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AD A129029

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER M24/83	2. GOVT ACCESSION NO. AD A129029	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) The Effects of "Jet-Lag" on Exercise Performance		5. TYPE OF REPORT & PERIOD COVERED
AUTHOR(s) James A. Vogel, Ph.D.		6. PERFORMING ORG. REPORT NUMBER
PERFORMING ORGANIZATION NAME AND ADDRESS US Army Research Institute of Environmental Medicine, Natick, MA 01760, USA		8. CONTRACT OR GRANT NUMBER(s)
CONTROLLING OFFICE NAME AND ADDRESS US Army Medical Research and Development Command Fort Detrick, Frederick, MD 21701		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE 11 May 1983
		13. NUMBER OF PAGES 20
		15. SECURITY CLASS. (of this report)
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)
DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DTIC
ELECTIC
JUN 7 1983
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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES
To be published in Medicine Science in Sports and Exercise as a Symposium

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
Translocation, jet-lag, stress, exercise capacity, physical performance, aerobic power, muscle endurance, muscle strength, circadian rhythms

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)
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The Effects of "Jet-Lag" on
Exercise Performance

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Running head: Jet-Lag and Exercise Performance

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The Effects of "Jet-Lag" on
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HUMAN RESEARCH

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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ABSTRACT

The behavioral and cognitive changes resulting from crossing multiple time zones are well known. Amongst the symptoms usually observed are fatigue and lassitude which suggests that exercise capacity may also be altered. Yet no controlled experimental studies have been reported of the effect of transcontinental flights on either athletic or occupational physical performance. Because of the obvious application to military deployment, a study was conducted (Wright, et al 24) which assessed physical exercise capacity and performance in eighty one soldiers five days before and five days immediately after crossing six time zones by jet aircraft. Measures of aerobic and anaerobic capacity and muscle strength were made as well as several physical performance tasks. Aerobic capacity as measured by treadmill maximal oxygen uptake was unaltered. Dynamic strength and endurance of the elbow flexors muscles declined significantly while isometric strength of upper torso, trunk and leg muscle groups was unchanged. Performance times increased after the transcontinental flight for a 270 meter sprint, 2.8 kilometer run and a 110 meter lift and carry while no alteration was observed in a 6.5 meter rope climb. These observations suggest that certain physical capacities are affected by multiple time zone translocation but they may be due to sleep loss induced fatigue rather than biorhythm disruption of physiological mechanisms. The specific mechanisms, duration, magnitude and ultimate impact of these effects on actual physical performance remain to be explored.

Key Words:

Translocation, jet-lag, stress, exercise capacity, physical performance, aerobic power, muscle endurance, muscle strength, circadian rhythms

The undesirable effects of rapidly crossing multiple time zones, commonly known as jet-lag, are well known to intercontinental travelers. This condition is the cumulative effect of not only disruption of circadian rhythms but also may include the effects of aircraft noise, vibration, confinement, dehydration and anxiety. Symptoms typically consist of fatigue, general malaise, sleep disturbance and decrements in cognitive and psychomotor performance. Experimental research on this subject has been essentially limited to psychomotor and cognitive function, principally of aircraft crews (1,2,4,5,8,9,11,13,14,18,20,22).

Most travelers, such as businessmen and women, tourists and air crews, are not normally concerned with physical tasks at their destinations and therefore physical performance has been ignored in research on jet-lag. Persons who are concerned are competitive athletes and, of a much larger magnitude, U.S. soldiers who are rapidly deployed from central United States to Western Germany. These military units cross six or seven time zones in jet aircraft and are expected to be physically capable of strenuous operations upon arrival. During peace time training, the U. S. Army routinely rotates large units to Europe and immediately deploys them in physically demanding training scenarios. In these training sessions unit commanders have observed apparent impaired job performance and general malaise in troops during the first week after arrival. Because of this perceived problem, a study was designed to assess the effects of jet-lag on subsequent physical capacity and performance. We were unable to locate any previous experimentally controlled studies of exercise performance in response to jet-lag in any type of population.

The question of whether the energy generating systems and neuromuscular mechanisms for muscular contraction could be affected by time zone translocation is open to speculation. These processes are highly integrated and

involve numerous physiological components. Some of these components respond to circadian cycles such as sympathetic and adrenal steroid activity (12,16,23). In regard to exercise capacity per se, aerobic power has been reported not to fluctuate during the circadian cycle. In contrast to aerobic power, anaerobic power and maximal strength involve extensive coordinated nervous system activity. The capacity to voluntarily exert maximal force (strength) and to maintain a normal pattern of maximal exertions over a period of time (strength endurance) requires a complex and highly coordinated pattern of excitation and inhibition of muscle fibers. Because of these neural involvements, it may be postulated that muscle strength and strength endurance would be more susceptible to disruption of biorhythms from transmeridian flights than aerobic power capacity.

This report reviews the salient features of a recent study carried out by our laboratory as previously reported in greater detail elsewhere (24).

Experimental Design

Ninety four soldiers from an infantry company volunteered (out of 97) for the study. Of these, thirteen were excluded for medical reasons, leaving eighty one in the experimental group. These 81 subjects were then randomly divided into 3 groups (designated as red, green and yellow). The entire sample averaged 22.9 ± 0.4 (S.E.M) years of age, 74.2 ± 1.5 kg body weight and $16.6 \pm 0.7\%$ body fat.

The subjects were studied for a 5 day period two weeks prior to and again during the first 5 days after a transatlantic flight from Fort Hood, TX to Nuremberg, West Germany. The flight was aboard a DC-8 chartered commercial aircraft. It departed Texas at 0200 hours CDT and arrived in Nuremberg at 2245 local time with a one hour intermediate stop in Philadelphia and 30 minute stop in Shannon, Ireland, for a total flight time of 14.75 hours and the crossing of six

time zones. The subjects were moved from the airport to the test site, arriving at 0115 in the morning. They were allowed sleep from 0300 to 0600 and reported for the commencement of testing at 0730 hours. Thus an additional 8.75 hours elapsed from touch down to testing or a total of 23.5 hours since departure in Texas. Testing was carried out according to the schedule depicted in Table 1.

Aerobic Fitness Capacity

Whole body mobility for periods of several minutes to several hours depends to a large extent upon one's aerobic power capacity, that is, the ability to transfer oxygen to the muscles and generate energy by aerobic metabolic pathways. This is also referred to as aerobic fitness or cardiorespiratory fitness.

In this study, aerobic power was determined by the most direct means - the determination of maximal oxygen uptake during uphill treadmill running, following the procedure of Mitchell, et al (19). The test began with an initial warm-up run at 6 mph and 0% grade for 6 minutes, followed by a 5-10 minute rest period. Two to four additional runs were performed, each 3-4 minutes in length and interrupted by rest periods. These runs progressively increased in work intensity by raising the speed or grade. During the last minute of each run, expired air was collected in plastic Douglas bags through a mouthpiece and low-resistance breathing valve for gas analysis. A plateau in oxygen consumption with increasing workload was considered indicative of achieving one's maximal oxygen uptake. A plateau was defined as an increase of less than 1.5 ml oxygen per kg body weight per minute with an increase of 2% in grade.

The results from our study (Table 2) indicate that this transmeridian flight had no effect on maximal oxygen uptake. This is not surprising when one considers the various means of adjusting blood flow and oxygen perfusion of the active muscles. Although resting heart rate does vary with the circadian cycle, maximum heart rate apparently does not (3). Even if it was affected by

circadian desynchronization, cardiac output, the primary determinate of maximal oxygen uptake in this situation, would be maintained by adjustments in stroke volume or arteriovenous oxygen extraction. This is in agreement with Faria and Drummond (7) who found no cyclic variations in maximal oxygen consumption throughout a 24 hour period. Moderate sleep loss also does not decrement aerobic capacity (17). Thus one can conclude that capacity per se for whole body exercise or mobility is not affected by intercontinental flights of this nature.

Muscle Strength and Endurance

Muscular strength can be defined as the ability of a body segment to exert maximal force in a single voluntary effort. Muscular endurance is the ability of a muscle (group) to exert force over a sustained period of time. Muscular strength and endurance appear to be limiting factors in many physical tasks. They reflect a component of physical performance that differs from aerobic type tasks since different physiological mechanisms and energy processes are involved. For this investigation a representative sample of muscle groups was selected for measurement. These muscle groups involved three major body segments (arms/shoulders, legs and trunk) of particular importance for military tasks. Tests involving both isometric (static) and dynamic strength as well as dynamic endurance were included.

Maximal static strength of three muscle groups was measured with a device designed in our laboratory (15) similar to that of Hermansen (10). The three muscle groups tested were: (a) the upper torso (arm and shoulder), (b) legs and (c) back (trunk). Three contractions of each muscle group were performed, each 3-4 seconds. The force was registered on a spring-loaded force transducer connected to a bar against which the subject exerted force. In all cases the subject was instructed and encouraged to exert as much force as possible.

Maximal dynamic muscular strength and endurance of two muscle groups, the arm flexors and knee extensors, were determined utilizing isokinetic (constant velocity) measuring equipment (Cybex II dynamometer, Lumex Corp., Cybex Div., Bay Shore, NY). The isokinetic device allows the subject to exert a maximal voluntary contraction at a constant velocity and thus allows the production and quantification of maximal force (torque) throughout the range of motion. Dynamic muscle strength was assessed with two individual contractions for each muscle group at each of two contractile velocities. Strength at low contraction speed was measured at 36 degrees per second. The ability to exert force at higher contractile velocities, which represents a different neuromuscular capability, was assessed at 180 degrees per second. Muscle endurance was quantified from a 60 second bout of repeated maximal contractions of 180 degrees per second.

The results from this study indicated that changes in isometric strength for all muscle groups from pre- to post-deployment were small, inconsistent and not statistically significant (Fig. 1). In contrast, dynamic strength of the elbow flexor muscles was significantly decremented after arrival in Germany as depicted in Figure 2. The decrease was greatest at the faster contraction velocity. Significant reductions were also observed in dynamic elbow strength endurance (peak torque output) as illustrated in Figure 3. Dynamic leg strength and endurance changes were inconsistent and appeared to be confounded by the fatigue of other tests involving the legs. Nevertheless, the results with dynamic arm strength and endurance suggest that translocation does have an effect on some aspect of the muscle contractile process. Likely sites of action for this effect would be motor control or fiber recruitment. There is no comparable data in the literature however to support this finding or the proposed mechanism.

Task Performance

In the study reviewed here, a task performance battery was developed from events which would reflect ability in basic military physical skills. The ability to carry out physically demanding tasks is dependent both on one's physiological capacity, as measured by aerobic and anaerobic power and strength, as well as the person's willingness or motivation to perform. Thus, these tasks were designed to evaluate the possible effect of jet-lag on the combination of exercise ability and willingness to perform. They included a six meter vertical rope climb, 100 meter fireman carry, 270 meter sprint and 2.8 kilometer run. All were timed to the nearest second. The results are depicted in Figures 4 and 5.

No decrements were observed in the rope climb as a function of the translocation (Fig. 4). For the 100 meter fireman's lift and carry, only one out of the three groups exhibited a significant decrement (Fig. 5). All groups, however, had a decrement in the performance of the sprint event, significant at the $P < .05$ level (Fig. 5). Only one group showed a significant decrement in the 2.8 km run, the same group with a decrement in the fireman carry (Fig. 4).

The observed decrement in the sprint task performance would be in agreement with the changes recorded in muscle strength and endurance of the arms rather than what was observed with leg strength. This decline in sprint performance along with those in the lift and carry task and run, in the absence of a decrement in aerobic power, suggests that translocation of this magnitude may well have a motivational or willingness component to its overall affect on exercise ability.

Rutenfranz and Colquhoun (21) suggest that changes in task performance after circadian rhythm disruption are probably largely related to sleep cycles. This leads one to question whether alterations in physical performance as the result of jet-lag are related at all to the crossing of time zones per se or whether

they are the result of "fatigue" emanating from sleep loss or disruption. The latter idea is proposed by Dodge (6) who has argued that physiological regulatory mechanisms are not responsible but rather the fatigue resulting from sleep loss or sleep disruption due to altered light-dark relationships.

Conclusion

Soldiers and athletes are examples of groups who are subjected to physical performance demands soon after completing jet flights across numerous time zones. For both groups it is important to know what the nature, extent and duration of any reduced physical ability may be. Furthermore, it would be valuable to factor out the components of jet lag and identify whether physiological regulatory mechanisms are altered by desynchronization or it is simply a matter of fatigue due to sleep loss.

The study reviewed here only begins to address these questions and more research is needed. The clear cut reductions in arm dynamic strength and dynamic endurance, tests which are largely free of a motivational component, suggest that rapid multiple time zone translocation does produce some physiological regulatory impairment. The physiological impairment is suggested to be a central nervous system affect on muscle fiber recruitment but the origin of such a mechanism, if it exists, has not been identified. On the otherhand, decrements in task performance without consistent alterations in physiological capacity suggests behavioral alterations, probably a function of sleep loss and fatigue. The implications for athletes suggests that further research would be worthwhile.

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- Figure 1 - Isometric strength for three test groups (mean \pm SEM) of legs, upper torso and trunk muscles, T = Texas, G = Germany. From Wright, et al (24)
- Figure 2 - Isokinetic strength (torque in Newton meters) for three test groups of elbow flexors (mean \pm SEM). T = Texas, G = Germany. Asterisks indicate significant at $P < .05$. From Wright, et al (24)
- Figure 3 - Pre- and post-deployment elbow flexor endurance decay slopes for all groups combined (Newton meters) at 180 degrees per second. From Wright, et al (24)
- Figure 4 - Six meter rope climb and 2.8 km run performance task. Asterisks indicate difference significant at $P < .05$. From Wright, et al (24)
- Figure 5 - One hundred meter fireman carry and 270 meter sprint performance tasks. Asterisk indicates difference significant at $P < .05$. From Wright, et al (24)

TABLE 1. Testing Schedule of Three Randomly Assigned Groups on Three Sets of Measurements

	Day				
	1	2	3	4	5
<u>Group</u>					
Red	AC	TP	MS	AC	TP
Green	TP	MS	AC	TP	MS
Yellow	MS	AC	TP	MS	AC

AC: Aerobic capacity, MS: Muscle Strength and Endurance, TP: Task Performance. Adapted from Wright, et al (24).

TABLE 2. Maximal Oxygen uptake (mean \pm SD) during treadmill running before and after translocation (ml/kg/min). Adapted from Wright, et al (24).

Texas		Germany				
Group	Day: 1 2 3 4 5					
Red	46.3 \pm 8.1	46.3 \pm 6.9			47.0 \pm 7.9	
Yellow	47.0 \pm 6.3		48.4 \pm 5.4			47.6 \pm 5.5
Green	48.1 \pm 5.2			50.4 \pm 5.3		

Figure 1

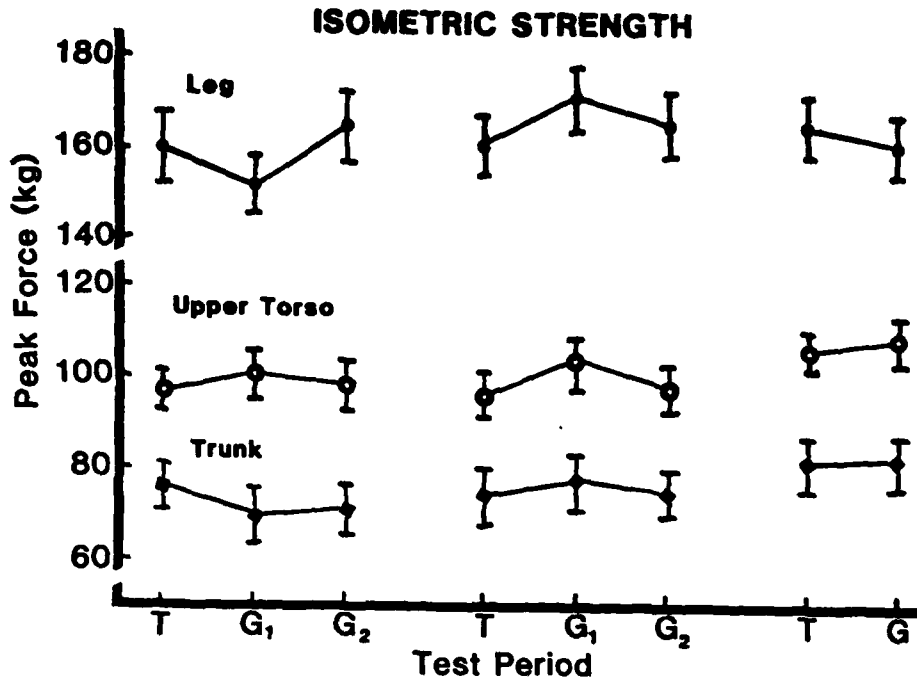


Figure 2

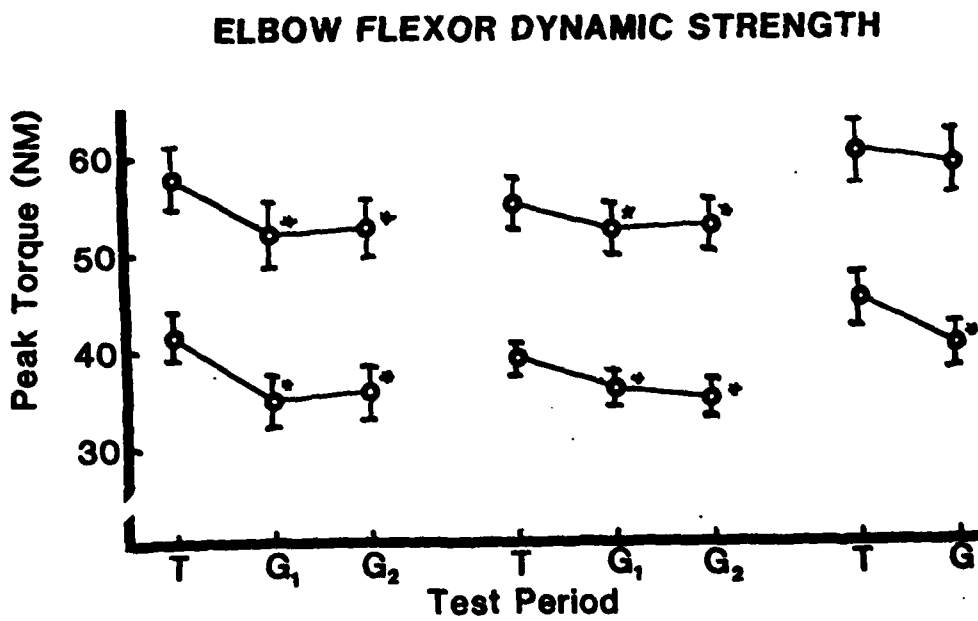


Figure 3

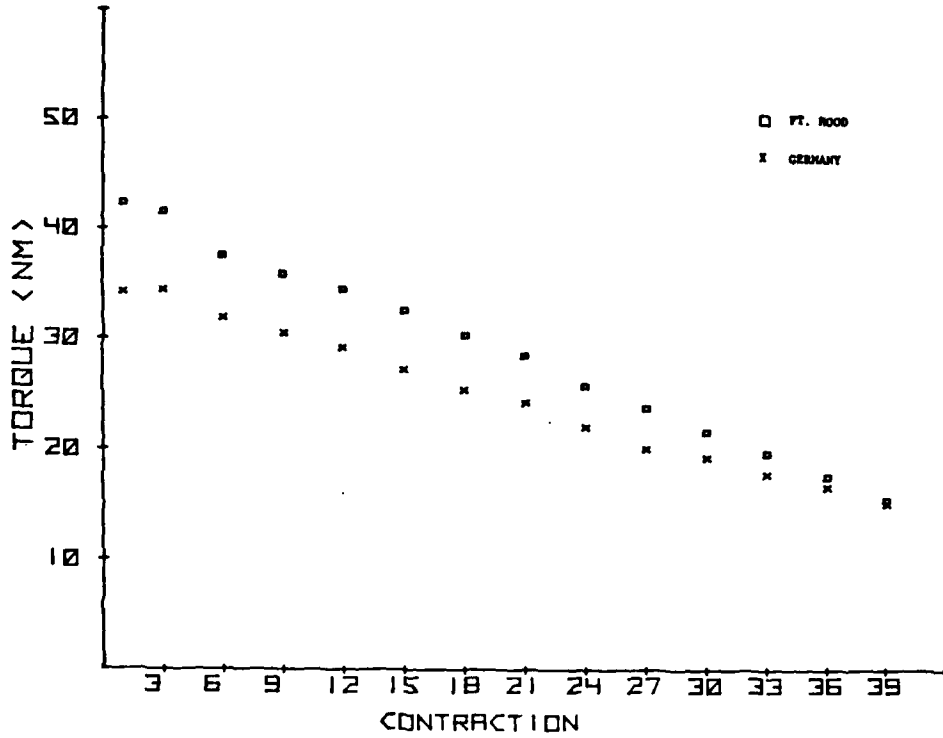


Figure 4

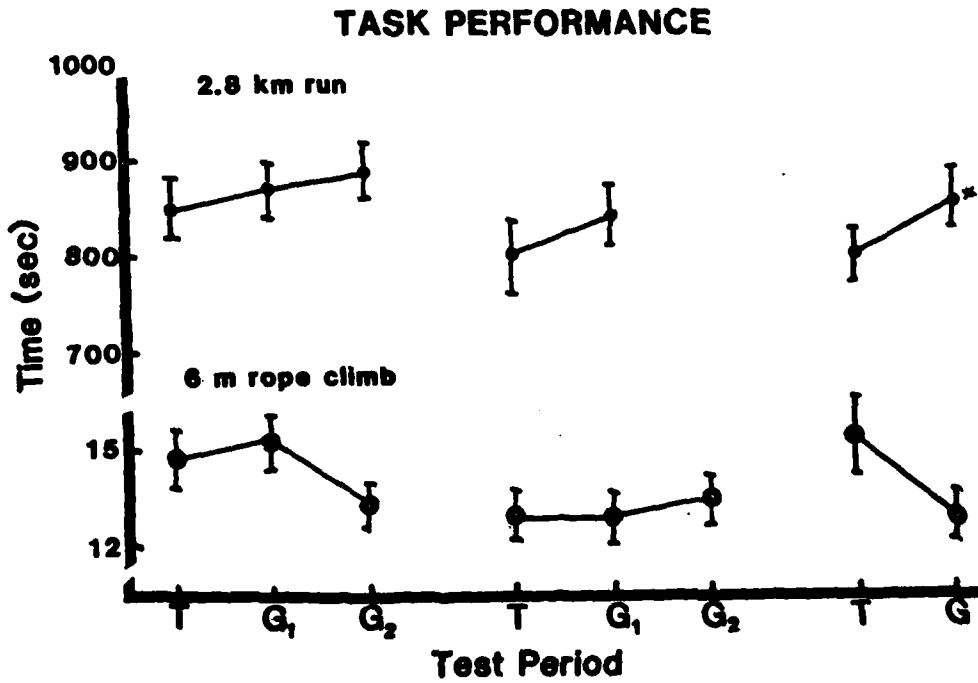
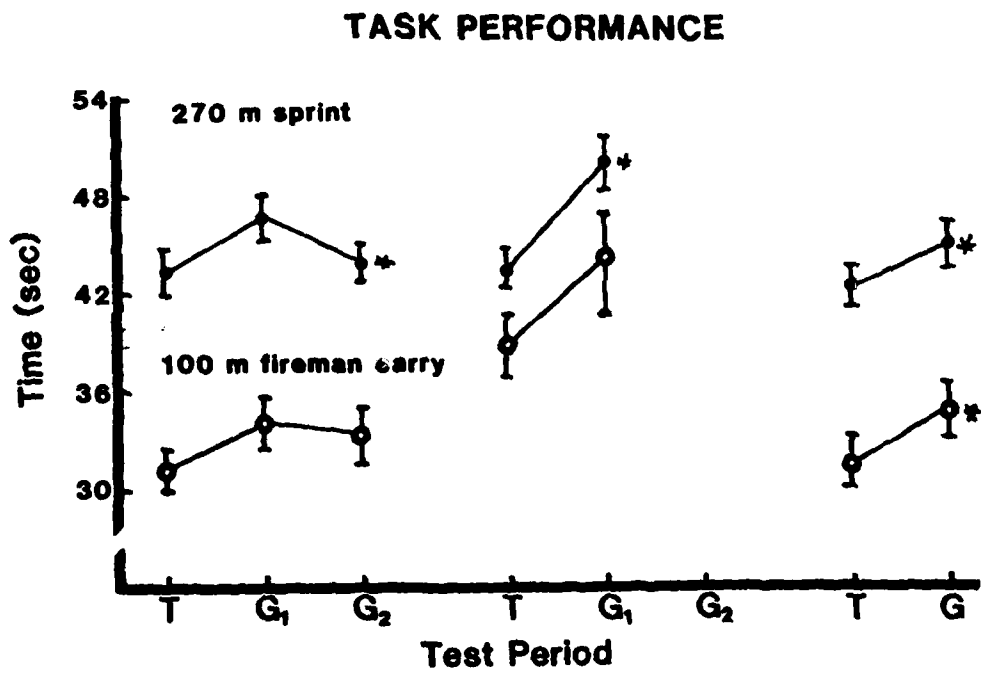


Figure 5



HUMAN RESEARCH

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 70-25 on Use of Volunteers in Research.

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