is expressed as:

$$(MAHR)_X = K - (AHR)_S$$

where K = a constant derived by adding $(DHR)_S$ and $(CHR)_X$

Substituting, then, using the example:

When $(AHR)_S = 100$

$(MAHR)_X = 60 + 170 - 100$

$= 230 - 100 = 130$

or, when $(AHR)_S = 80$

$(MAHR)_X = 60 + 170 - 80 = 150$

This procedure would be adhered to until such time in the program that the subject's $(AHR)_S$ decreases. As the decrease occurs the $(MAHR)_X$ can be automatically elevated to the next level. Thus, it is a useful procedure for monitoring the subject's progress as a self-pacing method. By charting his progress related to time, along with the exercise records, the method becomes a strong motivating factor in stimulating him to continue the program. His progress can be guided by this method. Each exercise may be continued so long as the pre-determined $(MAHR)_X$ is not exceeded during the 20-minute exercise period.

Mitigating Factors

Should any adverse medical problems be found during the physical examination, the $(MAHR)_X$ can be adjusted downward 10 or more points, very easily, according to the condition found. This adjustment should be made by the examining physician, based on his professional judgment. Adjustment of the $(CHR)_X$ upward would not be advisable for anyone except perhaps well-conditioned athletes engaging in competition. In such case, however, this program would not be necessary at all.

Phase II covers the initial step of a long-term program to apply the methods of Phase I to the conditioning of DAC pilots for the purpose of improving their tolerance to fatigue in the course of their flying duties. Secondary objectives were the reduction of weight, smoking, and other harmful health factors where indicated.

Methods and Procedures

Pilot S's were all on flying status and therefore had passed their flight physical exams. In addition, S's were given a supplementary examination that included the recording of physical anthropometric data, height, weight, age, skinfold thickness data, from which the percent body fat was calculated, examination of the heart, lungs, abdomen, back, and extremities. History of past illnesses and injuries was obtained, with particular attention being paid to any which might be significant with regard to a conditioning program. Dietary, drinking, and smoking habits were ascertained, as well as the type, level, frequency and duration of any exercise in which the subject normally engaged. ECG, finger pulse waveform, and BP were recorded. BP was recorded before and after exercising and after showering.

During the exercise, HR and TM speed were recorded simultaneously on the two-pen X-Y Plotter. When the session was completed, the data sheet indicated the following parameters: exercise stress level (TM speed in mph); duration of the session (warmup walk, run, cool-down walk, and rest); HR rate of change with change of stress level; time required for HR to reach the maximum allowable for that S at the given stress level; recovery time to HR 120 in the cool-down walk; and time to HR 90 when resting after cool-down. With successive exercise sessions, each daily record was compared with that of the previous and earlier sessions so that the S obtained "biofeedback" regarding his progress. The chart was placed so as to be visible to the S during his run for additional biofeedback. Pre-exercise and post-shower records were made of weight, RHR and BP. Additional feedback was provided to the S in the form of the graphic Progress Chart. One S requested a summary total of miles run in a given period to apply for and receive a Presidential Fitness Citation for running a distance of 125 miles in a 4-month period.

Phase II Results

Three pilot subjects began the program at the end of June 1973. Two S's were unable to continue to maximum benefit due to frequent absences caused by conflicting flight schedules. Although definite improvement was evident, participation was too brief for valid evaluation. One subject was able to participate consistently for 5 months. His progress is shown intermittently in Figures 4, 5, 6, and 7, as selected samples of his daily records. A summary of these subjects' progress is shown in Table 4, as well as the benefits realized by Subject Number 1.

Additional comments expressed by this subject were: "...When making 4-5 hour flights I don't get tired and have no back problem while other pilots complain of both....I smoke less, although I haven't quit.... When I took my Navy flight physical exam, the Flight Surgeon was very pleased with my weight loss, my blood pressure drop, and my resting heart rate reduction. He pointed me out as a good example to pilots who were half my age, and said they, too, should begin a conditioning program, because I was in better shape than they were...."

Summary

An improved method has been presented for the determination of beginning physical stress levels for unconditioned air crewmen in a physiological conditioning program aimed at the prevention or reduction of fatigue in flight operations. Human error is less likely to be made if fatigue can be prevented or delayed. This prevention technique, if followed as recommended in this paper, will result in an automatically self-regulating program with increased safety for the participant. It would appear that this method may be safer than other programs based on distance covered as a function of time and which often have the effect of over-motivating and over-stimulating the participant. It would also appear to be of value in avoiding the very common muscle, tendon, ligament, and joint injuries often seen in programs in which the trainee pushes himself too hard. Subjects participating in this program have not been troubled by such injuries. If applied to other segments of society, e.g. - factory workers, executives, truck drivers, alcohol and drug victims, very significant cost savings could be realized through reduction of accidents, lost time due to illness, higher efficiency on the job, and an improved attitudes and outlook on the part of employes.

BIBLIOGRAPHY

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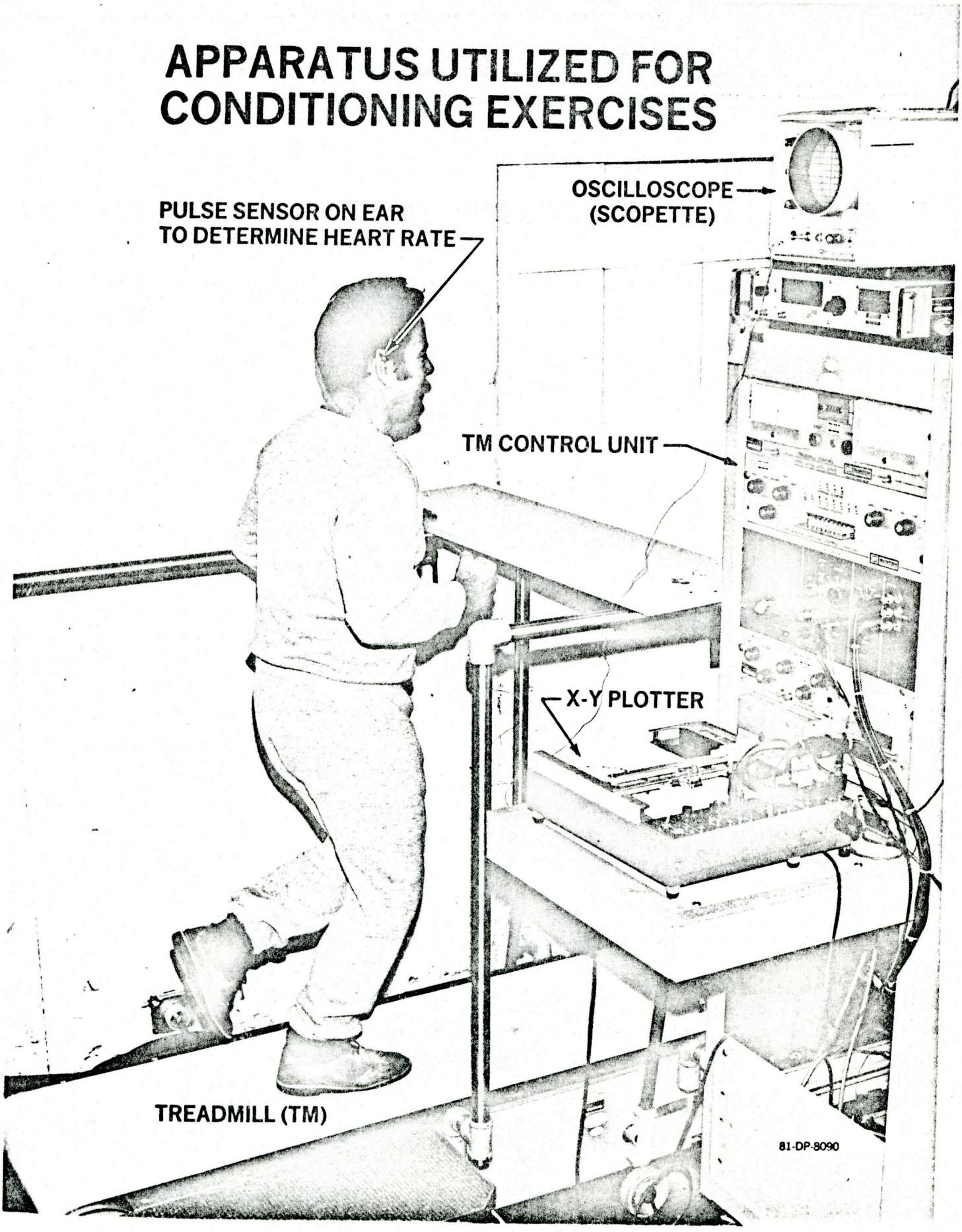
5. K. H. Cooper. The New Aerobics. M. Evans and Company, New York. 1970

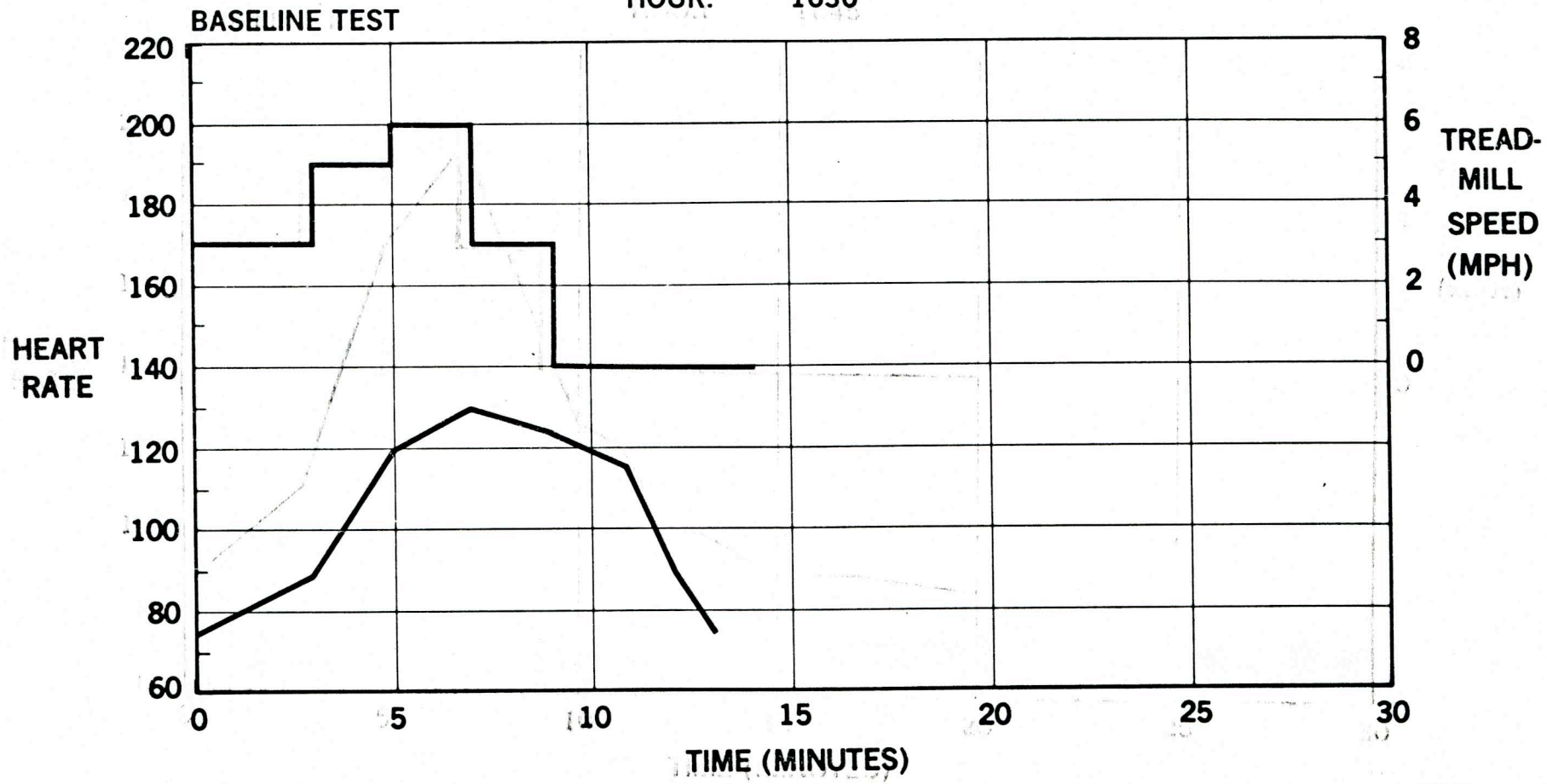
APPARATUS UTILIZED FOR CONDITIONING EXERCISES



PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

DATE: 8-7-69
SUBJECT: P.B. — 29
WEIGHT: 150
HOUR: 1630



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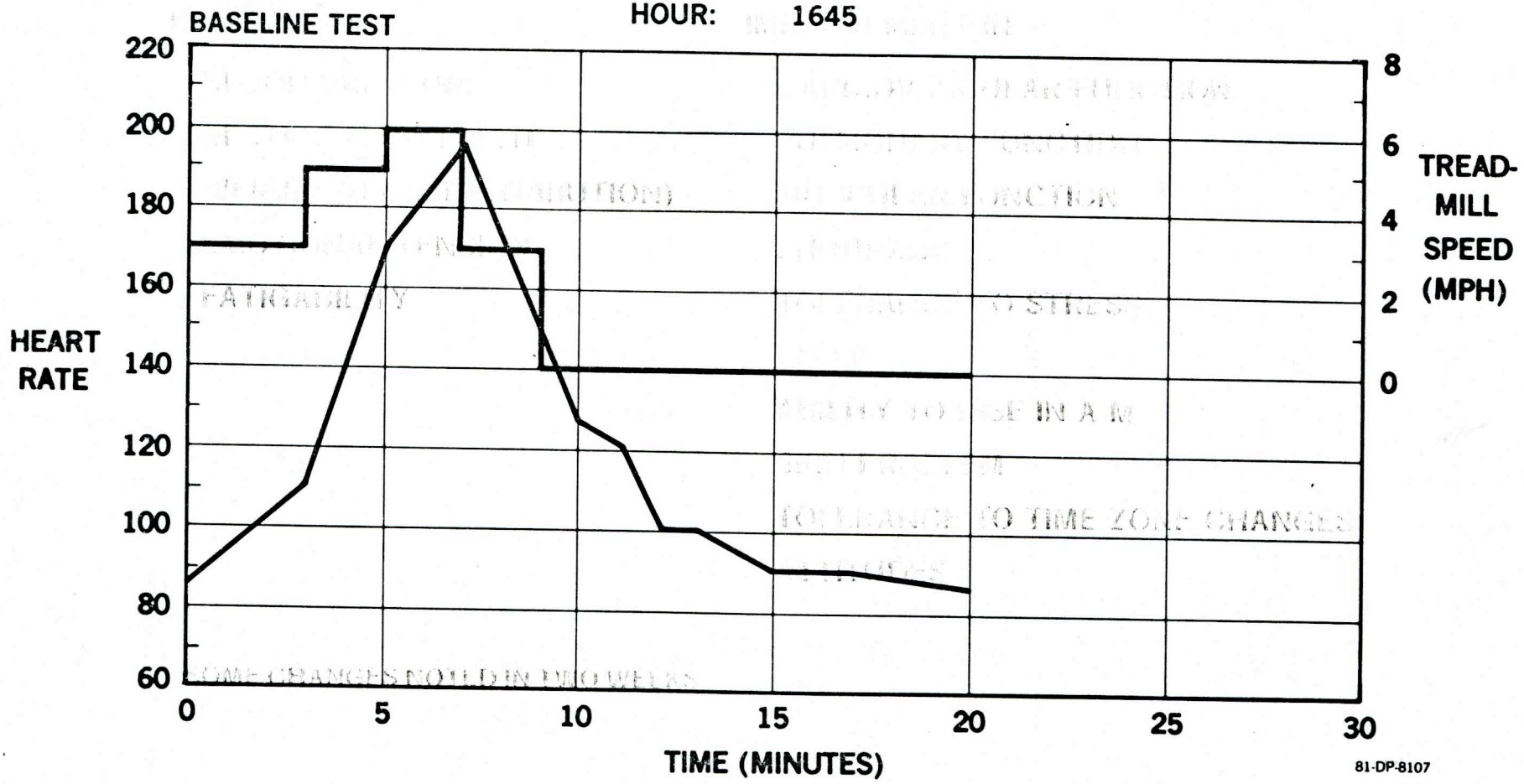
PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

DATE: 8-11-69
SUBJECT: J.T. — 44
WEIGHT: 191
HOUR: 1645



BENEFICIAL EFFECTS NOTED*

REDUCTION OF:

- BLOOD PRESSURE
- RESTING HEART RATE
- WEIGHT (OR REDISTRIBUTION)
- EMOTIONAL TENSION
- FATIGABILITY

IMPROVEMENT IN:

- CARDIOVASCULAR FUNCTION
- PULMONARY FUNCTION
- MUSCULAR FUNCTION
- ENDURANCE
- TOLERANCE TO STRESS
- SLEEP
- ABILITY TO RISE IN A.M.
- SKIN PROBLEM
- TOLERANCE TO TIME ZONE CHANGES
- ATTITUDES

*SOME CHANGES NOTED IN TWO WEEKS

81-DP-8099

BLOOD PRESSURE CHANGES
(FOUR SUBJECTS)

SUBJECT	AGE	BEFORE	AFTER	TIME
1	24	140/90	110/60	1 MONTH
2	29	140/90	115/65	3 MONTHS
3	39	135/80	118/72	2.5 MONTHS
4	55	180/90	130/70	3 MONTHS

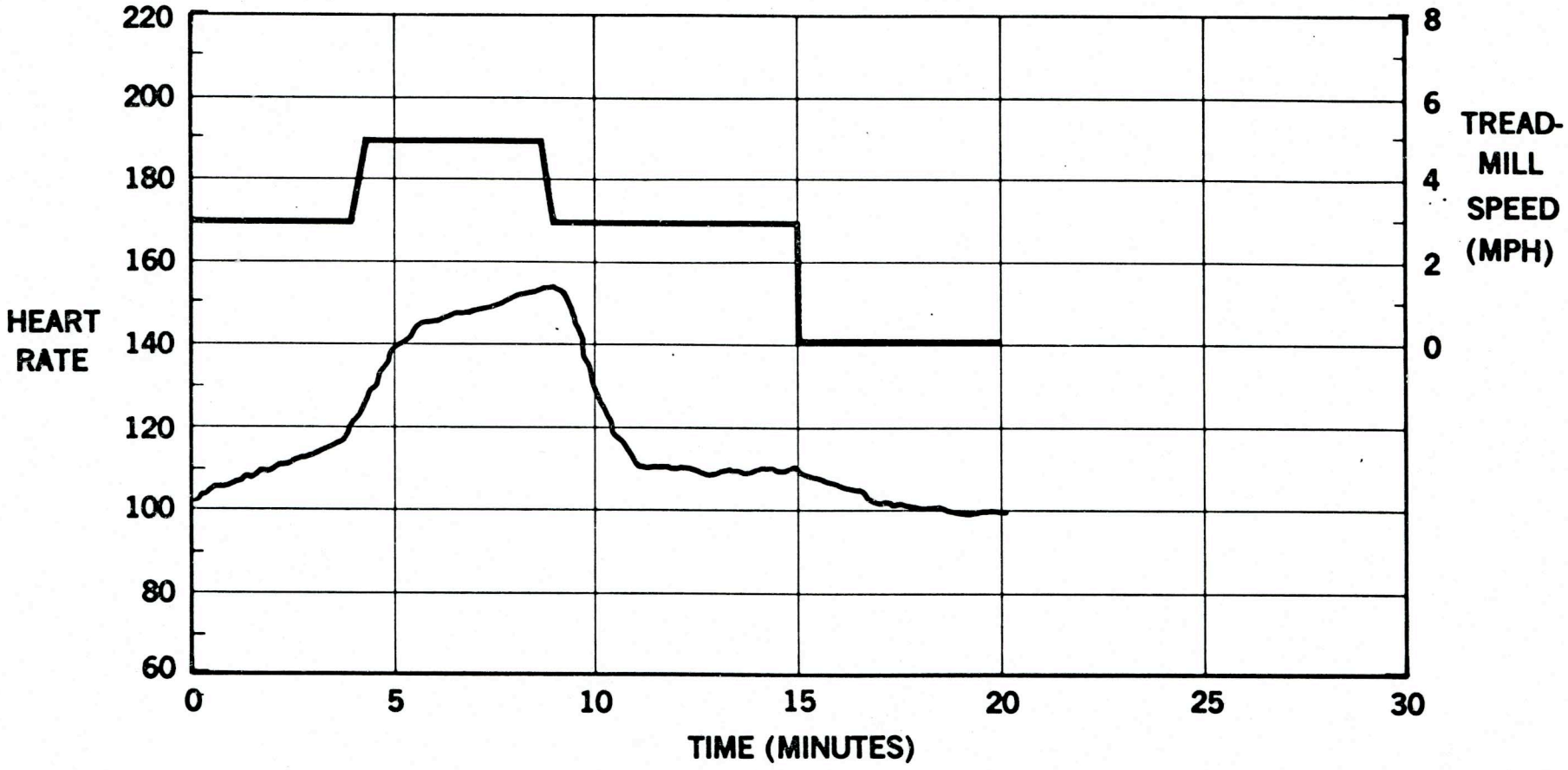
DETERMINATION OF MAXIMUM ALLOWABLE HR DURING EXERCISE

$(AHR)_S$	$(DHR)_S$	$(CHR)_{EX}$	$(MAHR)_{EX}$
110	60	170	120
100	60	170	130
90	60	170	140
80	60	170	150
70	60	170	160
60	60	170	170

PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

			PRE	POST	POSTSHOWER
NAME:	SUBJECT NO. 1				
DATE:	6-26-73	BP	138/88	132/88	128/88
HOUR:	1045	HR:	90	100	100
		WEIGHT:	193-1/4		192-3/4

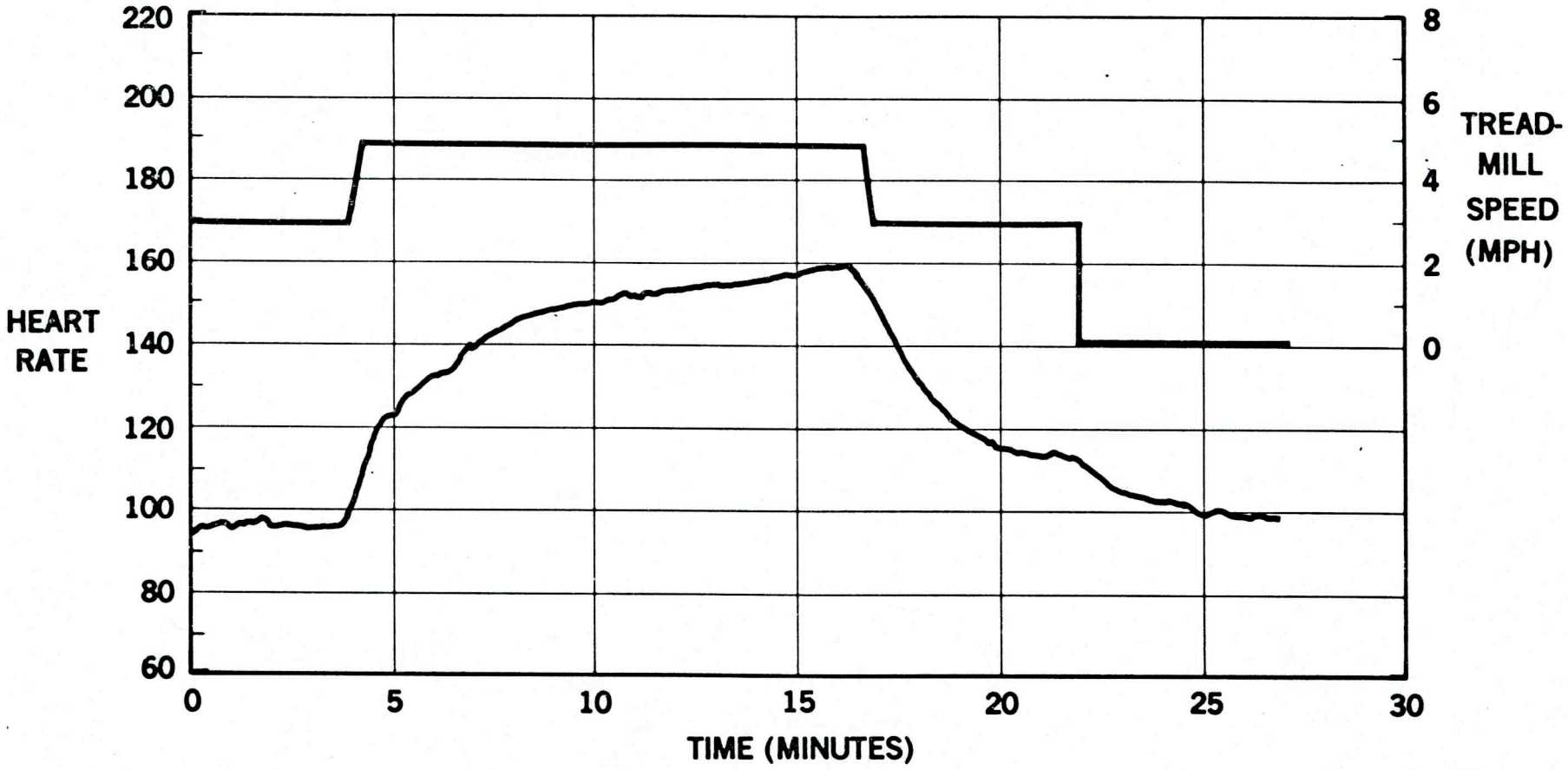


81-DP-8097

PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

			PRE	POST	POSTSHOWER
NAME:	SUBJECT NO. 1				
DATE:	7-6-73	BP:	124/86	112/83	126/86
HOUR:	1030	HR:	70	98	95
		WEIGHT:	193-1/2		192-3/4

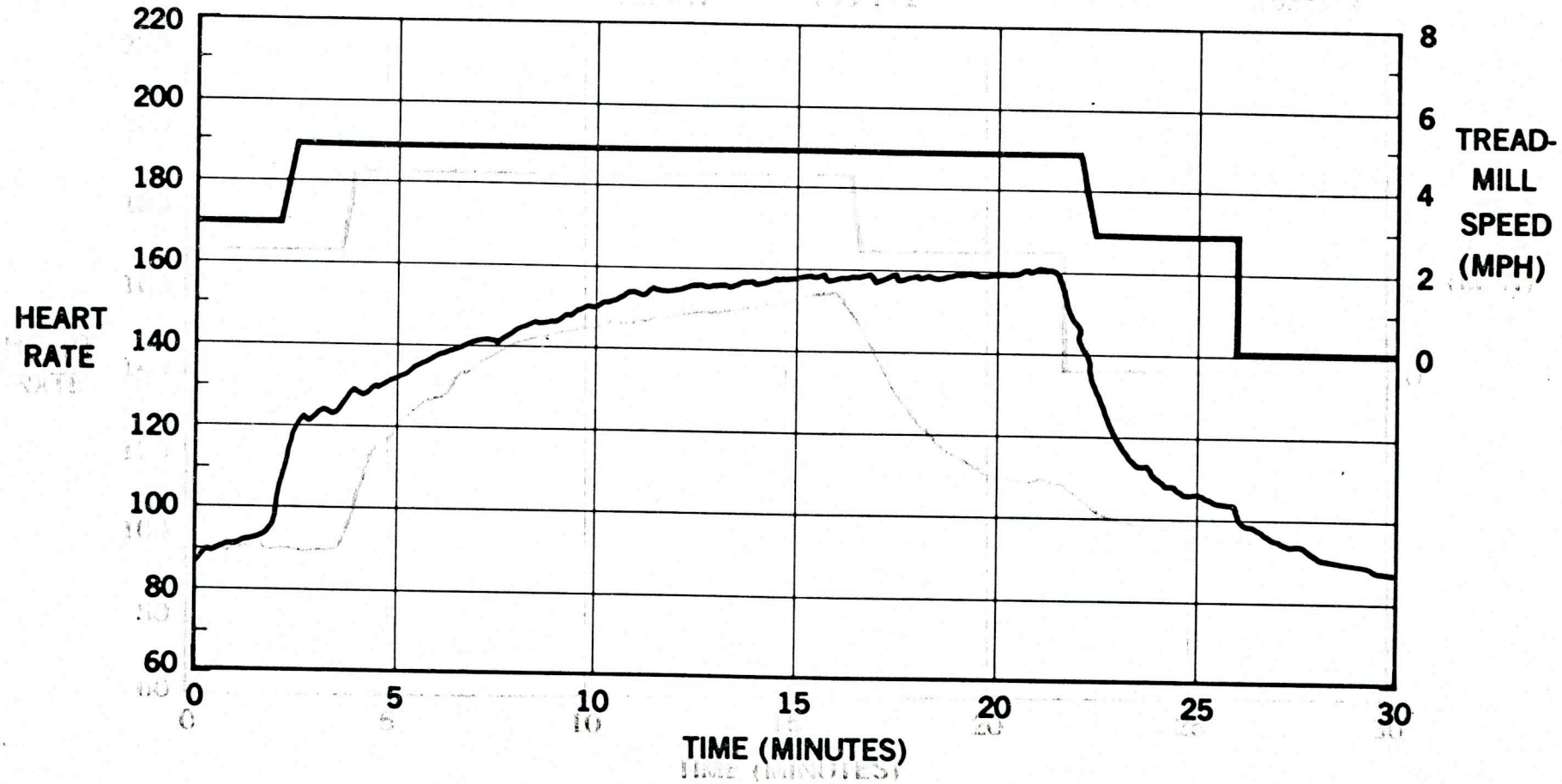


81-DP-8092

PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

NAME:	SUBJECT NO. 1			
DATE:	7-13-73			
HOUR:	1030			
		PRE	POST	POSTSHOWER
	BP:	118/80	106/78	108/75
	HR:	68	110	98
	WEIGHT:	190		189

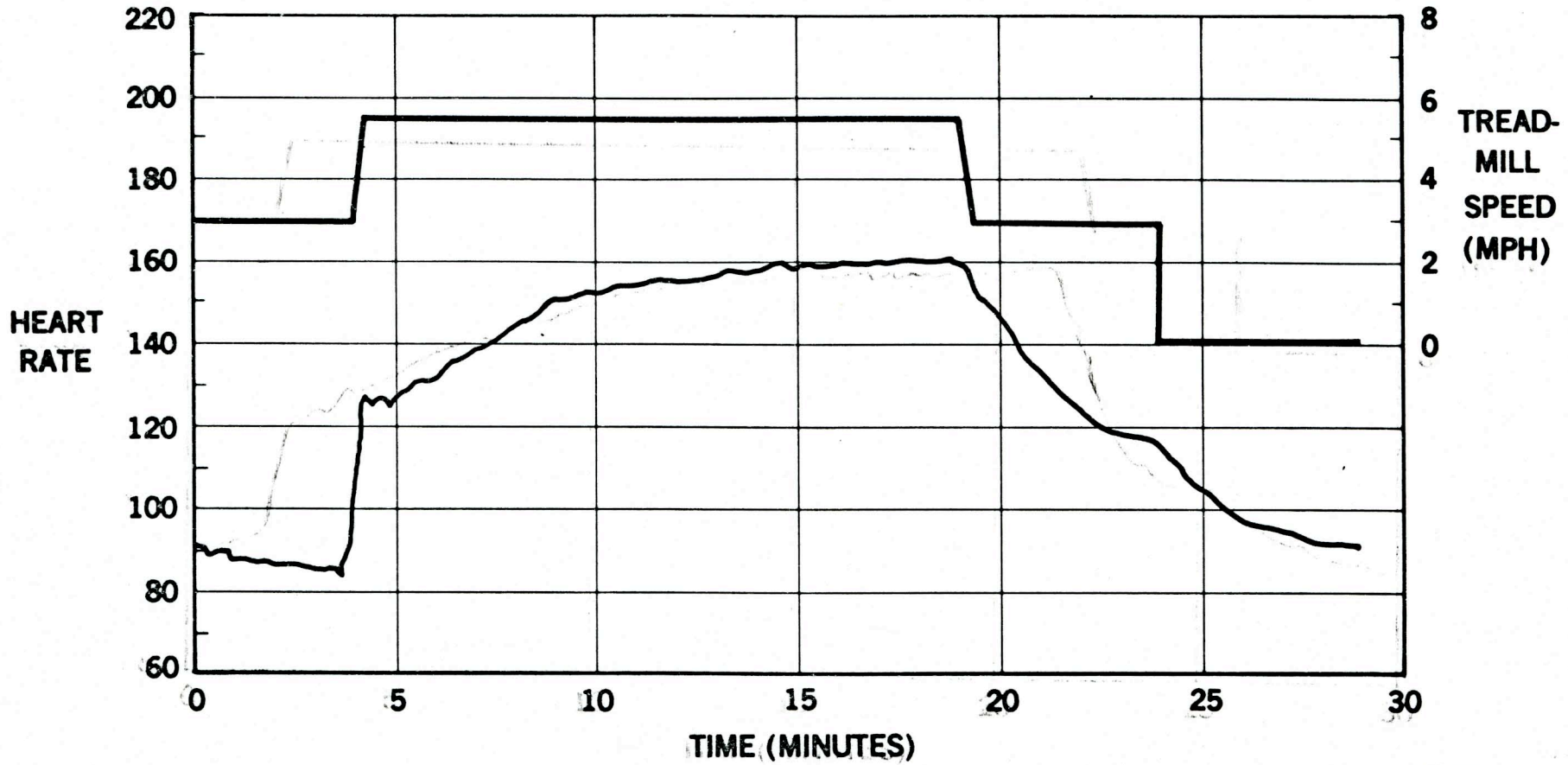


81-DP-8098

PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

			PRE	POST	POSTSHOWER
NAME:	SUBJECT NO. 1				
DATE:	8-30-73	BP:	130/79	121/75	106/78
HOUR:	1045	HR:	75	90	100
		WEIGHT:	179		178

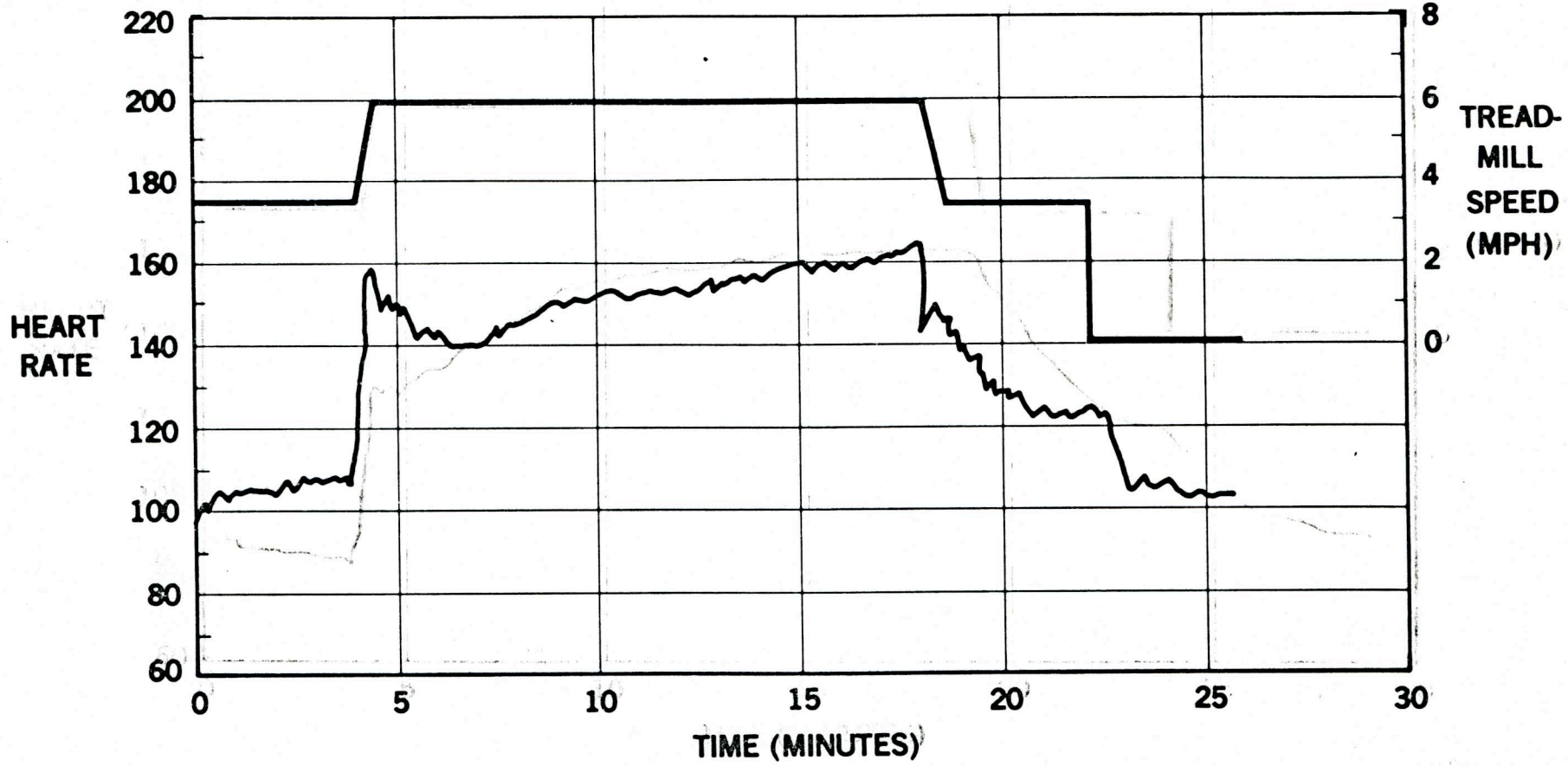


81-DP-8095

PHYSICAL CONDITIONING AND FATIGUE

EXERCISE RECORD

			PRE	POST	POSTSHOWER
NAME:	SUBJECT NO. 1				
DATE:	11-8-73	BP:	106/78	100/66	112/75
HOUR:	1120	HR:	68	92	85
		WEIGHT:	172-3/4		172



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BENEFITS NOTED BY SUBJECT NO. 1

OBJECTIVE

WEIGHT REDUCTION 21 LB
(NO SPECIAL DIET)

BP REDUCTION (20 POINTS
SYSTOLIC, 12 DIASTOLIC)

% BODY FAT REDUCED FROM
18.5 TO 12.5%

WAIST — 3-INCH REDUCTION

RHR REDUCED FROM 90 TO 60

LOOKS BETTER

SUBJECTIVE

FEELS MORE ALERT

LESS FATIGUE
NONE WHILE FLYING OR DRIVING
CLIMBS MOUNTAINS MORE EASILY

LESS EMOTIONAL TENSION AND
FRUSTRATION

HIGHER LEVEL OF ENDURANCE AND
TOLERANCE TO STRESS, ALL KINDS

EASIER TO RISE IN THE MORNING

IMPROVED ATTITUDE — EASIER TO
GET ALONG WITH (WIFE'S COMMENT)

SUMMARY OF PROGRESS

SUBJ	AGE	HEIGHT (IN.)	DURATION	WEIGHT (LB) PRE	WEIGHT (LB) POST	BP PRE	BP POST	RHR PRE	RHR POST	% BODY FAT PRE	% BODY FAT POST
1	44	70-1/4	5 MONTH	193	172	130/86	110/74	90	60	18.5	12.5
2	50	71	2.5 MONTH INTERMITT	172.5	177	112/76	108/68	75	64	15.5	—
3	52	74	2 WK	210.5	210	122/90	104/76	80	80	19.0	—