HHS Public Access

Author manuscript

J Vestib Res. Author manuscript; available in PMC 2021 April 28.

Published in final edited form as:

J Vestib Res. 2012 ; 22(4): 191–196. doi:10.3233/VES-2012-0456.

Posturography and locomotor tests of dynamic balance after long-duration spaceflight

Helen S. Cohen, EdD[1], **Kay T. Kimball, PhD**[2], **Ajitkumar P. Mulavara, PhD**[3], **Jacob J. Bloomberg, PhD**[4], **William H. Paloski, PhD**[4],[5]

[1)]Bobby R. Alford Department of Otolaryngology – Head and Neck Surgery, Baylor College of Medicine.

[2)]Statistical Design and Analysis.

[3)]Universities Space Research Association.

[4)]Neuroscience Research Laboratories, NASA/ Johnson Space Center.

Abstract

The currently approved objective clinical measure of standing balance in astronauts after space flight is the Sensory Organization Test battery of computerized dynamic posturography. No tests of walking balance are currently approved for standard clinical testing of astronauts. This study determined the sensitivity and specificity of standing and walking balance tests for astronauts before and after long-duration space flight. Astronauts were tested on an obstacle avoidance test known as the Functional Mobility Test (FMT) and on the Sensory Organization Test using sway-referenced support surface motion with eyes closed (SOT 5) before and six months after (n=15) space flight on the International Space Station. They were tested two to seven days after landing. Scores on SOT tests decreased and scores on FMT increased significantly from pre- to post-flight. In other words, post-flight scores were worse than pre-flight scores. SOT and FMT scores were not significantly related. ROC analyses indicated supra-clinical cut-points for SOT 5 and for FMT. The standard clinical cut-point for SOT 5 had low sensitivity to post-flight astronauts. Higher cut-points increased sensitivity to post-flight astronauts but decreased specificity to pre-flight astronauts. Using an FMT cut-point that was moderately highly sensitive and highly specific plus SOT 5 at the standard clinical cut-point was no more sensitive than SOT 5, alone. FMT plus SOT 5 at higher cut-points was more specific and more sensitive. The total correctly classified was highest for FMT, alone, and for FMT plus SOT 5 at the highest cut-point. These findings indicate that standard clinical comparisons are not useful for identifying problems. Testing both standing and walking balance will be more likely to identify balance deficits.

Keywords

functional mobility; space flight; locomotion; adaptation; recovery; astronauts

Correspondence to: Helen S. Cohen, EdD, Department of Otolaryngology, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77030, USA, hcohen@bcm.tmc.edu.

[5)]Current affiliation, Center for Neuromotor and Biomechanics Research, University of Houston.

1. Introduction

The only objective neurologic test of balance that is currently approved for standard clinical testing of astronauts is computerized dynamic posturography, using the Equitest (Neurocom International), an excellent test of dynamic balance during standing [13]. Astronauts have decreased scores on the Sensory Organization Test following space flight [1, 7, 16]. One subtest of this battery, Condition 5 of the Sensory Organization Test (SOT 5) – in which subjects close their eyes while standing on a force platform that moves in phase with their anterior-posterior postural sway – is also particularly sensitive to patients with vestibular disorders [13, 14]}. This test, however, only measures standing balance. Many activities of daily living require good walking balance. Performance on standing balance tests may not predict performance on walking balance tasks since different mechanisms may mediate standing and walking balance [8].

Obstacle avoidance is an important component of tasks that involve walking. During emergency egress from a vehicle and while exploring a planetary surface astronauts may need to have good obstacle avoidance skills. Age, adaptation to sensorimotor change, and vestibular disorders are all associated with decreased obstacle avoidance skill. Older adults perform worse than younger adults on such tasks [3, 4, 19] and normals undergoing sensorimotor adaptation perform more poorly than their pre-adaption scores on obstacle avoidance [5, 10, 11]. Our previous work with normals and patients who have vestibular impairments has shown that an obstacle avoidance task is almost as sensitive to vestibular impairments as computerized dynamic posturography and the two tests, combined, are very sensitive [6]. The obstacle avoidance task had sensitivity of 78, i.e. 78% of patients were correctly classified, and specificity of 80, i.e. 80% of normals were correctly classified. The total correctly classified was 79%. SOT 5 had 85% sensitivity, 77% specificity and 81% total correctly classified. When those tests were combined sensitivity of SOT 5 + obstacle avoidance was higher, 90%, although specificity was lower, 70%, but the total correctly classified was approximately the same, 80%. For purposes of identifying an impaired population sensitivity was the more clinically significant value.

The goal of the present study was to determine whether performance on computerized dynamic posturography, alone -- especially the SOT 5 condition, or combined with performance on an obstacle avoidance task better identifies balance problems in astronauts after long-duration space flight. In particular we sought to determine how sensitivity and specificity vary on those tests. The clinical population may be a useful model for the astronaut population in this instance. Although all crewmembers are functionally impaired after long-duration space flight to avoid safety problems caused by premature return-to-duty astronauts and flight surgeons may need to test astronauts for functional impairment until recovery is complete, so sensitivity of the test may be the more important value.

2. Methods

2.1 Subjects

Data were available from 15 astronauts (14 males, 1 female; mean age, 44.9 yrs., S.D. 5.2) who had flown on the International Space Station for approximately 6 months (mean

mission duration, 180 days, S.D. 17 days). Posturography data were collected as part of the standard flight medical assessment testing. Anonymized data were extracted from the medical records. This study was approved by the Institutional Review Board for Human Subjects Research for Baylor College of Medicine and Affiliated Hospitals and the NASA/ Johnson Space Center Committee for Protection of Human Subjects.

2.2 Apparatus

As a medical requirement, all astronauts are tested before and after space flight on SOT. This test is performed with the standard Equitest computerized dynamic posturography system (Neurocom Intl, Clackamas, OR). This device includes a force platform that measures the change in the center of pressure under the feet as the individual sways during several balance conditions. An obstacle avoidance task, the Functional Mobility Test (FMT) was used to test astronaut locomotion. The FMT was set up on a surface of 10 cm thick, medium density foam (Sunmate foam, Dynamic Systems, Inc., Leicester, NC (USA)) for safety and to provide a challenging walking surface. The 6.0 m × 4.0 m course included a “portal” made of a foam-covered horizontal bar hung at shoulder height over two 31 cm high Styrofoam blocks, another 46 cm Styrofoam block, a ”gate” made of a pair of foam pylons hung from the ceiling, and 5 other foam pylons hung from the ceiling so that the astronaut had to change direction continuously to move through the course [12].

2.3 Procedures

SOT includes 6 subtests: 1) control, quiet standing, 2) eyes closed, 3) eyes open as the visual surround sways in phase with postural sway (sway-referenced); conditions 4, 5 and 6 repeat conditions 1, 2 and 3, respectively with the addition of sway-referenced movement of the force platform. Conditions 5 and 6, with sway referenced platform movement and either absent vision or sway-referenced visual surround, are the most challenging to the vestibular system. In the clinical population SOT 5 and 6 yield similar results so only SOT 5 will be discussed further. To perform FMT the astronaut was instructed to walk through the course as quickly and safely as possible without running or touching any of the obstacles. Safety guarding was provided throughout the test. See Figure 1. Six trials of FMT took approximately 10 minutes. The dependent measure was time (sec) to traverse the course The post-flight FMT data were collected within a 7-day period and SOT data collections were interspersed within that period; therefore, an order effect of testing was highly unlikely.

Pre-flight SOT data were available from 92 crewmembers. This sample of astronauts was used to establish levels of sensitivity and specificity targeted to the astronaut population. Although SOT is a well-normed and widely used clinical test, astronauts -- who must meet rigorous criteria for selection into the corps -- spend many hours practicing tasks that require good vestibular function and have greater levels of fitness and vigilance than the general population. Astronauts were tested post-flight at approximately Day 3 after landing, but some astronauts were tested at Day 2 or 4 (early post-flight tests), and on Days 7 to 10 (late post-flight tests), depending on their schedules. Participation in FMT by astronauts was voluntary. Post-flight data on both SOT and FMT were available from 15 crewmembers who had all experienced long duration space flight of 6 months on the International Space Station. Crewmembers were tested on FMT Day 3 or 4 after landing.

Before flight, astronauts are generally more physically fit than their average contemporaries. Therefore, analyses used the published norms (cut-points) for SOT Condition 5 (eyes closed, sway-referenced platform motion) and also used higher cut-points for SOT 5 based on tables from Receiver Operating Characteristics (ROC) analyses [9]. When choosing cut points, sensitivity, i.e. the accurate prediction of post-flight crewmembers, was emphasized over specificity, i.e. the accurate prediction of pre-flight crewmembers. No published norms were available for FMT. Therefore, pre-flight data from crewmembers were examined. The 95th percentiles and tables from ROC analyses were used to determine the cut-points for FMT time. As with the SOT data, sensitivity was emphasized over specificity. Stata statistical software was used for analyses [21].

3. Results

All crewmembers fell within the young adult age range for the manufacturer's clinical norms. Using those clinical norms, SOT 5 is very highly specific to pre-flight astronauts but poorly sensitive to post-flight astronauts. (See Table 1.) Raising the cut-point slightly decreases specificity to a moderate level but increases sensitivity to moderately high. Raising the cut-point further decreases specificity more but makes the test highly sensitive. The selected cut-point for time on FMT was moderately highly sensitive and highly specific. See Table 1 and Figure 1.

We also examined sensitivity and specificity to combinations of SOT and FMT, with three cut-points for SOT, the standard clinical cut-point and two higher cut-points. As shown in Table 1 FMT plus the standard, clinical norm on SOT did not change the result from SOT with the clinical cut-point, alone. FMT plus a slightly higher SOT cut-point increased specificity to the entire cohort and increased sensitivity considerably. FMT plus the highest SOT cut-point maintained specificity to the entire cohort and again increased sensitivity, although sensitivity remained below that of both tests independently. The total correctly classified was highest for FMT alone, and for FMT plus SOT at the highest cut-point. See Table 2.

As shown in Table 3 crewmembers' scores decreased from pre- to post-flight. Paired t-tests showed significant differences between pre- and post-flight SOT 5, $t = 5.26$, $p = 0.0002$ and between pre- and post-flight FMT, time: $t = 5.65$, $p < 0.0001$. Details of changes in FMT data have been reported previously [12] and will not be discussed further. Similarly, details of the SOT performance of crewmembers following short-duration space flight have also been reported previously [7, 18] and will not be discussed further. Pearson product moment correlations showed no significant relationship between FMT time and SOT 5 scores, as illustrated in Figure 3.

4. Discussion

Using a pre-selected cut-point to define normal behavior is a standard clinical practice. The Equitest battery has pre-set cut-points for young, middle-aged and older adults, above which any apparent differences are considered to be normal variations in behavior with no known clinical or practical significance. In that context, the finding that one crewmember scored

below the 95th percentile on FMT is not surprising and of no functional significance. Even in a high- functioning population, such as pre-flight crewmembers, a range of motor skill level is possible. The finding that SOT had decreased specificity with higher cut-points is not surprising. Some crewmembers may have had lower vigilance during pre-flight testing owing to the pressures of their training schedules or, possibly, mild, subclinical balance decrements that had no functional significance and did not affect their skill in performing either routine activities of daily living or tasks specific to astronauts.

The data on post-flight astronauts indicate that three or more days after returning from long duration space flight crew members out-perform patients with vestibular disorders, who fail at the standard clinical cut-point [14]. A higher cut-point for astronauts indicates better performance. This finding, however, does not mean that post-flight crewmembers perform normally for their highly select peer group. SOT 5 was administered under relatively quiet conditions, similar to a clinical laboratory, and the individual crewmember could concentrate on the task. Previous research from the NASA/ Johnson Space Center Neuroscience Laboratory has shown that in the acute phase of recovery from space flight, i.e., three days post-flight and sometimes longer, crewmembers have significant balance and locomotor deficits [12, 17]. Jain et al [7] showed that the diagnostic accuracy of SOT 5 using clinical cut-points was quite high for astronauts on short-duration missions (area under ROC curve > 0.9) compared with standard bedside clinical neurologic tests and only 58% of crewmembers tested using a sharpened version of SOT 5 had recovered to within 25% of their preflight values by post-flight day 3.

Astronauts are highly intelligent and trained to perform under difficult conditions. Perhaps if they had been asked to perform a cognitive task that interferes with concentration while they were performing the tests crewmembers would have had decreased scores. The slightly higher cut-point for astronauts increased sensitivity only moderately. When the cut-point for astronauts was raised again, however, the test did select most post-flight crewmembers. This finding suggests that clinical norms, developed from data on average adults, are not adequate when testing astronauts, who are highly trained and have greater motor ability than many average people. Instead, when used as an individual medical requirement, the cut-point should be raised to a level based on ROC analyses of crewmember data.

Control of balance and mobility require different mechanisms for static and dynamic balance [11, 20]. FMT assesses different aspects of balance than SOT. As the individual moves through space different skills are probably needed to maintain stability than the skills needed to be stable during quiet standing [8]. Therefore, just assessing standing balance does not provide a good indicator of how astronauts, and probably other people, will perform when walking around the environment, avoiding obstacles, and stepping on surfaces that may be somewhat unstable, such as a sandy planetary surface or plush, indoor carpeting. To understand how an individual will respond to such environmental challenges dynamic balance while moving through space and avoiding obstacles should be assessed as directly as possible. These data support that idea.

The pre-flight FMT data are as specific as pre-flight SOT data at the standard clinical cut-point and more specific than SOT 5 data at the higher cut-points. The combined pre-flight

test scores are most specific. These data indicate that at pre-flight tests crewmembers have both sets of skills. The post-flight FMT data have high sensitivity, suggesting that these different dynamic balance skills are also impaired post-flight. The same individuals may not be equally impaired on both sets of skills, however, as reflected in lower post-flight sensitivity on SOT 5 scores except at the highest cut-point.

The combined SOT plus FMT data support that idea. At the highest SOT cut-point SOT 5 plus FMT correctly identifies all pre-flight crewmembers as normal. The finding that sensitivity is somewhat decreased with the combined tests suggests that some crewmembers can do one test better than the other. Post-flight sensitivity is decreased, consistent with the variability in post-flight astronaut responses on other tests [2, 15].

FMT is relatively inexpensive, easy to administer and requires minimal crew time. It adds an additional dimension to testing not available with the current criterion standard, computerized dynamic posturography. Development of a single test battery with attributes of both tests would be useful.

Acknowledgements

We thank the staff of the Center for Balance Disorders, Baylor College of Medicine, and Scott Wood, PhD, Universities Space Research Association, for his invaluable assistance in moving the process forward. Supported by NIH grant R01DC04167 (HSC) and the National Space Biomedical Research Institute through NASA NCC 9-58 (JJB).

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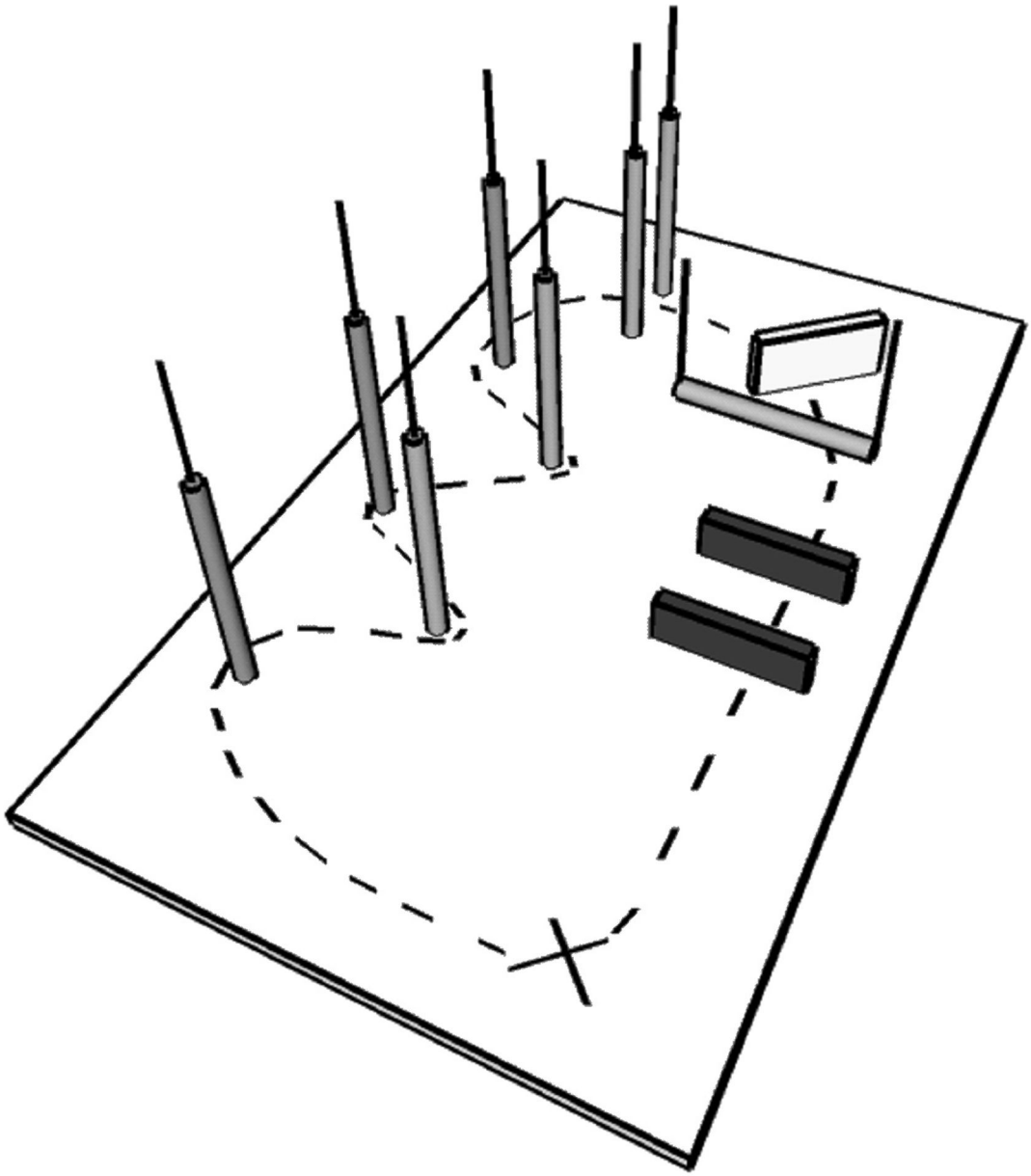

Figure 1.

Plan view of the Functional Mobility Test at NASA/ Johnson Space Center. The course is set upon foam pads. Horizontal rectangles are Styrofoam blocks Vertical cylinders are pylons suspended from the ceiling. The horizontal cylinder is suspended from the ceiling over the white Styrofoam block, making a “portal” through which the astronaut stepped. (From Mulavara et al [12] and used by permission)

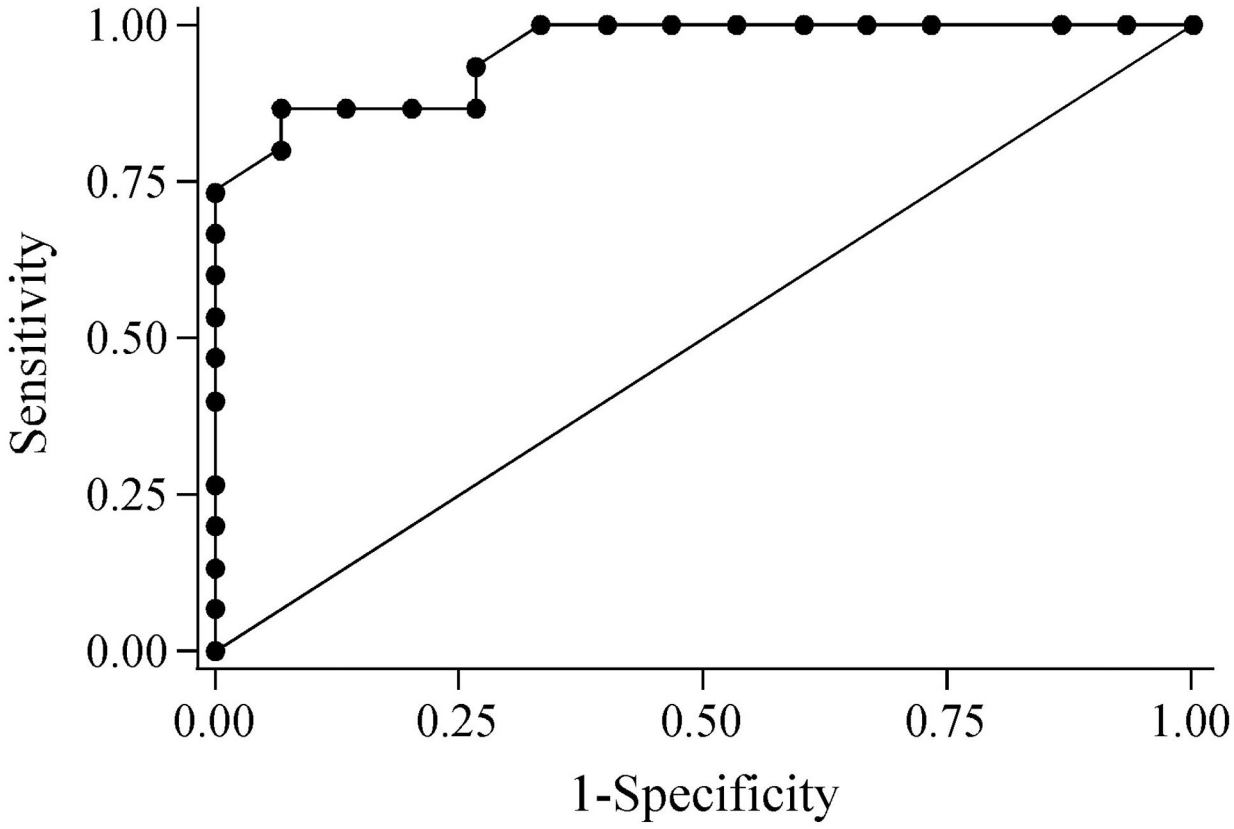

Figure 2.
ROC curve for time to navigate the FMT course. Specificity refers to astronauts pre-flight; sensitivity refers to astronauts post-flight.

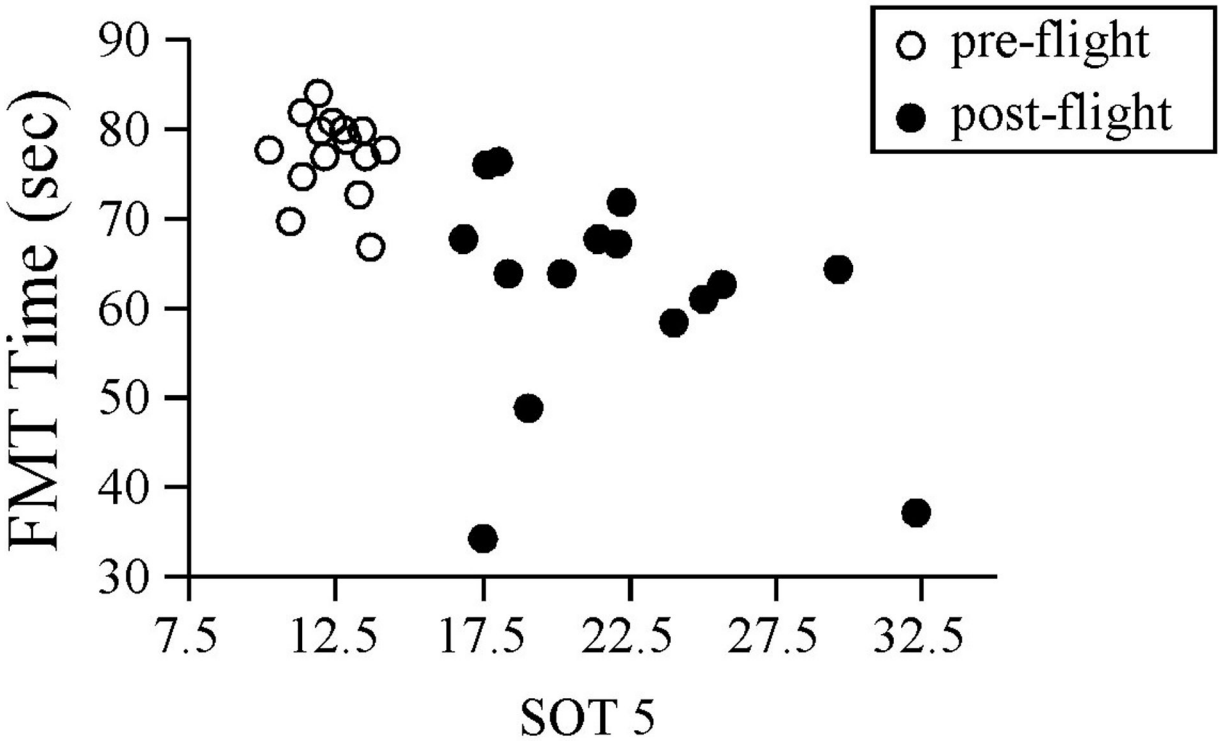

Figure 3.
Relationship between mean FMT time and mean SOT 5 equilibrium scores. Post-test data represent the first available post-flight test data.

Table 1.

Sensitivity (percent of post-flight astronauts correctly classified), specificity (percent of pre-flight astronauts correctly classified) and total (percent correctly classified) for individual tests, using > 0 falls on SOT Condition 5 as a cut-point plus either standard SOT scores or higher cut-points.

Test	Sensitivity (classifies post-flight crew members)	Specificity (classifies pre-flight crew members)	Total correctly classified
FMT time (cut-point, 14.1 sec)	80%	93%	87%
SOT 5 (clinical cut-point, 52)	7%	95%	83%
SOT 5 (cut-point, 63)	36%	83%	76%
SOT 5 (cut-point, 68)	71%	73%	73%
SOT 5 (cut-point, 72)	86%	63%	66%

Table 2.

Sensitivity, specificity, and total correctly classified for combined tests, using > 0 falls on SOT Condition 5 as a cut-point plus either standard SOT scores or higher cut-points.

Test	Sensitivity (classifies post-flight crew members)	Specificity (classifies pre-flight crew members)	Total correctly classified
Combined FMT time + SOT 5 (cut-point, 52)	7%	100%	54%
Combined FMT time + SOT 5 (cut-point, 68)	64%	100%	82%
Combined FMT time + SOT 5 (cut-point, 72)	71%	100%	86%

Table 3.

Pre- and post-flight crewmember scores. SOT 5 post-flight on Days 2,3,4. FMT post-flight on Days 3,4.

	Pre-flight	**Post-flight**
SOT5 Means (SD, ranges)	77.4 (4.5, 67 to 84)	64.4 (10.2, 34.7 to 76.7)
FMT mean time (sec) (SD, ranges)	12.3 (1.1, 10.2 to 14.1)	15.3 (1.8, 12.7 to 18.8)