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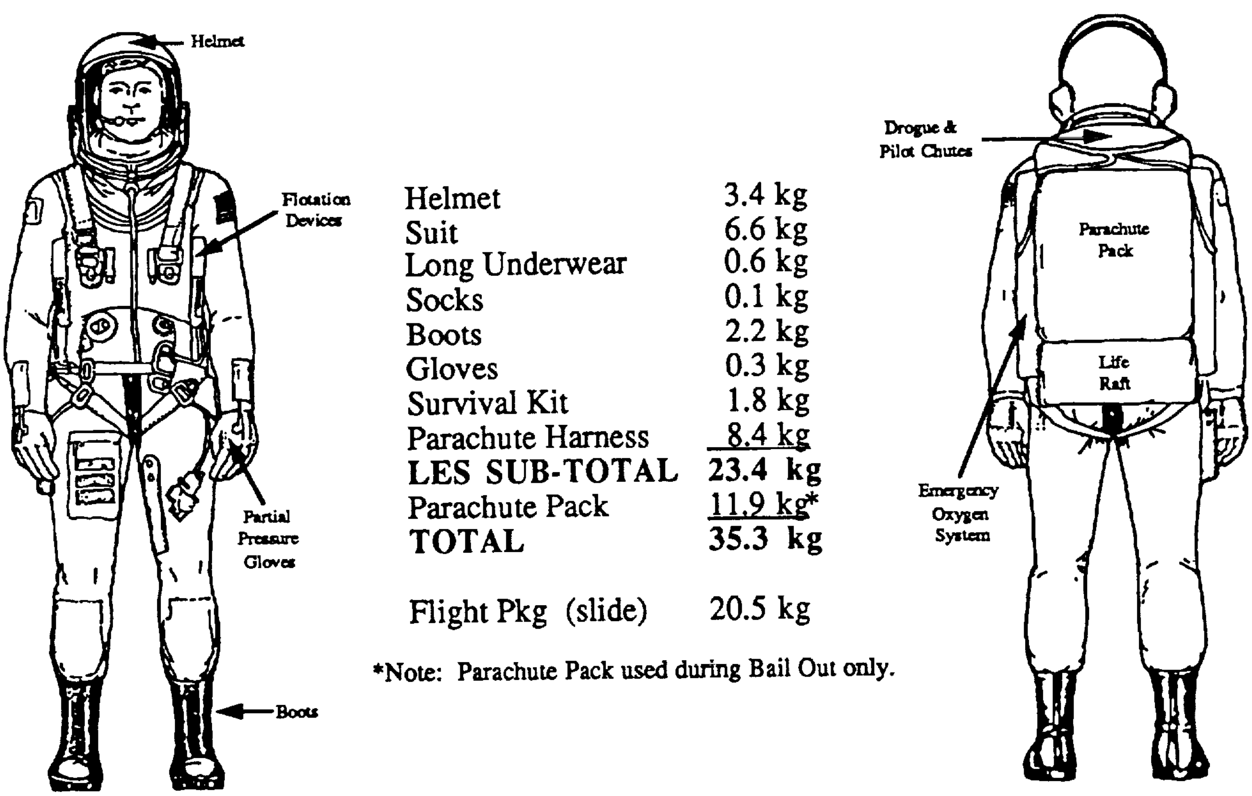
INTRODUCTION

The NASA launch and entry suit (LES) is a life support suit currently worn by crewmembers during ascent and descent of the Orbiter. The LES weighs approximately 35.5 kg (78 lbs). The impact of suit weight on a crewmember's agility and physical performance during an emergency egress from the Orbiter is unknown. The effect of this additional weight may be magnified upon return from prolonged exposure to microgravity, as decrements in orthostatic tolerance, aerobic capacity, and muscle strength have been observed immediately postlanding [1].

In an effort to identify physiological responses while wearing the LES, a study was conducted by the Exercise Physiology Laboratory (EPL) and the Anthropometry and Biomechanics Laboratory (ABL) at the NASA/Johnson Space Center to evaluate exercise responses while wearing the LES. The LES is a partial-pressure, dual-bladder suit and features a built-in g-suit, gloves that are pressurized on the dorsal surface only, and a helmet that has a double neck dam (Fig. 1).

A second suit, the NASA prototype advanced crew escape suit (ACES), was also tested in this study. The prototype ACES, which is a full pressure suit of approximately the same weight as the LES, has features that make it similar to the NASA extravehicular activity (EVA) suit used when exposed to the vacuum of space. The ACES also contains a detachable g-suit and has more extensive ventilation. The ACES helmet has a single neck dam. The ACES is currently being evaluated by NASA and may be worn in place of the LES in future missions.

The purpose of this study was to measure isokinetic muscle strength and metabolic responses to ambulatory exercise while wearing



Helmet	3.4 kg
Suit	6.6 kg
Long Underwear	0.6 kg
Socks	0.1 kg
Boots	2.2 kg
Gloves	0.3 kg
Survival Kit	1.8 kg
Parachute Harness	8.4 kg
LES SUB-TOTAL	**23.4 kg**
Parachute Pack	11.9 kg*
TOTAL	**35.3 kg**
Flight Pkg (slide)	20.5 kg

*Note: Parachute Pack used during Bail Out only.

FIG. 1. Launch and entry suit (LES)

the LES and ACES. These responses were then compared to similar measurements taken while unsuited.

METHODS

Six subjects (five males, one female) participated in this study (Table 1). The order of the two-suited exercise sessions was randomized and was performed on consecutive days; the unsuited test (shorts, T-shirt) was performed 1 to 2 weeks later. Suited testing incorporated all components worn during Orbiter ascent and descent, including thermal underwear and socks, g-suit, life support suit, helmet, boots, gloves, and a parachute harness weighing approximately 23.5 kg (52 lbs). The visor of the helmet was left open for all testing, and subjects were not allowed to cool themselves through the air ventilation port of the suit during testing. Approximately 10 minutes after donning the suit, subjects performed 3-maximal, isokinetic-concentric repetitions at 30 and 180 deg/s about the knee, shoulder, and elbow joints on the right side (LIDO Multi-Joint Isokinetic Dynamometer, Loredan Biomedical, Sacramento, CA). Each joint was tested with the subject in the supine position. The entire test sequence was then repeated on the subject's left side. Subjects rested for a 5-minute period after the strength testing was completed and prior to the treadmill walking. Each subject then walked on a motorized treadmill (Quinton Q65, Quinton Instruments, Seattle, WA) at 5.6 km/h (3.5 mph) for 5 minutes. Heart rate (3-lead Quinton Q5000) and metabolic responses (Quinton QPLEX) were recorded every 30 secs during each exercise session. Heart rate (HR) was obtained from the ECG tachometer and verified through hand calculation. Metabolic responses measured included relative oxygen consumption ($\dot{V}O_2$), minute ventilation ($\dot{V}_e$), and tidal volume ($\dot{V}_t$). Three of the six subjects volunteered to perform a maximal graded exercise test [2] as part of their unsuited test session.

RESULTS

Five-Minute Walk (n = 6)

Metabolic data ($\dot{V}O_2$, HR, $\dot{V}_t$, $\dot{V}_e$) were averaged over the entire 5-minute period. A multivariate repeated measures ANOVA was performed, and significant ($p < 0.05$) differences among suited conditions were found for each metabolic variable. Paired *t*-tests were used to identify significant differences among the three conditions (Tables 2 and 3). No significant ($p = 0.6232$ and $p = 0.5471$, respectively) difference was found between $\dot{V}O_2$ and HR while exercising in the LES and ACES. There also was no significant ($p = 0.9506$ and $p = 0.4772$, respectively) difference between minute ventilation ($\dot{V}_e$, BTPS) and tidal volume ($\dot{V}_t$) while walking at 5.6 km/h (3.5 mph) in the LES and ACES. Significant ($p < 0.05$) differences, however, were noted in HR, $\dot{V}O_2$, $\dot{V}_e$, and $\dot{V}_t$ when the LES and ACES were compared to the unsuited condition.

TABLE 1. *Physiological characteristics (mean ± SD) of subjects tested in the LES, ACES, and unsuited*

	n = 6	n = 3*
Age (yr)	34 ± 2	36 ± 1
Height (cm)	176.1 ± 5.5	176.1 ± 3.9
Weight (kg)	70.7 ± 4.6	72.4 ± 3.9

*Maximal treadmill testing

TABLE 2. *$\dot{V}O_2$ and HR responses (mean ± SD) to the LES, ACES, and unsuited conditions at 5.6 km/h (3.5 mph)*

	$\dot{V}O_2$ (mL • kg^{-1} • min^{-1})			HR (bpm)		
	Mean	± SD	*p**	Mean	± SD	*p**
LES	24.4	1.9	0.0001	140	16	0.0001
ACES	24.2	2.3	0.0001	137	13	0.0001
Unsuited	15.7	1.2	---	105	11	---

*Compared to unsuited condition

TABLE 3. *$\dot{V}_e$ and $\dot{V}_t$ responses (mean ± SD) to the LES, ACES, and unsuited conditions at 5.6 km/h (3.5 mph)*

	$\dot{V}_e$ (L/min)			$\dot{V}_t$ (liters)		
	Mean	± SD	*p**	Mean	± SD	*p**
LES	43.8	11.1	0.0058	1.9	0.6	0.0176
ACES	43.6	9.3	0.0028	1.8	0.3	0.0006
Unsuited	24.7	5.6	---	1.3	0.3	---

*Compared to unsuited condition

Strength Testing (n = 6)

A multivariate repeated measures analysis of variance was used to determine significant differences in isokinetic muscle strength between the two suits and the unsuited condition. No significant ($p > 0.05$) differences occurred among the three conditions at either 30 or 180 deg/s for muscles about the elbow and knee joints. There was a significant ($p = 0.0164$) difference among the three suited conditions for shoulder extension at 30 deg/s. A post-hoc dependent *t*-test indicated a significant ($p = 0.0215$) difference between the new ACES versus the unsuited condition on the right shoulder extension. While no significant differences between the two suits were apparent, this significance was not demonstrated at 180 deg/s. Mean torque values and standard errors for each muscle group are presented in Figs. 2 through 7.

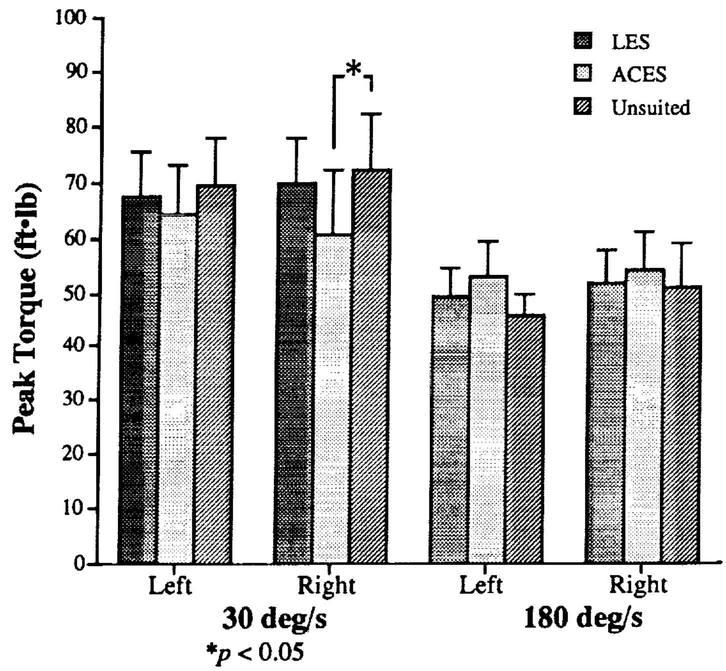


FIG. 2. Shoulder extension

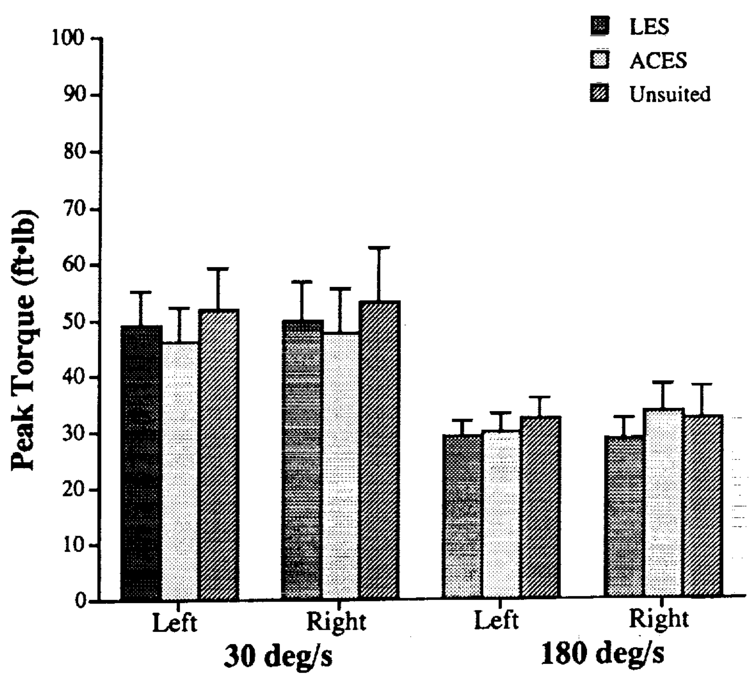


FIG. 3. Shoulder flexion

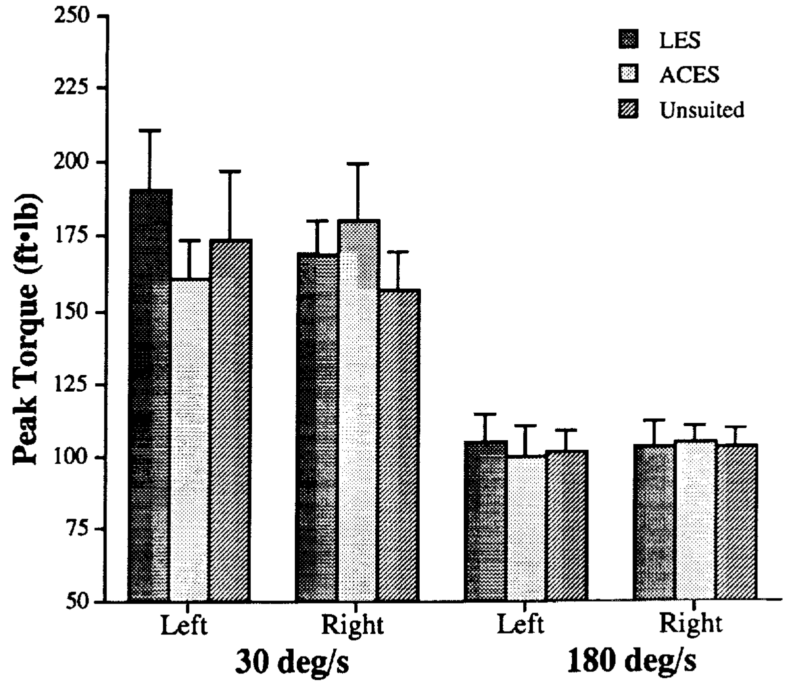


FIG. 4. Knee extension

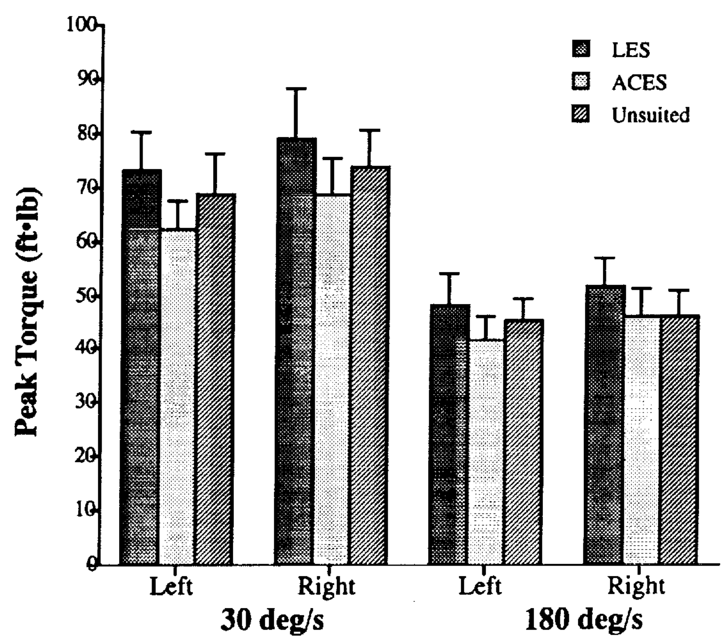


FIG. 5. Knee flexion

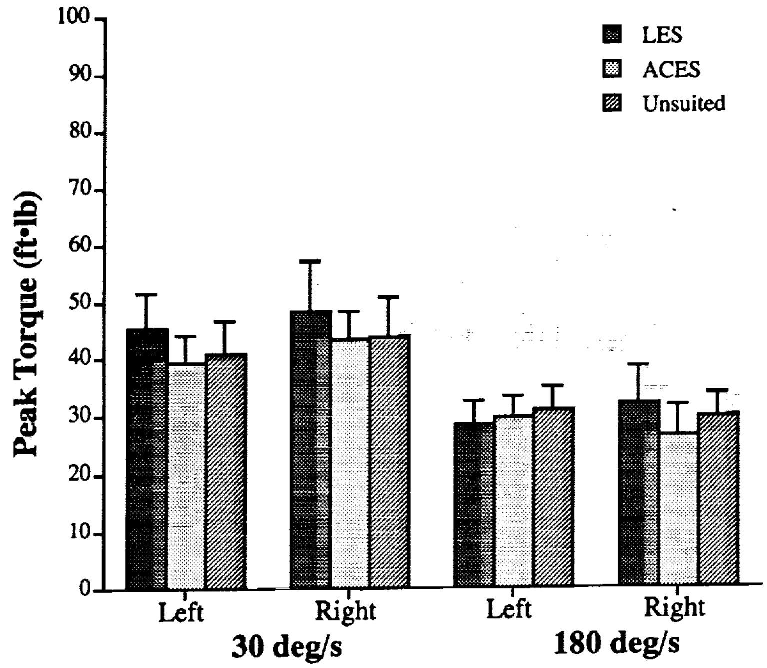


FIG. 6. Elbow extension

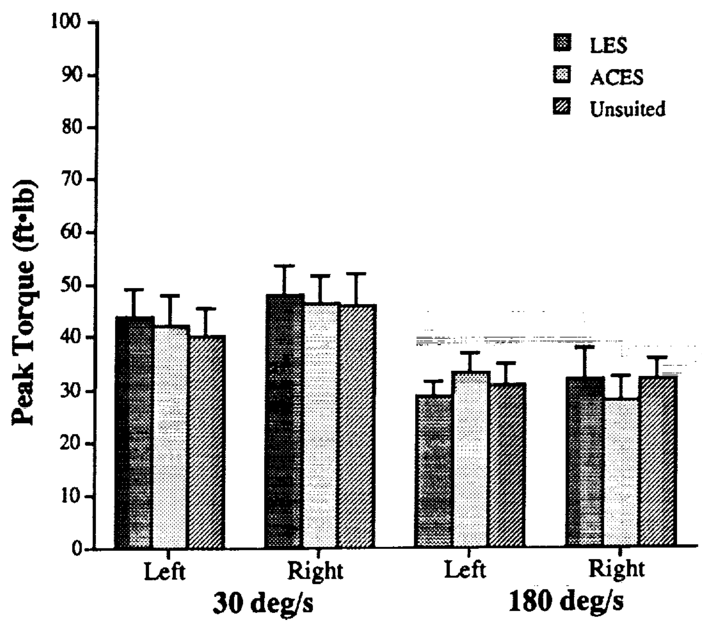


FIG. 7. Elbow flexion

Maximum Treadmill Results (n = 3)

The treadmill responses of the subjects who volunteered to perform a maximal test as part of their unsuited session are shown in Table 4. The percentage of maximal exercise at which subjects were working while walking at 5.6 km/h (3.5 mph) in the LES, in the ACES, and while unsuited is presented in Table 5.

CONCLUSION

Similar metabolic responses to ambulatory exercise were obtained for the LES and ACES. However, metabolic responses were significantly higher during ambulation while wearing either suit when compared to the unsuited condition. A 15-20% increase was noted in the maximal exercise response seen for all metabolic variables when walking at 5.6 km/h (3.5 mph) in the suited condition.

No apparent impact was observed on concentric muscle strength about the knee and elbow joints at the angular velocities tested while wearing a suit. Shoulder strength during extension, however, appears to be compromised at a velocity of 30 deg/s but not at the higher velocity of 180 deg/s. This seems to be due to higher torque values in the unsuited condition. Therefore, wearing a suit while performing egress from the Orbiter would impose a significant metabolic demand on the crewmember, and selective upper body strength movements may be compromised while wearing either the LES or ACES.

TABLE 4. *Maximal treadmill responses (mean ± SD)*

Variable	Mean	± SD
$\dot{V}O_2$ (mL · kg^{-1} · min^{-1})	61.1	12.3
HR (bpm)	202	4
$\dot{V}_e$ (L/min)	161.4	28.9
$\dot{V}_t$ (L)	3.0	0.3

TABLE 5. *Percentage of maximal exercise responses (± SD) while walking at 5.6 km/h (3.5 mph) in the LES and ACES and while unsuited*

Variable	LES	ACES	Unsuited
%$\dot{V}O_2$ (mL · kg^{-1} · min^{-1})	41.6 ± 10.1	42.4 ± 10.1	26.5 ± 4.5
%HR (bpm)	67.1 ± 10.1	66.0 ± 4.3	50.8 ± 5.8
%$\dot{V}_e$ (L/min)	26.9 ± 12.5	28.2 ± 9.0	16.3 ± 4.2
%$\dot{V}_t$ (L)	69.9 ± 17.8	64.1 ± 0.7	44.6 ± 4.1

The findings of this study are somewhat limited. First, only six subjects were tested. Second, it should be noted that the subjects wore the same suit size (a criteria for subject selection). Crewmembers at the extreme limits for height and weight, per astronaut corps specifications, were not represented. Third, the impact of thermal load on exercise responses and the time course of thermal demands on body were not investigated. A better understanding of the physiological demands of wearing a suit during exercise will be obtained with further testing.

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13. ABSTRACT *(Maximum 200 words)*
The launch and entry suit (LES) is a life support suit worn during Orbiter ascent and descent. The impact of suit weight and restricted mobility on egress from the Orbiter during an emergency is unknown. An alternate suit – the advanced crew escape suit (ACES) – is being evaluated. The physiological responses to ambulatory exercise of six subjects wearing the LES and ACES were measured and compared to those measurements taken while unsuited. Dependent variables included heart rate and metabolic response to treadmill walking at 5.6 km/h (3.5 mph), and also bilateral concentric muscle strength about the knee, shoulder, and elbow. No significant ($p > 0.05$) differences in heart rate or metabolic variables were measured in either suit while walking at 5.6 km/h. Significant ($p < 0.05$) decreases in all metabolic variables were remarked when both suits were compared to the unsuited condition. There were no significant ($p > 0.05$) differences among the three suit conditions at 30 or 180 deg/s for muscles about the elbow and knee; however, about the shoulder, a significant ($p = 0.0215$) difference between the ACES and the unsuited condition was noted. Therefore, wearing a life support suit while performing Orbiter egress imposes a significant metabolic demand on crewmembers. Selective upper body strength movements may be compromised.

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