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REPORT NO T11-90

PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO PROLONGED TREADMILL LOAD CARRIAGE

U S ARMY RESEARCH INSTITUTE
OF
ENVIRONMENTAL MEDICINE
Natick, Massachusetts

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PHYSIOLOGICAL AND PERCEPTUAL RESPONSES TO PROLONGED TREADMILL LOAD CARRIAGE.

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The objectives of this study were to : 1) determine the physiological and perceptual responses to prolonged, level treadmill walking (fixed distance of 12 km) at speeds of 3.96, 4.86, and 5.76 km/hr, unloaded (clothing wt of 5.2 kg) and with external loads (load carriage equipment + backpack) of 31.5 and 49.4 kg, 2) determine the ability of subjects to perform high intensity, anaerobic exercise (Wingate test) immediately after load carriage, and 3) compare the energy cost and perceptual responses of carrying the standard external frame pack to that of the new internal frame system. Fifteen male subjects performed nine load carriage trials with an external frame pack (ALICE) and two trials with an internal frame pack (IIFS) in random order over a 7 week period. At the end of each trial blood samples were taken for the measurement of lactate and subjects performed either an upper or lower body anaerobic power test. VO2, VE, heart rate, and differentiated ratings of perceived exertion (RPE) were determined at the end of the first 10 min and every 20 min thereafter for the duration of the trial. A 10 min rest period was allowed each hour. No changes occurred in VO2 over time in

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the unloaded condition at any speed. The 31.5 and 49.4 kg loads, however, produced significant increases (p .05) at the two fastest and at all three speeds, respectively, equating to exercise intensities greater than 26% VO2max. Similar results were also seen for VE, heart rate, and differentiated RPE's. Following load carriage, no significant differences were found in either upper or lower body power output as measured by the Wingate test. In addition, no significant differences were seen in blood lactate levels with respect to either speed or load. No significant differences were found for any of the physiological or perceptual responses between the external and internal frame pack systems. The results show that: 1) energy cost during prolonged load-carriage is not constant but increases significantly over time at relative intensities below 30% VO2max, 2) the load-carriage conditions of this study were not sufficient to cause fatigue as assessed by blood lactate levels and maximal power outputs, and 3) the two load-carriage systems studied did not differ as to their effects on physiological and perceptual responses to prolonged treadmill walking. (KT)

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FOREWORD

Throughout the history of warfare the combat soldier has been required to carry more weight than practical when deployed into battle (26). Indeed, the problems of the overloaded soldier were as evident in the Falklands and Grenada campaigns as in any conflict in the past.

With the recent addition of the light infantry division to the US Army force structure, the soldiers mobility as related to his load will be a major factor determining success on the battlefield (20). The tactical mobility of a light infantry division is limited at the battalion and company levels since it requires the soldier to transport his own equipment. Current doctrine states that the light infantry division will carry supplies and equipment to be self-sustained for a period of 48 hours after which resupply will be required by external service support.

The US Army Infantry School's load carriage standards are 48 pounds (21.8 kg) for a fighting load and 72 pounds (32.7 kg) for an approach march load. Soldier loads, however, typically exceed these values. In an exercise conducted by a light infantry division to outload a rifle company for a 48-hour, low-intensity operation, the average load was 145 pounds (11).

A technology demonstration entitled Lightening the Soldier's Load (LTSL) was initiated in 1986 (39) to bring focus to the soldier's load problems within the Army research and development community. This tech demo was directed to review all soldier carried equipment to include weapons, radios, food, and clothing, as well as research information on load carriage performance. With regard to the latter, the US Army Medical Research and Development Command was requested to conduct energy cost studies of load carriage and to develop specific training programs for light infantry division forces (44). This report presents an initial effort in the development of a laboratory model to study prolonged load carriage performance by assessing the physiological and perceptual responses to external loading during prolonged walking on a motor-driven treadmill.

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EXECUTIVE SUMMARY

The purposes of this study were to: 1) assess the physiological and perceptual responses to prolonged load-carriage, 2) determine the ability of soldiers to perform high-intensity, short term exercise immediately following load-carriage, and 3) compare the energy cost of carrying loads with the Army's standard external frame pack system to the new internal frame system. Fifteen subjects marched on a level treadmill at speeds (3.96, 4.86, 5.76 km/hr) and with loads (5.2, 31.5, 49.4kg) expected to be encountered by light infantry division soldiers. The distance marched was held constant at 12 km and the Army's external frame pack system (ALICE) was utilized. Physiological (oxygen uptake, minute ventilation, and heart rate) and perceptual (differentiated ratings of perceived exertion) responses were measured throughout each trial. Immediately following the completion of a trial, subjects performed either an upper or lower body high-intensity, anaerobic power test and blood lactate levels were measured. Subjects also performed two trials carrying the 31.5 and 49.4 kg loads at 5.76 km/hr using the Army's new internal frame pack system (IIFS). Based upon the data obtained, it was concluded that 1) physiological and perceptual responses to prolonged load-carriage are not constant but increase significantly over time with external loading even at relative exercise intensities below 30% of maximal aerobic capacity, 2) use of the predictive equation to estimate energy expenditure during prolonged load-carriage could underestimate the actual metabolic cost by 10-16% depending on the load and speed, 3) the exercise intensity associated with carrying the loads at the speeds used in this study did not result in any evidence of fatigue following load-carriage as assessed by the ability to produce maximal anaerobic power

or by blood lactate levels, and 4) there were no differences in the physiological or perceptual responses between the ALICE and IIFS pack systems suggesting that other techniques i.e., assessment of comfort or biomechanical factors, may be more appropriate in evaluating load-carriage systems.

INTRODUCTION

The ability of soldiers to carry heavy loads has been the subject of considerable research (recent reviews: see 19, 24, 35). The metabolic costs associated with carrying a variety of loads at a wide range of speeds over different terrain conditions while walking have been determined (17, 42, 43) and predictive formulae derived (16, 31). However, the majority of studies assessing the physiological responses to various loads and loading configurations have utilized relatively short-term (less than 30 minutes) load-carriage tasks. With the exception of a recent study by Epstein et al, (12), little attention has focused on prolonged load-carriage covering distances which may be expected of light infantry soldiers during an approach march situation. Other studies which have dealt with prolonged load-carriage either did not measure oxygen uptake (34) or used self-paced tasks (21, 30).

In addition to the energy cost of prolonged load-carriage, the fatigue caused by the continuous muscular effort during such activity is another important element related to soldier mobility. According to Dubik and Fullerton (10) the overloaded condition of the soldier in Grenada frequently produced fatigue sufficient to result in either poor fighting or the inability to fight at all. In the words of Marshall (26) a soldier "is given great weights to carry, but unlike a pack animal or vehicle, his chief function in war does not begin until the time he delivers that burden to the appointed ground".

A similar situation in the athletic community is the effect of long duration events such as the marathon on the subsequent ability of the muscle to produce force and power.

Participants in these events have often described an acute impairment of muscular strength accompanied by diminished performance capacity. Forsburg et al, (14) were perhaps the first to report an acute loss of muscular strength after prolonged exercise (an 85-km ski race). More recently, Sherman et al, (41) reported significant reductions in maximal peak torque and total work of the leg extensors immediately following a marathon. Conversely, Wallingford and Hetherington (47) found no significant loss of strength following a 25-mi distance race in an earlier study. All of these studies, however, have been limited to either isometric or isokinetic measurements. No studies have examined the effects of prolonged exercise on the subsequent ability of the upper or lower body to produce maximal power.

Another aspect of load-carriage which has received little attention is the influence of pack-type on performance. In a study which examined changes in body posture due to pack type, Bloom and Woodhull-McNeal (5) hypothesized that an internal frame pack would provide greater stability and less moment of inertia during walking than an external frame pack. The US Army has recently developed an internal frame pack system to replace the standard rucksack with external frame. An important consideration, therefore, is whether differences in pack type translate into differences in the energy cost or perceptual responses of carrying heavy loads.

The objectives of this study, therefore, were threefold: 1) to determine the energy cost of prolonged load-carriage at speeds and loads expected to be encountered by light infantry soldiers, 2) to determine the ability of these soldiers to perform high intensity anaerobic exercise of the upper and lower body immediately following load-carriage, and 3) to compare the energy cost and perceptual responses of carrying the standard US Army pack system to the new internal frame system.

METHODS

Subjects. Sixteen healthy, male soldiers were recruited following either advanced individual training (Ft. Jackson) or one-station unit training (Ft. Benning). All were fully briefed regarding the purpose and nature of the study and informed consent was obtained prior to participation.

Design. During the first week subjects were familiarized with the laboratory procedures and measurements were made of physical fitness and body composition. These included upper and lower body anaerobic power (Wingate test), maximal aerobic power (treadmill), and body density (underwater weighing). In addition, subjects were accustomed to walking on the treadmill at speeds and loads used during data collection. During the next 7 weeks subjects performed 11 load-carriage trials on a motorized treadmill (Quinton Model 24-72). The loads, speeds, and pack-type were as follows:

Trial	Load,kg	Speed,km/hr	Pack Type
1	5.2	3.96	ALICE
2	5.2	4.86	ALICE
3	5.2	5.76	ALICE
4	31.5	3.96	ALICE
5	31.5	4.86	ALICE
6	31.5	5.76	ALICE
7	49.4	3.96	ALICE
8	49.4	4.86	ALICE
9	49.4	5.76	ALICE
10	31.5	5.76	IIFS
11	49.4	5.76	IIFS

The order of trials was randomly assigned to minimize any training effects. A maximum of two trials was performed by the same subject each week and at least two days separated successive trials. The distance was the same for all trials and was fixed at 12 km. Thus the total time (including rest periods) to complete the 12 km at each speed was: 212 min at 3.96 km/hr, 168 min at 4.86 km/hr, and 145 min at 5.76 km/hr. Subjects were allowed a 10 min rest period at the end of each hour.

Oxygen uptake ($\dot{V}o_2$) was determined between minutes 8 and 10 and every 20 min thereafter using the Douglas bag technique. Duplicate 30-60 s bag collections were taken at each time interval. Gas volumes were determined with a Collins chain-compensated gasometer and expired O_2 and CO_2 fractions were determined with Applied Electrochemistry S-3A and Beckman LB-2 analyzers, respectively. Heart rates from a modified V5 electrocardiographic recording and ratings of perceived exertion (RPE) according to the Borg scale (7) were taken at the above times. RPE's were differentiated as to central or upper body (involving the cardiorespiratory system and the effects of load on the upper body), local or lower body (involving the exercising muscles and joints of the lower extremities), and overall (integrating the upper and lower body ratings). Before and immediately following each trial a 2 ml blood sample was taken from the antecubital vein and blood lactates were measured in duplicate with a micro blood lactate analyzer (Model 640, Wolverine Medical, Alto, MI). Also, within 5 min following completion of each trial, subjects removed their equipment and performed either an upper or lower body anaerobic power test according to the Wingate protocol.

Pack Systems and Loads. The pack systems were the standard Army load carriage system designated as all-purpose, lightweight, individual carrying equipment (ALICE) and the newly developed integrated individual fighting system (IIFS). Each was individually adjusted and the weight distributed as evenly as possible about the center of gravity. The loading configuration was made as similar as possible between the two systems. The ALICE system consisted of a rucksack with external frame and the standard equipment belt to which attached the canteen, ammunition pouch, etc. The IIFS was comprised of a tactical load-bearing vest and a field pack with an internal frame.

The 5.2 kg load consisted of the battle dress uniform, boots, and helmet. For the 31.5 kg and 49.4 kg loads, 13.6 and 31.5 kg, respectively, were carried in the rucksack. The remaining 17.9 kg consisted of 12.7 kg distributed on the equipment belt and the 5.2 kg noted above.

Aerobic Power. Maximal oxygen uptake ($\dot{V}o_2$max) was determined using a discontinuous, progressive protocol on a motor-driven treadmill (29). Subjects ran initially at 6 mph, 0% grade for 6 min after which the grade was increased to 5% and the speed held constant or increased to 6.5-7.0 mph. Each subsequent bout of exercise was performed for 3 min at grades increased by 2.5% until a plateau occurred in $\dot{V}o_2$. Gas volumes and expired O_2 and CO_2 fractions were measured as previously described. Heart rate was monitored electrocardiographically throughout the test.

Anaerobic Power. Maximal anaerobic power was determined by the Wingate test (3) for both the upper (arm-cranking) and lower body (leg cycling). Subjects were randomly assigned to perform one or the other. The test was carried out on a cycle ergometer modified with a lever arm for instantaneous application of resistance (15). The subject cycled or cranked at maximal RPM's for 30 s at resistance settings of 0.075 and 0.050 kg/kg body weight, respectively. The number of revolutions and the resistance were used to calculate power output in watts (W). Power outputs were expressed as peak power (the mean power of the highest 5 s period), mean power (the average power over the 30 s), and power decrease (the difference between peak power and the last 5 s interval expressed as a percentage).

Body Composition. Body density was determined by hydrostatic weighing. Subjects entered a weighing tank clothed in a swimsuit with the water maintained at a constant temperature (35-36°C). Subjects sat on an aluminum chair submerged and exhaled as much air as possible to their residual volume. A strain gauge recorded the underwater weight (13). Residual lung volume was determined prior to entrance into the tank using the oxygen rebreathing method of Wilmore et al, (48). Three trials were taken and the closest two values were averaged (45).

Statistical Analysis. A one-way analysis of variance for repeated measures was used to determine changes in the physiological and perceptual responses to load-carriage over time. A two-way analysis of variance was used to determine differences in upper and lower body anaerobic power outputs following load-carriage and in energy cost between the external and internal frame pack systems. Multiple comparisons using the Tukey test were performed on significant F-values to determine which differences were significant. An alpha level of 0.05 was used to indicate statistical significance.

RESULTS

The subject's descriptive anthropometric and physiological values are summarized in Table 1. The mean (± SD) for %body fat was comparable to other Army populations of similar age (45) while $\dot{V}o_2max$ (58.5 ± 5.9 $ml \cdot kg^{-1} \cdot min^{-1}$) was slightly higher than that reported for soldiers upon completion of advanced training (46). One subject was removed early in the study due to a groin strain. Five others were unable to complete one or more of the 49.4 kg load-carriage trials due to discomfort in the neck and shoulder areas. Thus the sample size is 15 for the 5.2 kg and 31.5 kg trials and 10 for the 49.4 kg trials.

Table 1. Subject descriptive data (n=15)

Variable	Means	(SD)	Range
Age, yrs	21.1	(3.9)	18 - 33
Height, cm	173.9	(7.5)	165.5 - 190.5
Mass, kg	77.1	(10.8)	55.9 - 92.4
Body fat, %	17.4	(3.2)	12.1 - 24.4
$\dot{V}o_2max$, $l \cdot min^{-1}$	4.47	(0.67)	2.97 - 5.76
$\dot{V}o_2max$, $ml \cdot kg^{-1} \cdot min^{-1}$	58.5	(5.9)	50.2 - 68.4
$\dot{V}_E$, $l \cdot min^{-1}$	155	(23)	109 - 196
HRmax, $b \cdot min^{-1}$	195	(7)	186 - 208

The effects of load (using the ALICE pack) and speed over the 12 km distance on oxygen uptake, minute ventilation, heart rate, and differentiated RPE's are presented in Figures 1-6. The 49.4 kg load elicited significantly higher (p<.01) energy costs than the 31.5 kg load at each speed (Figure 1). Significant increases in oxygen uptake over time were also seen at all three speeds when carrying the 49.4 kg load. This amounted to an increase of 18.4% at 5.76 km/hr. The 31.5 kg load produced significant increases in $\dot{V}o_2$ ($p<.05$) at the two fastest speeds only, whereas no change occurred at any march rate with the 5.2 kg load.

Similar results were seen in minute ventilation and heart rate (Figures 2 and 3). Significant increases over time occurred at all three trials with the 49.4 kg load while no changes were seen when marching with the 5.2 kg load at any speed. With the 31.5 kg load, V_E increased only during the 5.76 km/hr march rate while heart rate increased at both the 4.86 and 5.76 km/hr rates.

Similar changes were also seen in the differentiated RPE's (Figures 4-6) for both the 31.5 and 49.4 kg load trials. Significant increases, however, were also evident with the 5.2 kg load at each march rate.

Values for energy cost expressed in l/min, kcal/min, and as a percentage of maximal oxygen uptake are presented in Table 2. These values were taken at the end of the first 10 min and during the final two min of each trial. It can be seen from carrying the 31.5 kg load at 4.86 km/hr that $\dot{V}o_2$ increased significantly over time even at an initial relative exercise intensity of less than 30% $\dot{V}o_2$max. In addition, the %$\dot{V}o_2$max did not exceed 41% for any of the trials except when carrying the heavy load (49.4 kg) at the fastest speed where it increased from 41.7 ± 4.4% at 10 min to 50.4 ± 6.4% during

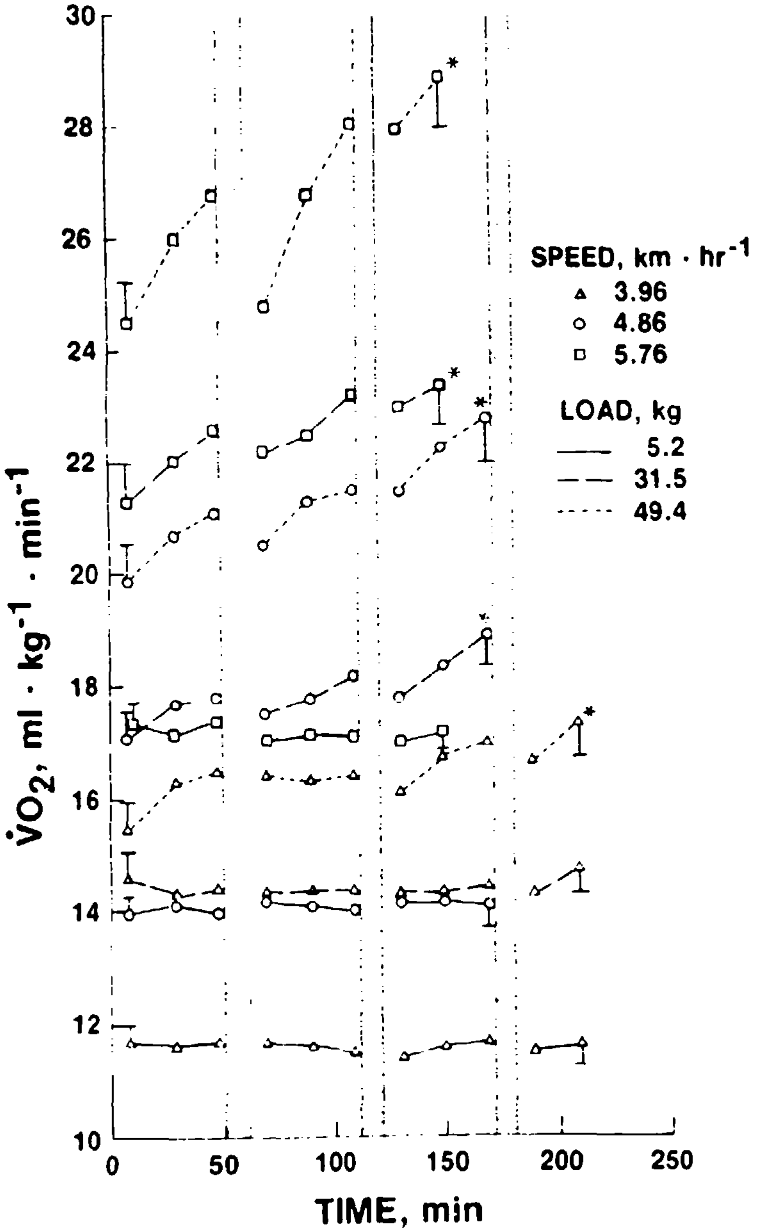

Figure 1. Oxygen uptake (relative to body mass) over time for each load carriage condition (means ± SD). *p<.05 compared to the initial measurement. Stippled area represents 10 min rest periods.

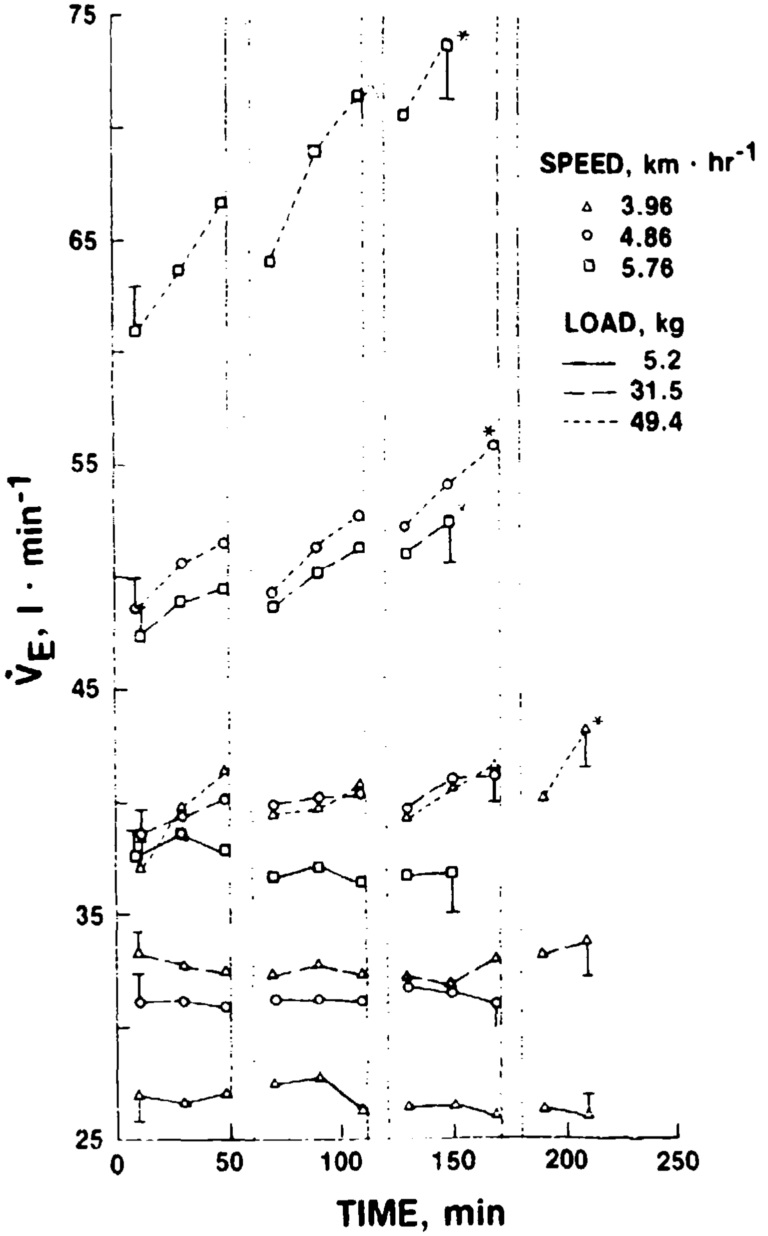

Figure 2. Minute ventilation over time for each load-carriage condition (means ± SE). *$p<.05$ compared to initial measurement. Stippled area represents 10 min rest periods.

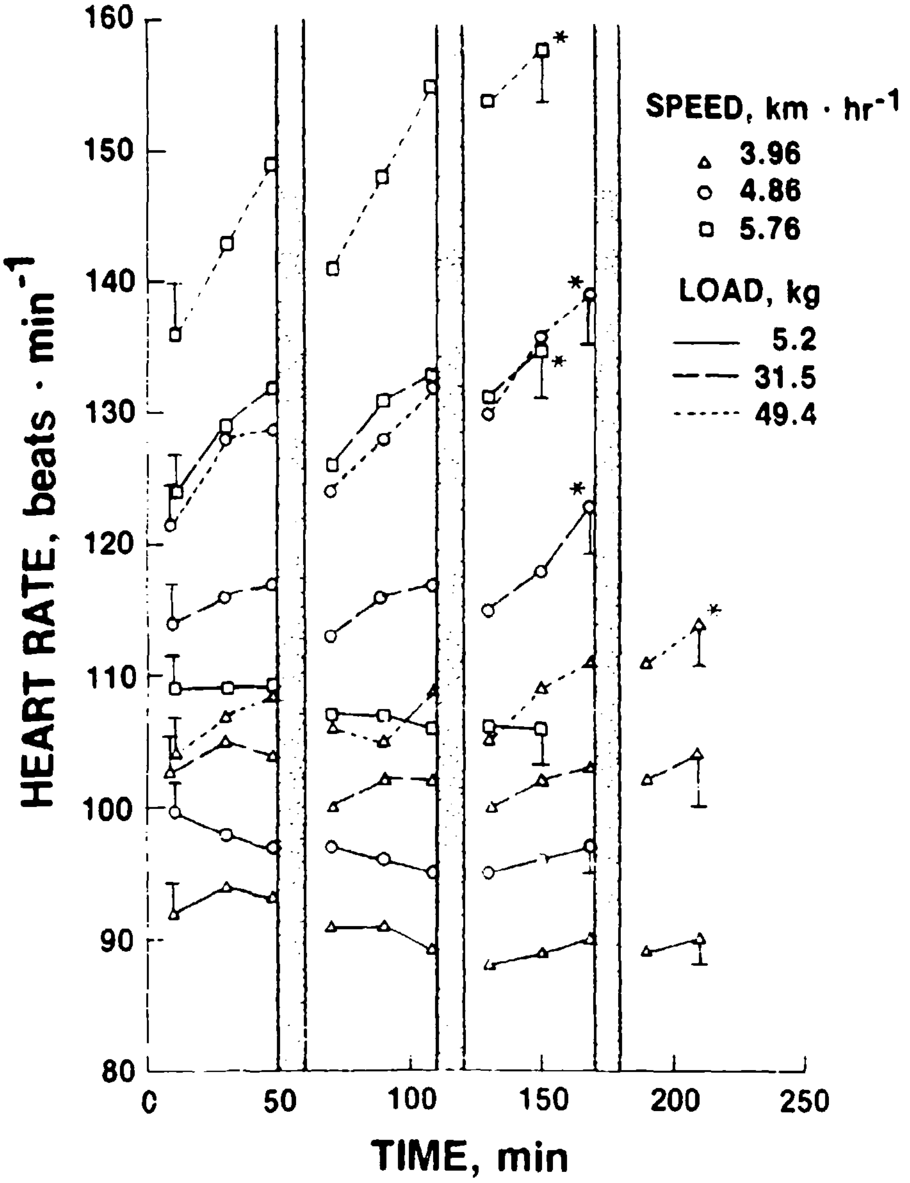

Figure 3. Heart rate response over time for each load-carriage condition (means ± SE). *p<.05 compared to the initial measurement. Stippled area represents 10 min rest periods.

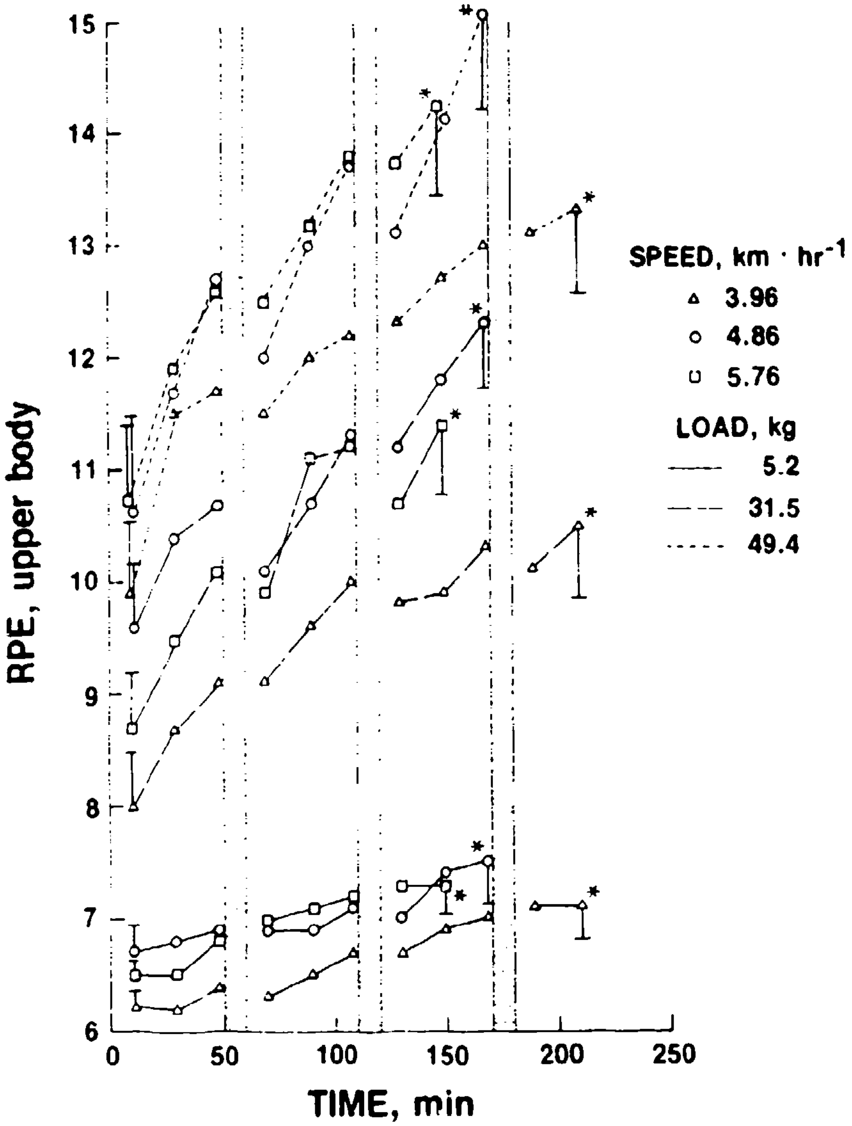

Figure 4. Upper body ratings of perceived exertion over time for each load-carriage condition (means ± SE). *p<.05 compared to initial measurement. Stippled area represents 10 min rest periods.

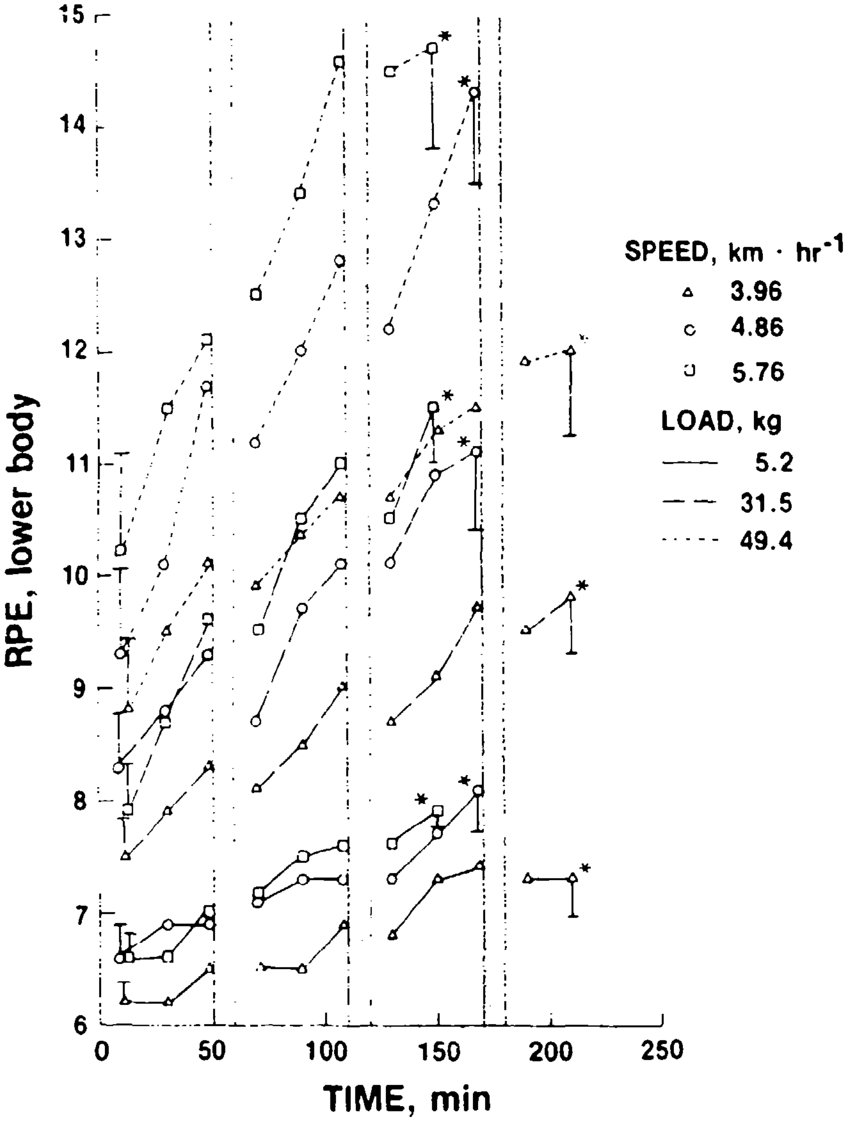

Figure 5. Lower body ratings of perceived exertion over time for each load-carriage condition (means ± SE). *p<.05 compared to initial measurement. Stippled area represents 10 min rest periods.

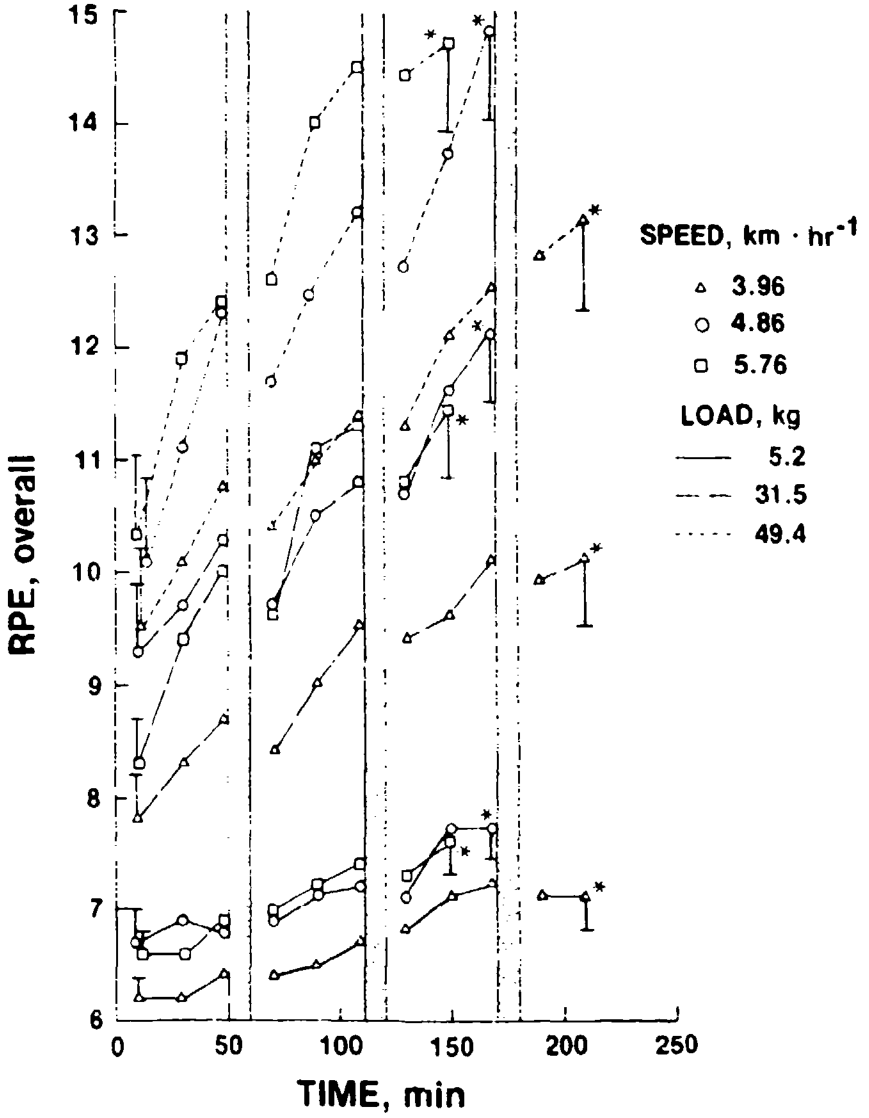

Figure 6. Overall ratings of perceived exertion over time for each load-carriage condition (means ± SE). *p<.05 compared to initial measurement. Stippled area represents 10 min rest periods.

the final minute of exercise.

Table 2. Energy cost and percent maximal oxygen uptake for each load carriage condition (means ± SD).

Speed, km/hr	Load, kg	$\dot{V}o_2$, $l \cdot min^{-1}$ I	$\dot{V}o_2$, $l \cdot min^{-1}$ F	kcal/min I	kcal/min F	$\%\dot{V}o_2max$ I	$\%\dot{V}o_2max$ F
3.96	5.2	0.90	0.90	4.49	4.47	20.2	20.2
		0.12	0.12	0.61	0.61	2.6	2.4
	31.5	1.12	1.14	5.60	5.71	24.5	25.0
		0.13	0.14	0.66	0.72	3.4	3.7
	48.4*	1.25	1.39	6.23	6.96	26.4	29.5
		0.14	0.15	0.68	0.73	3.1	3.6
4.86	5.2	1.07	1.08	5.33	5.40	24.1	24.3
		0.13	0.15	0.66	0.76	2.8	3.1
	31.5*	1.30	1.43	6.49	7.13	29.4	32.4
		0.17	0.15	0.83	0.77	4.0	4.8
	49.4*	1.59	1.83	7.96	9.14	33.8	38.8
		0.12	0.19	0.61	0.97	3.8	5.1
5.76	5.2	1.31	1.31	6.54	6.57	29.6	29.7
		0.15	0.18	6.54	6.57	3.6	4.3
	31.5*	1.62	1.78	8.10	8.89	36.8	40.6
		0.18	0.23	0.91	1.13	5.8	7.7
	49.4*	1.97	2.38	9.83	11.66	41.7	50.4
		0.16	0.28	0.82	1.42	4.4	6.4

I = Initial, $\dot{V}o_2$ measured between 8 and 10 min.
F = Final, $\dot{V}o_2$ measured during final two min.
* Significant difference between initial and final values.

A comparison of values for oxygen uptake (Watts) measured between 8-10 min and during the final two min of each trial with those predicted from the equation of Pandolf et al, (31) are presented in Table 3. With the exception of trials where oxygen uptake was less than 400 W, there was no significant difference between the predicted values and those measured between minutes 8-10. However, significant differences between predicted values and those measured during the final minute occurred for all conditions with one exception. For those load-carriage trials where oxygen uptake increased significantly over time, the difference between the final measured and predicted values ranged from approximately 10 to 16%.

Table 3. Comparison of measured versus predicted values for oxygen uptake (Watts) at each load-carriage trial (means ± SD).

		Predicted[*]	Measured			
Speed	Load		Initial	%diff	Final	%diff
3.96	5.2	266	313[#]	17.7	312[#]	17.3
		36	43		43	
	31.5	345	391[#]	13.3	399[#]	15.7
		30	46		50	
	49.4[•]	441	434	1.6	485[#]	10.0
		35	48		51	
4.86	5.2	341	372[#]	9.1	377[#]	10.6
		46	46		53	
	31.5[•]	445	453	1.8	498[#]	9.7
		40	58		54	
	49.4[•]	561	555	1.1	637[#]	13.5
		42	42		68	
5.76	5.2	433	456	5.3	458	5.8
		57	54		64	
	31.5[•]	565	565	0.0	621[#]	9.9
		52	63		79	
	49.4[•]	705	686	2.7	814[#]	15.5
		51	57		99	

[*] Predicted from equation of Pandolf, et al (31)
[•] Load carriage trials with significant increases in $\dot{V}O_2$ over time
[#] Significantly different ($p<.05$) compared to predicted value
Initial = measurement taken between 8 and 10 min
Final = measurement taken during final two min

Table 4 compares upper and lower body ratings of perceived exertion for each of the trials. While no significant differences were found for any condition, ratings were generally higher for the upper body in the loaded conditions (31.5 and 49.4 kg) irrespective of speed, and higher in the lower body in the unloaded (5.2 kg) conditions.

Table 4. Comparisons of ratings of perceived exertion between upper and lower body (means ± SD).

		Initial		Final	
Load, kg	Speed, km/hr	Upper Body	Lower Body	Upper Body	Lower Body
5.2	3.96	6.20	6.20	7.07	7.27
		0.41	0.41	1.28	1.28
	4.86	6.67	6.60	7.53	8.07
		1.11	1.30	1.41	1.44
	5.76	6.53	6.60	7.33	7.93
		0.64	0.63	1.11	1.16
31.5	3.96	8.00	7.53	10.53	9.80
		2.07	1.73	2.83	2.83
	4.86	9.60	8.27	12.33	10.93
		2.35	1.83	3.09	3.86
	5.76	8.67	7.87	11.40	11.47
		2.16	1.69	2.85	2.80
49.4	3.96	9.90	8.80	13.80	12.00
		2.56	2.10	2.62	2.67
	4.86	10.60	9.40	15.10	14.30
		3.03	2.55	2.47	2.79
	5.76	10.70	10.20	14.70	14.70
		3.16	2.86	2.67	2.98

Initial: RPE's taken during the ninth min.
Final: RPE's taken during final min.

The data for upper and lower body anaerobic power are shown in Tables 5 and 6, respectively. Neither peak nor mean power outputs from the upper body were significantly different for either loaded condition compared to the unloaded trial at any speed. Significantly lower power outputs were found in the lower body when the 49.4 kg load was compared to the unloaded condition at the slowest speed. However, no significant differences among loads were seen at the other speeds.

Table 5. Upper body anaerobic power following load carriage (means ± SD, n=6).

Speed, km/hr	Load, kg	Peak power, W	Mean power, W
3.96	5.2	614 ± 79	440 ± 63
	31.5	599 ± 89	453 ± 58
	49.4	604 ± 91	440 ± 65
4.86	5.2	603 ± 89	435 ± 62
	31.5	593 ± 67	418 ± 48
	49.4	607 ± 82	431 ± 53
5.76	5.2	609 ± 97	434 ± 59
	31.5	624 ± 92	445 ± 64
	49.4	623 ± 88	442 ± 55

Table 6. Lower body anaerobic power following load carriage (means ± SD, n=6).

Speed, km/hr	Load, kg	Peak power, W	Mean power, W
3.96	5.2	612 ± 101	430 ± 76
	31.5	602 ± 123	424 ± 111
	49.4	576 ± 96*	393 ± 80*
4.86	5.2	620 ± 105	426 ± 97
	31.5	615 ± 88	410 ± 94
	49.4	607 ± 88	417 ± 80
5.76	5.2	672 ± 81	445 ± 51
	31.5	633 ± 58	421 ± 56
	49.4	649 ± 25	459 ± 45

*$p < 0.05$ compared to 5.2 kg load.

Blood lactate levels measured before and immediately after each load carriage trial are shown in Table 7. No significant differences were found with either speed or load.

Table 7. Blood lactate levels before and after load carriage (means ± SD, n=5).

		Blood lactate, mmol/l	
Load, kg	Speed, km/hr	Before	After
5.2	3.96	2.27 ± 0.77	2.24 ± 1.13
	4.86	2.60 ± 1.07	1.79 ± 0.40
	5.76	2.47 ± 0.69	2.08 ± 0.63
31.5	3.96	2.26 ± 0.89	2.06 ± 0.72
	4.86	2.77 ± 0.91	1.86 ± 0.74
	5.76	2.44 ± 0.64	2.05 ± 0.62
49.4	3.96	2.05 ± 0.49	1.99 ± 0.16
	4.86	2.42 ± 0.52	2.04 ± 0.31
	5.76	2.40 ± 0.79	2.40 ± 0.48

A comparison of the physiological and perceptual responses between the ALICE and IIFS pack systems is presented in Table 8. No significant differences were found in any of the variables at either the initial or final measurement periods. In Figure 7, values for oxygen uptake relative to body weight are presented for the two trials used to compare systems. At no point during either trial were differences found between packs.

Table 8. Comparisons of energy cost variables and perceived exertions between pack systems (means ± SD).

	Initial		Final	
	ALICE	IIFS	ALICE	IIFS
Speed: 5.76 km/hr Load: 31.5 kg (n=12)				
$\dot{V}O_2$, ml·kg^{-1}·min^{-1}	20.7	21.2	22.4	22.7
	±3.1	±2.8	±3.5	±3.5
$\dot{V}_E$, l·min^{-1}	47.0	48.3	50.3	50.6
	±6.1	±5.8	±8.2	±7.2
Heart rate, b·min^{-1}	123	126	131	134
	±14	±13	±17	±10
RPE, upper body	7.8	8.8	10.8	11.5
	±1.4	±2.2	±2.1	±2.9
RPE, lower body	7.6	8.6	11.1	11.1
	±1.4	±1.6	±2.4	±2.8
RPE, overall	7.9	8.7	11.1	11.6
	±1.4	±1.9	±2.2	±2.9
Speed: 5.76 km/hr Load: 49.4 kg (n=6)				
$\dot{V}O_2$, ml·kg^{-1}·min^{-1}	25.0	25.0	29.7	28.2
	±3.4	±3.7	±4.2	±4.9
$\dot{V}_E$, l·min^{-1}	58.3	57.7	73.0	65.7
	±3.6	±8.2	±9.0	±11.0
Heart rate, b·min^{-1}	136	138	160	156
	±13	±9	±12	±11
RPE, upper body	9.7	10.3	14.8	15.5
	±2.5	±1.9	±2.8	±2.4
RPE, lower body	9.2	9.8	14.2	15.2
	±2.2	±1.5	±3.3	±2.5
RPE, overall	9.7	10.0	14.3	15.3
	±2.5	±1.7	±3.1	±2.7

Initial: Measurements taken between 8 and 10 min.
Final: Measurements taken during final two min.

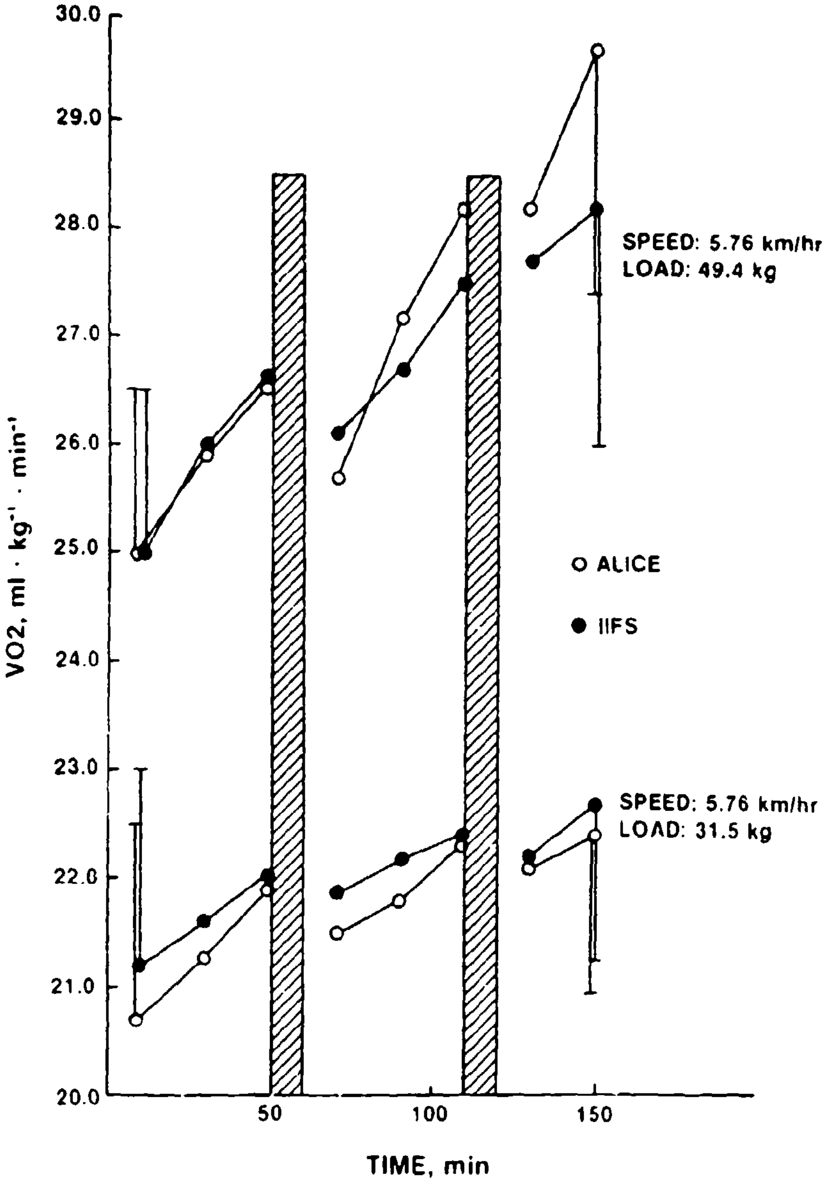

Figure 7. Comparisons of oxygen uptake over time between the ALICE and IIFS pack systems.

DISCUSSION

The primary objective of this study was to determine the physiological and perceptual responses to prolonged load-carriage. The results demonstrate that oxygen uptake, minute ventilation, and heart rate as well as ratings of perceived exertion are not constant but increase significantly over time with external loading at relative exercise intensities of 26% $\dot{V}o_2$max and higher. The increase in energy expenditure agrees with the recent work of Epstein et al, (12) who found an 8.8% increase in $\dot{V}o_2$ over 2 hours while carrying a 40 kg load at 4.5 km/hr, 5 % grade. These authors concluded, however, that the intensity had to exceed 50% of $\dot{V}o_2$max before $\dot{V}o_2$ increased since carrying a 25 kg load (46% $\dot{V}o_2$max) caused no change over time. The discrepancy between this conclusion and the increase in $\dot{V}o_2$ found in the present study (which occurred even with a 10 min rest period each hour) may be due to differences in the load carriage conditions, i.e. speed, loads and length of march between studies or to the higher aerobic capacity of the subjects in this study (mean $\dot{V}o_2$max of 58.5 $ml \cdot kg^{-1} \cdot min^{-1}$) compared to that of Epstein et al (mean $\dot{V}o_2$max of 52.9 $ml \cdot kg^{-1} \cdot min^{-1}$). Regardless, the present results show that to prevent an increase in $\dot{V}o_2$ over time while carrying external loads of 31.5 and 49.4 kg, march rates would have to be less than 4.86 and 3.96 km/hr, respectively.

A gradual increase in $\dot{V}o_2$ during prolonged, submaximal exercise which appears unrelated to either intensity or duration has been shown with various exercise conditions (18,23,28,38,40). A number of factors have been postulated to account for this finding and include: 1) increased body temperature, 2) increased minute ventilation, 3) increased blood lactate concentration, 4) reduced mechanical efficiency, and 5) a shift in substrate utilization as reflected by decreased respiratory exchange ratio (RER) (8,23). Of these factors, the only one which can be ruled out as contributing to the increase seen in this study is blood lactate concentration which did not change from baseline levels following any of the load-carriage trials. This agrees with the finding that $\dot{V}O_2$ was less than 50% $\dot{V}O_2$max for nearly all trials.

Kalis et al, (23) have shown that the combined effect of minute ventilation, rectal temperature, and RER, accounted for 70% of the increase in $\dot{V}O_2$ seen during 90 min of cycle ergometer exercise at a rate equivalent to 40% of $\dot{V}O_2$max. These factors may also have played a significant role in the increased $\dot{V}O_2$ seen herein as suggested by the significant rise in $\dot{V}_E$ that occurred in those trials where $\dot{V}O_2$ also increased. Unfortunately, rectal temperature and RER were not measured.

A factor of particular relevance to the increase in $\dot{V}O_2$ seen with prolonged load carriage is a reduction in mechanical efficiency due to altered locomotion biomechanics as the subject becomes fatigued. Givoni and Goldman (16) suggested some time ago that as the product of speed (km/hr) and load (kg) exceeds the numerical value of 100, there is an inefficiency which increases energy cost. More recently, Martin and Nelson (27) in a study on the walking patterns of men and women during load-carriage, found a decrease in stride length and swing rate while stride rate increased with increasing load. In addition, there was an increased forward inclination of the trunk at the heaviest loads (36 kg). Stride length is one factor known to affect $\dot{V}O_2$ during running where variations from an optimum length result in increasingly greater energy demands

(9). In conclusion, several mechanisms could be responsible for the continuous rise of $\dot{V}O_2$ during heavy load carriage but the relative contribution of altered biomechanics may be greater compared to that which occurs with submaximal, unloaded (running) or supported (cycling) exercise.

The significant difference between measured $\dot{V}O_2$ and values predicted from the equation of Pandolf et al, (31) agree with Pimental et al, (32) who showed that the formula underestimated energy expenditure for level walking at low exercise intensities (3.96 km/hr, 0 and 15 kg loads) by 14-18%. At higher intensities (either by increasing speed, load, or grade) the predicted values, however, were found to be quite accurate (32) which also supports the present findings. The equation of Pandolf et al, was based on relatively short-term (<20-30 min) steady-state exercise and does not address the possibility of an increase in $\dot{V}O_2$ with load-carriage exercise of longer duration. Thus using the prediction model to estimate energy expenditure during prolonged load-carriage could underestimate the actual metabolic cost of the activity by 10-16% as seen for the loads and speeds employed herein.

The increase in $\dot{V}O_2$ over time also has considerable practical importance to load-carriage performance. This is particularly true for those trials which resulted in %$\dot{V}O_2$max exceeding 35-40%. It is generally accepted that well-trained men can not be expected to exercise all day at an intensity equivalent to more than 50% of $\dot{V}O_2$max without becoming fatigued (1). Indeed a number of investigators have suggested that an acceptable intensity for an 8-hr day without incurring undue fatigue is in the range of 35-40% of $\dot{V}O_2$max (2,4,37). Furthermore, the relative energy expenditure for self-paced, load-carriage exercise of trained men was shown to be 35% $\dot{V}o_2$max (25). Assuming that $\dot{V}o_2$ continues to increase with time, it becomes readily apparent that carrying loads of 31.5 and 49.4 kg at 5.76 km/hr as well as the 49.4 kg load at 4.86 km/hr would result in energy expenditures either approaching or exceeding 50% $\dot{V}o_2$max.

Previous studies reporting on perceptual responses to load carriage exercise (33,36) have shown that when carrying light loads at slow to moderate speeds, lower body (local) and upper body (central) signals of exertion are not different from the overall sensation, i.e. they contribute equally to formation of the undifferentiated (overall) signal. With heavier loads (40 kg) (33) or higher speeds (greater than 4.8 km/hr) (36), however, central and local signals, respectively, are perceived to be more intense and become the dominant factors in shaping the overall sensation of exertion. The present results do not support these conclusions since neither the heavier load nor faster speed conditions resulted in the predomination of central or local sensations in the determination of overall perceived exertion. While there was a tendency for the central ratings to be higher than the local ratings in the loaded conditions, the differences were not statistically significant. An additional observation of interest is that all ratings of perceived exertion, particularly the central rating, appear to be more affected by load than are the physiological variables (see Figures 1-6). The trials which elicited the highest RPE's were those with the heaviest load irrespective of speed whereas a combination of the heaviest loads and fastest speeds produced the highest values in $\dot{V}o_2$, V_E, and heart rate.

The second objective of this study was to determine if subjects, upon completion of prolonged treadmill walking with external loads, experienced sufficient muscular fatigue to effect their ability to perform subsequent high-intensity exercise. This is of particular concern to the light infantry soldier who must, upon contact with the enemy, perform a variety of highly intense, physical tasks. Participants in athletic events exercising for long durations often describe an acute loss of muscle function and delayed muscle soreness that impairs subsequent performance capacity. Forsburg et al, (14) were perhaps the first to report an acute loss of muscular strength as measured by maximal peak torque (MPT) during isokinetic knee extension after prolonged exercise (an 85-km ski race). Jacobs et al, (22) and Sherman et al, (41) also reported significant impairment of MPT and increased fatigue during 50 consecutive isokinetic contractions following marathon running. Results from the present study, however, showed no decrements in the ability of either the upper or lower body to produce power as measured by the Wingate test following any of the load-carriage trials. This is not surprising in light of the fact that the intensity of exercise reached only 50% of $\dot{V}o_2$max when carrying the heaviest load at the fastest speed. This intensity is not sufficient to produce any significant depletion of muscle glycogen which may be an important factor in the decreased muscular strength seen by others (22,41). The lack of an increase in blood lactate following any of the trials also suggests that the level of exercise was below that which produces the accumulation of lactate in the blood which is a contributing factor to muscular fatigue.

The final objective of this study was to compare physiological and perceptual responses between external and internal-frame pack systems. In general, the results support the previous work of Winsmann and Goldman (49) who concluded that the specific design of load-carriage systems has little influence on energy cost and that weight is the most important factor as long as it is centrally carried on the trunk. Furthermore, these authors also found that undifferentiated ratings of perceived exertion are insensitive to design variations in pack type. This seems reasonable since such ratings have been linked to underlying physiological changes (7). These data suggest, therefore, that for systems of identical weight and similar distribution, techniques such as the assessment of comfort (complaints associated with strap pinching, local pressures on bone and muscle, etc) and biomechanical factors (muscle EMG activity, joint angle changes, etc) may be more sensitive and thus more appropriate for comparing load-carriage systems. Indeed, in evaluating the effect of two different load placements on muscle EMG activity and heart rate, Bobet and Norman (6) concluded, based on significant differences in EMG activity but not in heart rate, that metabolic measures alone are not sufficient to assess tasks which evoke primarily local muscle demands such as the contraction of low back muscles during load-carriage.

CONCLUSIONS

1. Physiological and perceptual responses to load-carriage are not constant but increase significantly over time with external loading even at relative intensities below 30% $\dot{V}o_2$max.

2. Use of the predictive equation to estimate energy expenditure during prolonged load-carriage could underestimate the actual metabolic cost by 10-16% depending on the load and speed.

3. The exercise intensity associated with carrying the loads at the speeds used in thios study did not result in any evidence of fatigue following load-carriage as assessed by the ability to produce maximal anaerobic power of by blood lactate levels.

4. There were no differences in the physiological or perceptual responses between the ALICE and IIFS pack systems suggesting that other techniques (i.e., assessment of comfort or biomechanical factors) may be more appropriate in evaluating load-carriage systems.

RECOMMENDATIONS

1. Unit leaders should take into account the gradual increase in oxygen uptake over time when conducting prolonged load carriage marches. To prevent an increase in $\dot{V}o_2$, march rates must be less than 4.86 and 3.96 km/hr when carrying external loads of 31.5 and 49.4 kg, respectively.

2. The predictive equation to estimate energy expenditure underestimates the actual metabolic cost for prolonged load carriage and should therefore be modified for use under such conditions.

3. Biomechanical factors should be utilized to evaluate the effects of prolonged load carriage on posture, gait, etc. as well as differences in pack systems.

4. Unit leaders can expect that no decrements will occur in high intensity physical tasks following prolonged load carriage if the intensity of the marching does not exceed 50% of $\dot{V}o_2$max.

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