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TECHNICAL NOTE

Comparison of Current Shuttle and Pre-Challenger Flight Suit Reach Capability During Launch Accelerations

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The Challenger accident prompted the creation of a crew escape system which replaced the former Launch Entry Helmet (LEH) ensemble with the current Launch Entry Suit (LES). However, questions were raised regarding the impact of this change on crew reach capability. Our study addressed the question of reach capability and its effect on realistic ground-based training for Space Shuttle missions. Eleven subjects performed reach sweeps in both the LEH and LES suits during 1 and 3 G_x acceleration trials in the Brooks AFB, TX, centrifuge. These reach sweeps were recorded on videotape and subsequently analyzed using a three-dimensional motion analysis system. The ANOVA procedure of the Statistical Analysis System (SAS) program was used to evaluate differences in forward and overhead reach. The results showed that the LES provided less reach capability than its predecessor, the LEH. This study also demonstrated that, since there was no substantial difference between 1 and 3 G_x reach sweeps in the LES, realistic Shuttle launch training may be accomplished in ground-based simulators.

CREWMEN ABOARD the Space Shuttle are subjected to accelerations of up to $+3\ G_x$ (eyeballs in) during launch. However, crew performance during spaceflight under varying G loads has only received cursory attention in the past, despite anecdotal reports of performance limitations. To date, no truly quantitative reach study wearing actual crew equipment and using genuine shuttle seat/restraint systems has ever been conducted. This lack of reach performance data has raised a number of questions regarding the use of simulators in ground-based training for Space Shuttle missions, the effect of increased G loads on reach capability and the impact of the current Shuttle flight-suit on crew mobility. The objective of this study was to quantify and compare the effect of $+G_x$ launch accelerations on reach capability in both the pre-Challenger Launch Entry Helmet (LEH) ensemble and the current Launch Entry Suit (LES).

The LEH ensemble, shown at the top of Fig. 1, consisted of a coverall type flight-suit and a "clam shell" helmet. An inflatable life vest and harness assembly, jump boots and gloves completed the ensemble. The entire ensemble weighs about 9.6 kg (21.2 pounds).

The LES, pictured at the bottom of Fig. 1, was designed to function as a combination dry-type, anti-exposure suit and partial-pressure, high-altitude protection suit. The subjects wore this suit over a set of expedition weight Capilene® underwear. A specially designed torso harness was worn over the LES and connected by quick release fasteners to a personal parachute. This parachute was worn on the crewman's back and also functioned as a seat-back cushion. This entire assembly, including parachute, weighs approximately 38.6 kg (85 pounds).

METHODS

Seven veteran astronauts and four airmen from Brooks AFB, TX, volunteered as test subjects to evaluate maximum reach capability in the LEH and LES suits during both 1 and 3 G_x loading conditions. Table I contains summary anthropometric data on these subjects. The reach evaluations were conducted in the centrifuge at the USAF School of Aerospace Medicine. Each volunteer was briefed on the testing procedure, shown how to perform standardized reach sweeps and instructed to reach as far as they could during each sweep. During the centrifuge runs the subjects were strapped, in the Shuttle launch position, to a flight seat

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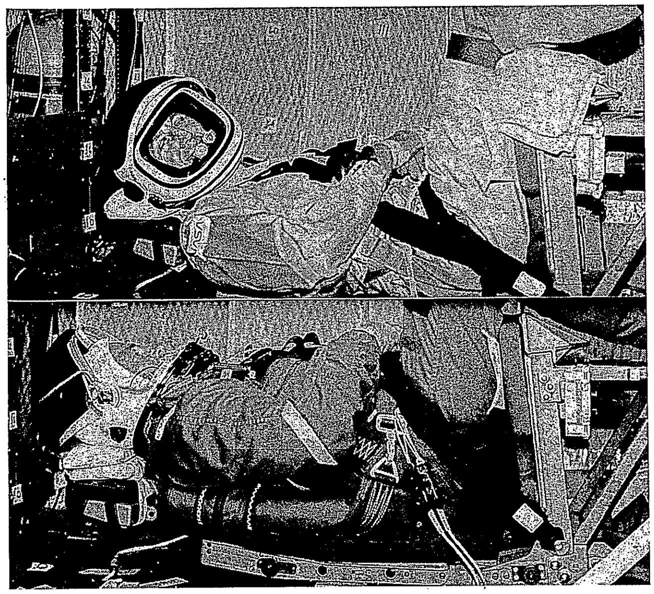

Fig. 1. Pre-Challenger Launch Entry Helmet (LEH) ensemble (upper) and current Launch Entry Suit (LES) (lower).

inside the centrifuge gondola (see Fig. 1) and instructed to perform these reach sweeps in a single, smooth, continuous motion at both G levels.

Each standardized reach sweep was initiated from a hand on knee position. The arm was swept up to the forward reach position directly in front of the subject. The sweep continued toward the aft wall of the gondola to the overhead position above the subject's head. Next the sweep passed along the sidewall and continued toward the forward wall of the gondola. The subject then completed the sweep by returning to the hand-on-knee position. These sweeps were practiced by the participants prior to the centrifuge runs.

Each subject wore the appropriately sized suits in a randomized order and rested for 30 min between the LEH and LES centrifuge runs. It should be noted that pressurization of the LES is initiated only after ambient cabin altitude exceeds 12,040 m (39,500 ft). Since no crew procedures are nominally planned for this remote possibility, no centrifuge trials were performed with the LES pressurized.

Four video cameras captured the standardized reach sweeps as they were performed by each participant. One camera was secured in each corner of the centrifuge gondola and oriented for an optimum view of the subject. The four views of each recorded motion were subsequently digitized and analyzed using the Ariel Performance Analysis System, developed by Ariel Dynamics, Inc. (La Jolla, CA) (1).

Briefly, this system integrates state-of-the-art computer and video processing hardware with specialized software modules that perform data collection, analysis and presentation. During the digitizing process, individual frames of the video recording are selected and digitally displayed on a video monitor. The user then manually identifies the body joint locations of interest by using the mouse. These digitized locations are saved by the computer for subsequent conversion into true three-dimensional image data. This two step transformation process consists of time synchronization of all simultaneous camera views and computation of the true three-dimensional image coordinates from the multiple sets of digitized body joint coordinates. The data can then be smoothed to remove small random digitizing errors and viewed or graphed (1,2).

TABLE I. POPULATION ANTHROPOMETRIC DATA.

Subject	Dominant hand	Sex	Height (cm)	Weight (kg)	Age
1	Right	M	182.0	85.0	28
2	Right	M	183.0	78.0	24
3	Left	M	182.9	81.8	37
4	Right	M	172.6	66.0	27
5	Right	M	188.0	86.4	41
6	Right	M	182.9	84.1	44
7	Right	M	181.2	87.0	29
8	Left	M	186.7	75.0	43
9	Right	M	172.7	70.5	43
10	Right	M	186.7	77.3	47
11	Right	M	175.3	72.3	46

Statistical Methods

Data obtained from motion analysis of the reach sweeps was normalized and prepared for statistical analysis. The cartesian coordinates of the left and right shoulder were noted while the subject was at rest during the 1 G_x loading condition. These coordinates were then used as the origin for reach measurements during the 1 and 3 G_x sweeps. In this way, reach was normalized for each subject.

Reach itself was defined as the distance, in centimeters, between the shoulder and the knuckles for each coordinate. Maximum reach capability was compared in the forward and overhead directions for all loading conditions. The measurement of lateral reach did not reflect a true maximum since all of the subjects were, at less than their full reach, able to touch the gondola sidewalls during the G_x exposures. Therefore, the lateral reach values were not considered meaningful and were eliminated from this analysis.

Significant differences in left and right reach in the forward and overhead directions were evaluated using the analysis of variance (ANOVA) procedure of the Statistical Analysis System (SAS) program. Our independent variables were arm, suit type, and G level. We also investigated the occurrence of any interaction between arm, suit type, and G level. The Student-Newman-Keuls (SNK) multiple range test was used to determine the point at which reach became significantly affected by any of these variables.

RESULTS

The results for the 1 and 3 G_x left and right reach sweeps are shown in Table II. At a significance level of $p = 0.050$, there were no significant interactions between arm, G level, or suit type for any reach sweeps. However, a significant difference ($p = 0.0001$) in forward reach was observed between the two suits. The SNK test revealed that, on the average, forward reach was 6.1 cm greater in the LEH suit at each G level for the entire population. This result is depicted in Fig. 2 for both left and right forward reach.

No significant difference was found to exist between left and right forward reach in either suit. However, a significant difference ($p = 0.0160$) in forward reach did exist between the 1 and 3 G levels. This trend of decreasing forward reach performance with increasing G-load is shown in Fig. 3. As indicated by the SNK test, on the average, 1 G_x forward reach was 3.7 cm greater than 3 G_x forward reach for both suits.

Comparison of overhead reach for the entire population revealed that there was a significant ($p = 0.0007$) difference between the two suits. On the average, overhead reach was found to be 6.2 cm greater in the LEH ensemble at each G level for the entire population. This result is shown in Fig. 4 for both left and right overhead reach.

No significant differences in overhead reach were observed between the two G levels. However, a significant difference ($p = 0.005$) in overhead reach did exist between the left and right sweeps for both suit types. As shown in Fig. 5, right overhead reach was, on the average, 5.1 cm greater than left overhead reach for both G levels. Since only two of the subjects studied were left-handed, it is uncertain whether this observed greater right overhead reach was related to subject's handedness or to suit design.

TABLE II. MEAN POPULATION REACH (in cm) DURING 1 AND 3Gx LOADING CONDITIONS.

	Forward reach				Overhead reach			
	Left		Right		Left		Right	
G level	LEH	LES	LEH	LES	LEH	LES	LEH	LES
1	47.39	41.94	47.16	43.33	62.44	54.81	66.26	60.08
3	44.99	38.61	45.24	36.46	60.55	55.80	67.57	60.73

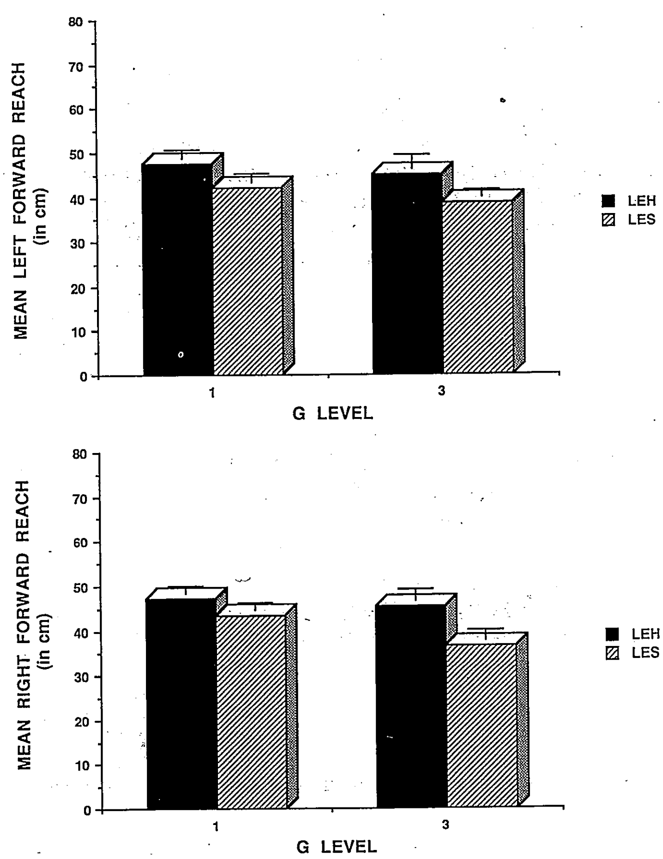

Fig. 2. Comparison of mean left forward reach (upper); and comparison of mean right forward reach (lower).

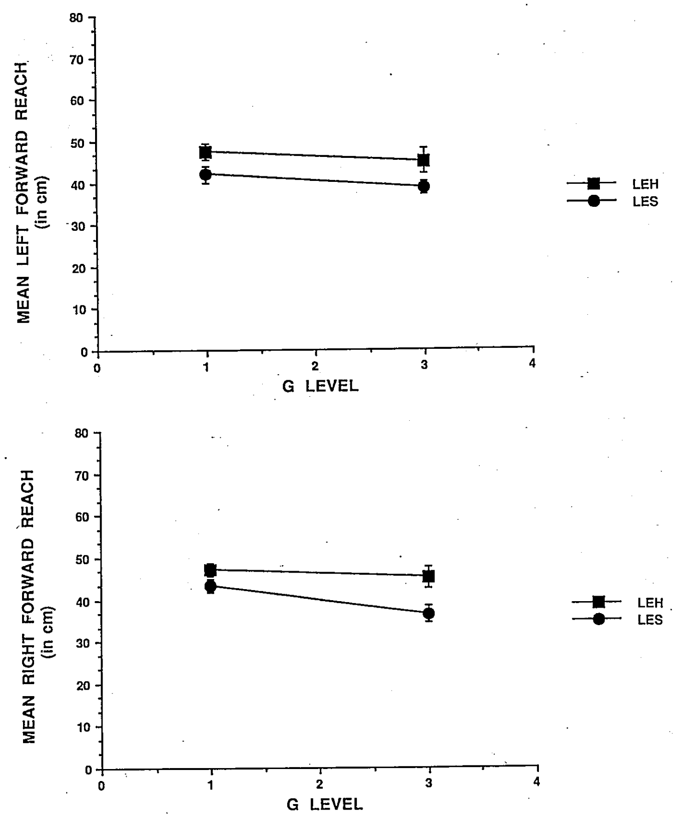

Fig. 3. Comparison of mean left forward reach (upper); and comparison of mean right forward reach (lower).

SUMMARY

Since all subjects practiced the standardized sweeps numerous times prior to data collection, and the observed standard errors were small, it is unlikely that any training effect was responsible for the results obtained.

The changes in forward reach were qualitatively what had been expected based on anecdotal reports received during Space Shuttle mission debriefings. On the average, the subjects experienced a 3.7-cm reduction in forward reach capability at 3 G_x versus 1 G_x for both suits. While this finding was anticipated, the magnitude of this change (8%) was not as great as expected. However, when comparing the two suits, it was determined that average forward reach in the LES was 6.1 cm less than that in the LEH at each G level. This finding indicated

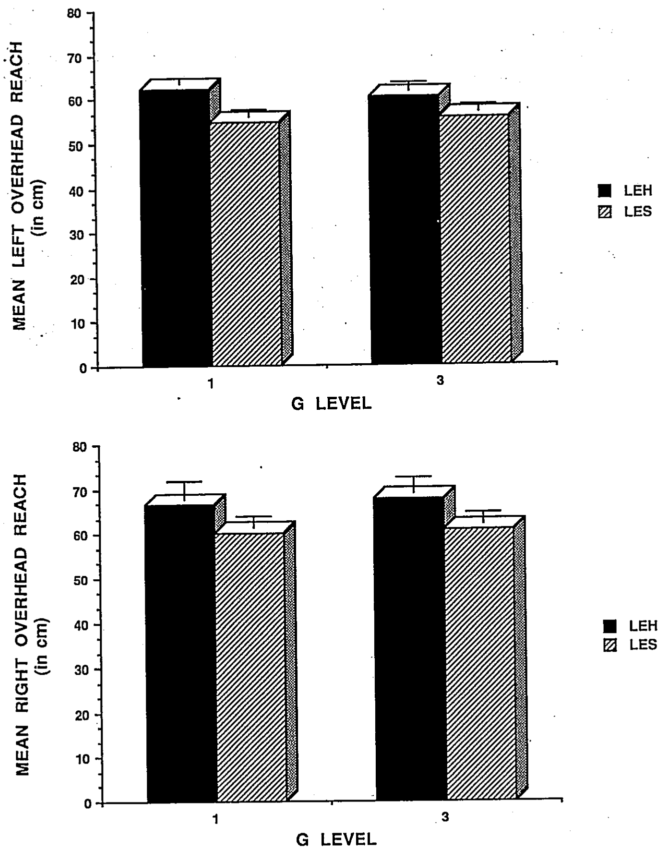

Fig. 4. Comparison of mean left overhead reach (upper); and comparison of mean right overhead reach (lower).

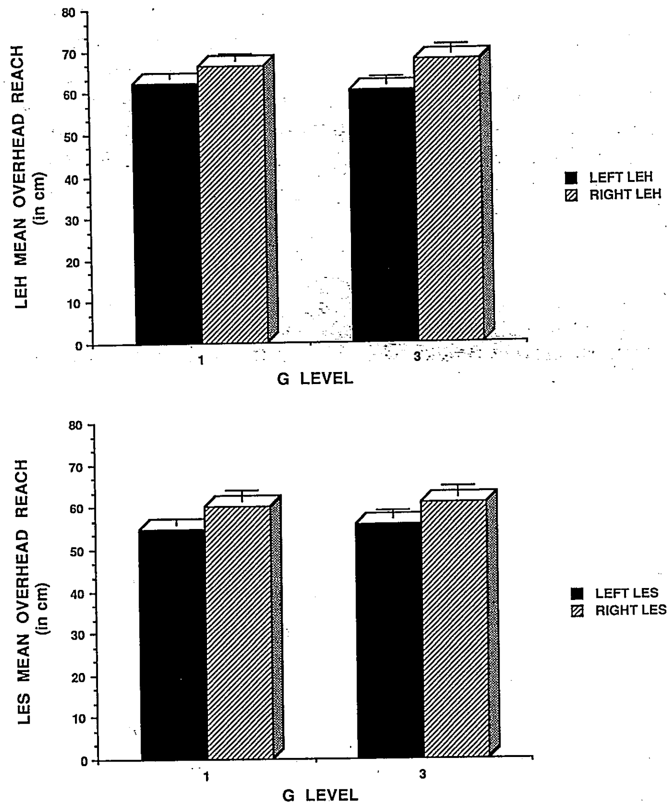

Fig. 5. Comparison of LEH left and right overhead reach (upper); and comparison of LES left and right overhead reach (lower).

that an average reduction in forward reach capability of 13% was inherently due to the change in required crew equipment.

Further comparison of the two suits revealed that the subjects experienced a 6.2-cm reduction in overhead reach while wearing the LES. This observed average reduction in overhead reach of 10% supported the hypothesis that crewmember reach capability has been impacted by the introduction of the LES.

Interestingly, right overhead reach was found to be 5.1 cm (8%) greater than the left for both suits at each G level. This finding was previously observed for the LES (2), but was not anticipated for the LEH. Since both suits were symmetrically constructed, it is unlikely that the suits alone were responsible for the observed asymmetry in overhead reach. The torso and parachute harnesses, which were worn over the LES, were not symmetrical. This was also the case with the LEH life vest and harness assembly. In addition, although only two left-handed subjects were studied, they also exhibited this greater right overhead reach capability. It is felt that this difference in right versus left overhead reach was unrelated to the subject's handedness, and that further research on equipment asymmetry may indicate ways to improve this 8% deficit in left overhead reach.

CONCLUSIONS

These data revealed that reach capability has been impacted by the introduction of the Launch Entry Suit. Although the LES permitted less forward and overhead reach capability than its predecessor, the LEH, the observed reductions are offset by the expanded crew escape and survival potential provided by this new suit. In addition, the subjects studied reported that the instantaneous and extreme field of view afforded by the LES is substantially greater than that in the LEH.

Further, these results indicated that ground-based training adequately simulates the feasibility of forward and overhead reach activities. Therefore, to maintain realistic training, crewmen should expect an 8% reduction in forward reach during 3 G_x, versus 1 G_x, simulations while wearing the LES. An 8% reduction in left overhead reach, as compared to right, should also be anticipated at all G levels while wearing this suit.

This study has also demonstrated the practical application of using three-dimensional motion analysis to quantify magnitudes of reach in any direction. In addition, since these data were collected and stored digitally, they are transferrable and can be used to predict reach capability in any environment where the same equipment and G loads are present. Currently, this reach information is being integrated into a graphics data base depicting the Space Shuttle cockpit panels. This will allow us to find the intersection of these two data bases and represent actual panel positions reachable by a specific subject. Our applications of these data include evaluation of new flight suit configurations and prediction of reach performance during Assured Crew Return Vehicle (ACRV) operations.

Finally, by quantifying 3 G_x reach capability, the development, evaluation, and implementation of many inflight emergency procedures can now be realistically accomplished in ground-based simulators. The resulting procedures will enhance operational safety by furnishing the Shuttle program with a collection of tasks which can be confidently performed by crewmembers at G loads up to 3 G_x.

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