Correlation of Space Shuttle Landing Performance with Post-Flight Cardiovascular Dysfunction

Author: R McCluskey

Running Head: Shuttle Landing Performance

Abstract word count: 198

Narrative text word count: 1368

Number of references: 10

Number of tables: 1

Number of figures: 0

Key words: space flight, pilot performance, orthostasis

ABSTRACT

Introduction: Microgravity induces cardiovascular adaptations resulting in orthostatic intolerance on re-exposure to normal gravity. Orthostasis could interfere with performance of complex tasks during the re-entry phase of Shuttle landings. This study correlated measures of Shuttle landing performance with post-flight indicators of orthostatic intolerance. **Methods:** Relevant Shuttle landing performance parameters routinely recorded at touchdown by NASA included downrange and crossrange distances, airspeed, and vertical speed. Measures of cardiovascular changes were calculated from operational stand tests performed in the immediate post-flight period on mission commanders from STS-41 to STS-66. Stand test data analyzed included maximum standing heart rate, mean increase in maximum heart rate, minimum standing systolic blood pressure, and mean decrease in standing systolic blood pressure. Pearson correlation coefficients were calculated with the null hypothesis that there was no statistically significant linear correlation between stand test results and Shuttle landing performance. A correlation coefficient $\geq$ 0.5 with a $p<0.05$ was considered significant. **Results:** There were no significant linear correlations between landing performance and measures of post-flight cardiovascular dysfunction. **Discussion:** There was no evidence that post-flight cardiovascular stand test data correlated with Shuttle landing performance. This implies that variations in landing performance were not due to space flight-induced orthostatic intolerance.

INTRODUCTION

Space flight induces cardiovascular changes in response to microgravity, including intra-vascular fluid loss and redistribution, cardiac deconditioning, and neuroendocrine changes (4,9,10). Return to normal gravity may cause transient orthostatic intolerance and has been extensively studied (1,3,5,6,7,8,10). Countermeasure protocols include in-flight exercise, fluid loading, and the use of inflatable g-suits, and have been shown to reduce post-flight orthostasis (2,6). Post-flight orthostasis has been recognized as possibly interfering with egress, but has not been studied in the context of pilot performance during the landing phase. Unfortunately, access to returning crews to study these performance and physiological changes is limited by operational constraints. Some very limited testing can be performed by the crew during or immediately after landing, but protective clothing, movement limitations, operational demands, and safety concerns restrict the amount and type of testing that can be performed.

A measure of performance during landing would be desirable to gain insight into the effects of early cardiovascular re-adaptation to gravity on human performance in general and pilot performance in particular. Given limitations on access to the crew during landing, we proposed to use the landing itself as a test of pilot performance by mission commanders, who usually performed manual landings at end of mission, assisted by the pilots and other flight deck crewmembers. Each landing of the Space Shuttle was carefully tracked by NASA and many parameters were measured and recorded for analysis. Pilot performance during landing was compared to physiological data collected after egress to determine whether pilot ability, and landing safety, was affected by spaceflight-induced cardiovascular changes.

METHODS

This study protocol was approved by the Johnson Space Center Institutional Review Board. Written informed consent was not required for this medical record review. There were 31 Shuttle missions launched between STS-41 (October 1990) and STS-66 (November 1994). One mission was excluded because the landing parameters were significantly altered for operational test purposes. Out of 30 missions, the mission commanders' stand test results of 27 missions were available for analysis. There were 20 commanders for 27 missions, because 7 commanders were assigned to two missions each during this period. All 27 missions were included in the study regardless of whether the commander had flown another mission during the study period. The commanders were all male veteran astronauts between the ages of 39.9 and 59.6 years (mean 46.7 ±3.8 yrs). All mission commanders underwent extensive annual and preflight physical examinations and were free of known cardiovascular disease.

Stand tests were performed on crewmembers preflight and post-flight as a medical requirement. The first opportunity for stand testing in the immediate post-flight period was on the Crew Return Vehicle or in the Multi-Functional Facility at Kennedy Space Center. This resulted in a 1-2 hour delay with possible re-adaptation before testing could be performed. During this delay, some crewmembers displayed symptoms of neurovestibular dysfunction. Fluid resuscitation or medication were administered to the most symptomatic crewmembers. Briefly, each stand test consisted of repeated blood pressure and heart rate measurements each minute for sixteen minutes using a Dynamap automated blood pressure device. One supine baseline measurement was followed by six supine measurements and ten standing measurements. Maximum standing heart rate (mean 95 +/- 14 bpm), mean increase in maximum heart rate from supine to standing (mean 33 +/- 19 bpm), minimum standing systolic blood pressure (mean 107 +/- 16 mmHg), and mean decrease in minimum standing systolic blood pressure from supine to standing (mean -7 +/- 7 mmHg) were calculated from post-flight stand tests. None of the subjects demonstrated orthostatis during pre-flight testing. Test results were stored in mission medical records and were retrieved for this study. Stand tests were not performed on commanders after STS-66.

Flight data for each landing were recorded and archived by Mission Operations Directorate at Johnson Space Center. Data for airspeed and vertical speed at touchdown, and downrange and crossrange positions at touchdown were easily extracted. Airspeed at touchdown was down-listed at 1Hz with an estimated system accuracy of +/- 19 KEAS at 200 KEAS. Target air speed varied with the weight and balance of each flight, but was either 195 KEAS or 205 KEAS. Target airspeed for each mission was provided and the difference calculated (mean 4.7 +/- 7.8 kts). Vertical speed at touchdown was down listed at 1 Hz with an accuracy of +/- 1 fps. Target vertical speed was -1 fps, but -2 to -3 fps was typical (mean 2 +/- 1 fps). Distance downrange at touchdown was measured on the ground by identifying tire tracks and was estimated to have an accuracy of +/- 1 inch. On cold nights when spin-up patches could not be positively identified, estimated touchdown locations were computed post-flight from onboard navigation data. Target downrange distance varied with the height over the threshold and speed at touchdown. The goal was to touch down on target speed, so if height over the threshold and speed at touchdown were on target, touchdown should have occurred at 2000 feet downrange. Target and measured downrange distances were provided and the differences calculated (mean -406.8 +/- 665.9 ft). Crossrange distance measured the distance to the left (negative) or to the right (positive) from the center line (mean 2.0 +/- 9.5 ft).

The null hypothesis (Ho) was that there was no statistically significant linear correlation between the stand test and flight data. Pearson's product moment correlation coefficients (r) were obtained along with the probability (p) of the correlation (Prob > |r| under Ho: Rho=0 for N=27) using SAS v6.12. The Bonferroni-corrected significance level was $p < 0.05$ for alpha=0.0025. For N=27, the level of significance for the correlation coefficient was $r \geq 0.5$ The independent variables were maximum standing heart rate, percent mean increase in standing heart rate, minimum standing systolic blood pressure, and percent mean decrease in standing systolic blood pressure, and mission elapsed time. The dependent variables were downrange and crossrange distances, airspeed at touchdown and vertical speed at touchdown, and mission elapsed time.

RESULTS

The Pearson correlation coefficients and probabilities for stand test and flight data are listed in Table I. None of the correlation coefficients reached the 0.5 level with a $p < 0.05$. The highest correlation between stand test results and landing performance data was 0.38 ($p = 0.04$) for decrease in systolic blood pressure on standing and airspeed at touchdown. Landing performance and stand test data did not correlate with mission elapsed time.

DISCUSSION

There was no evidence of a significant linear correlation between landing performance and post-flight measure of orthostasis, despite orthostasis being a well-documented post-flight phenomenon. Although signs of orthostasis were observed during commanders' stand tests, the magnitude of any orthostasis may not have been significant enough to overcome compensation and contribute to performance changes. All commanders followed in-flight exercise protocols, completed their fluid loading protocols prior to entry, were wearing g-suits, and were veteran astronauts. Also, piloting was primarily a cognitive activity and the commanders were seated and tightly focused on the flying task. In light of these findings, post-flight orthostasis may be primarily a vehicle egress phenomenon, and not a concern for pilot performance after short (<18 day) duration missions.

Mission duration did not correlate with either stand test data or landing performance. There was no indication that landing performance represented a limiting factor in mission length, at least for the mission durations included in this study. The lack of correlation between mission duration and stand test results had been observed in other studies (1,3,5,7). It was likely that fluid shifts and cardiovascular adaptation occurred early in flight and then plateaued for the duration of these relatively short missions.

This study examined data for missions no longer than 18 days and under nominal operational and weather conditions. While orthostasis did not appear to contribute to variations in landing performance under these conditions, the level of compensation required to maintain performance was not measured. Landing outside of accepted weather limits, mechanical malfunctions, unavailability of cardiovascular countermeasures, or other conditions causing increased workload could erode the available reserve of compensation. The current limit of 21 days for nominal Space Shuttle missions seems to be consistent with the findings of this study, however factors such as those listed above could have unknown effects on crew performance and ability to counter post-flight orthostasis.

REFERENCES

1 Bucky J, Lane L, Levine B, Watenpaugh D, Wright S, Moore W, Gaffney A, Blomqvist C. Orthostatic intolerance after spaceflight. J Appl Physiol 1996; 81(1): 7-18.

2 Bungo M, Charles J, Johnson P. Cardiovascular deconditioning during spaceflight and the use of saline as a countermeasure to orthostatic intolerance. Aviat Space Environ Med 1985; 56:985-90.

3 Charles J, Lather C. Cardiovascular adaptation to spaceflight. J Clin Pharmacol 1991; 31:1010-1023.

4 Fritsch-Yelle J, Whitson P, Bondar R, Brown T. Subnormal epinephrine release relates to presyncope in astronauts after spaceflight. J Appl Physiol 1996; 81 (5) 2134-2141.

5 Fritsch-Yelle J, Charles J, Jones M, Wood M. Microgravity decreases heart rate and arterial pressure in humans. L Appl Physiol 1996; 80(3): 910-914.

6 Lee S, Morre A, Fritsch-Yelle J, Greenisen M, Fortney Schneider S. Inflight exercise affects stand test responses after space flight. Med Sci in Sports Exerc 1999; 31(12):1755-1762.

7 Martin D, Meck J. presyncopal/non-presyncopal outcomes of post spaceflight stand tests are consistent from flight to flight. Aviat Space Environ Med 2004; 75:65-67.

8 Meck J, Reyes C, Perez S. Marked exacerbation of orthostatic intolerance after long vs. short-duration spaceflight in veteran astronauts. Psychosomatic Med 2003; 63:865-73.

9 Nicogossian A, Sawin C, Huntoon C. Overall physiologic responses to space flight. In: Nicogossian A, Huntoon C, Pool S, eds. Space Physiology and Medicine. Philadelphia: Lea and Febiger; 1994:213-227.

10 Whitson P, Charles J, Williams W, Cintron N. Changes in sympathoadrenal response to standing in humans after spaceflight. J Appl Physiol 1995; 79:428-433.

Table I. Pearson correlation coefficients (*p* values) for mission commander stand test data and Shuttle landing performance data for STS-41 - STS-66

	MET	DX	DY	VS	DEAS
MET	1 (0)	-0.09 (0.6)	0.15 (0.38)	-0.3 (0.07)	0.11 (0.51)
Minimum standing BP	0.2 (0.24)	-0.04 (0.81)	0.07 (0.7)	-0.2 (0.23)	0.02 (0.9)
Maximum standing heart rate	-0.07 (0.68)	-0.16 (0.34)	07 (0.7)	0.12 (0.49)	0.17 (0.32)
Decrease BP, standing	0.09 (0.66)	0.34 (0.08)	-0.03 (0.87)	-0.12 (0.53)	0.38 (0.04)
Increase heart rate, standing	0.11 (0.58)	0.11 (.57)	0.35 (0.08)	0.19 (0.35)	-0.21 (0.29)

(MET=mission elapsed time, DX=downrange distance at touchdown, DY= crossrange distance at touchdown, VS=vertical speed at touchdown, DEAS= estimated airspeed at touchdown)